**Government Laboratories:
Institutional Variety, Change and Design Space**

by

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ABSTRACT

This study examines Canadian federal government laboratories to better understand their institutional variety, changes in their institutional form, and their institutional design space. Three research questions are addressed: 1) how have the institutional forms of government laboratories been reconfigured during the period 1990-2005? 2) what are the laboratories' mandates and how do these reconfigurations affect the labs' ability to fulfill their mandates? and 3) how might science policy analysis better take account of the importance, diversity and complexity of government laboratories?

Three main arguments are advanced through the analysis of the evolution of Canadian science policy and through case studies of three Environment Canada laboratories. The first argument is that the traditional "make or buy" and related quasi-market lens on policy analysis related to government laboratories does not adequately capture the increasingly formal network-based approaches, both within the federal government (intra-sector networks) and with other sectors (inter-sector networks), to the delivery of government science. Accordingly, a broader "make, buy, or collaborate" mix of choices is called for.

The second argument is that government laboratories as institutions exhibit a remarkable degree of diversity that is often not clearly reflected in Canadian science policy. Policy analysis suffers from a failure to:

- understand the multiple (and potentially conflicting) mandates of government laboratories;
- appreciate that formal policy-induced networks are not necessarily the same as the informal networks that have long characterized scientific activity; and,
- recognize that formal networks and quasi-market approaches, while valuable and appropriate in many ways, can create problems for the labs in delivering their diverse mandates.

The third argument is that policy and institutional analysis of government laboratories requires an analytical approach that considers their core features as hierarchies, quasi-markets and networks in the context of their mandates, but that goes beyond this basic framework to differentiate inter-sectoral and intra-sectoral networks and reveal the more complex "institutional design space" for government laboratories. A specific purpose of this study, therefore, is to develop a typology that can be useful in gathering more policy-relevant information about government laboratories and in designing informed policies for the provision of government science.

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INTRODUCTION

I. PURPOSE, RESEARCH QUESTIONS, MAIN ARGUMENTS AND CONTRIBUTIONS

The purpose of this study is to critically examine Canadian federal government laboratories with a view to understanding better their institutional variety, changes in their institutional form, and the institutional design space for government laboratories.

Three central research questions are posed and addressed: 1) how have the institutional forms of government laboratories been reconfigured during the period 1990-2005? 2) what are the laboratories' mandates and how do these reconfigurations affect the labs' abilities to fulfill their mandates? and 3) how might Canadian science policy analysis better take account of the importance, diversity and complexity of government laboratories? Diversity and complexity refers here to the intricate mix of mandates and institutional forms such as hierarchies, quasi-markets and networks and their different combinations in the institutional make-up of the laboratories.

The study builds mainly on institutional analysis in which organizations are examined "as a whole" as opposed to other analytical approaches that either downplay the role of institutions or focus more narrowly on constituent institutional elements or processes (Perrow 1986, 157). Institutions are defined in an overall sense as entrenched

systems of behaviour centred around strong values and systems of norms and rules (Peters 1999, Ostrom 1990). As Chapter 1 discusses further, institutions involve historically embedded behaviour and norms but also exhibit inertia regarding change. “No organization...is free to act as if the situation were *de novo* and the world a set of discrete opportunities ready to be seized at will” (Perrow 1986, 158).

The federal government laboratory is the institution on which this dissertation focuses. I define a *government laboratory* broadly to be an organizational entity within a federal department or agency that serves as a locus for the performance of science and technology (S&T), in any of its forms (including theory, experimentation, observation, monitoring, modelling/simulation, prototyping, testing, etc.) and in any of the full range of S&T disciplines (i.e., the natural, health, and social/behavioural sciences, engineering and other technical disciplines). I elaborate on the definition of government laboratory in Chapter 1.

Government laboratories operate within mandates that specify their authorized roles or functions. The analysis, however, must also take into account as context, features that are exogenous to the lab as an institution. These include, in particular, the ongoing changes in government policies that impact on the labs (as discussed in Chapter 3) and also in the policies of the parent government department (as discussed in Chapter 3 and the cases studies), in this case Environment Canada. The focus of the dissertation is, nonetheless, on the institutional variety and form of laboratories and on issues regarding institutional design space. Institutional variety and form refers to the ways and degrees to

which labs reflect the central attributed features of hierarchies, markets and networks while institutional design space suggests a way in which this initial three-category approach to understanding the labs' institutional features needs to be amended to draw out more complex combinations of institutional forms.

In Canada, the federal government annually invests approximately \$5 billion on the performance of S&T activities within its own research establishments. The S&T delivered by these government laboratories supports a broad range of public policy goals in innovation, health and safety, and environmental stewardship. Government laboratories contribute vitally to the proper functioning of Canada's overall science and innovation system.

Despite their critical importance, however, government laboratories are poorly understood institutions. Public policy related to government laboratories, and especially the persistent pressures to adopt market-oriented roles and business-like operations, displays a failure to appreciate the diverse nature of government laboratories as institutions (Doern and Kinder 2002 and 2007; see also chapter 3 of this thesis).

Three main arguments are advanced and developed throughout the analysis of the evolution of Canadian science policy and three case studies of federal laboratories. The first argument is that the traditional "make or buy" and related quasi-market lens on policy analysis related to government laboratories does not adequately capture the increasingly formal network-based approaches to the delivery of federally-performed

S&T.¹ These formal network-based approaches are occurring both within the federal government (*intra-sector networks*) and with other sectors (*inter-sector networks*). Accordingly, a wider focus on a “make, buy, or collaborate” set of choices is necessary to understand these institutions.

The second argument is that government laboratories as institutions exhibit a remarkable degree of complexity and diversity but this multi-dimensionality is often not clearly reflected in policy analysis related to Canadian S&T policy. As the study will show, policy analysis often fails to understand the multiple (and potentially conflicting) mandates of government laboratories; fails to appreciate that formal policy-induced networks are not necessarily the same as the informal networks that have long characterized scientific activity; and, fails to recognize that formal networks and quasi-market approaches, while valuable and appropriate in many ways, can create problems for the labs in carrying out their diverse mandates.

The third argument of the study is that both federal S&T policy analysis and the academic analysis of laboratories requires an analytical approach to government laboratories that considers their core features as hierarchies, quasi-markets and networks in the context of their mandates, but that goes beyond this basic three-category framework to differentiate inter-sectoral and intra-sectoral types of networks and that reveals more complex mixes of institutional choice which I cast in this analysis as “institutional design space.” Such an extended approach captures better their multi-dimensionality, provides

¹ Hereafter, I will typically employ the shorthand term of “government science” when referring to the S&T activities performed by the Government of Canada.

better guides to data collection and analysis, and makes explicit the full range of institutional design options available to policy makers. A more specific purpose of this study, therefore, is to develop a typology of government laboratories that can be useful to analysts in gathering more policy-relevant information about these important institutions and designing better informed and more appropriately targeted policies for the provision of government science. The failure of policy analysis to reflect the multi-dimensionality of government laboratories, the nature of change regarding their hierarchical, quasi-market, and network forms, and the realities of complex institutional design space issues can be detrimental to the achievement of the full range of public policy goals that government science supports. Examining the laboratories' institutional variety via an initial hierarchies, quasi-markets and networks framework provides the basis for and establishes the need for the development of an institutional design space typology.

The results of this study can assist the formulation of a more informed Canadian science policy. Policy related to government laboratories in Canada has been hampered by a reliance on broadly applied, high-level abstractions regarding government science that flow “top-down” from sector-based stereotypes, market failure arguments, or generic New Public Management concepts. Meanwhile, through “institutional biographies” and case studies, what limited policy scholarship on Canadian government labs as does exist has provided a deeper, “bottom-up” understanding of individual laboratories but has not provided adequate typologies or taxonomies that could guide policy analysis more

generally. A middle path is needed. The present study seeks to strike such a path and offers several advantages over studies done to date.

The study makes research contributions at two levels: empirical and conceptual. At an empirical level, one aim of the project is to expand the base of empirical knowledge about Canadian government laboratories. Much of the existing research on Canadian government laboratories has focussed on the establishments of the National Research Council of Canada (NRC) (Doern 1970a, Doern and Lévesque 2002, Smith 2000 and 2003). Since the NRC differs from the traditional line departments in important ways this emphasis provides useful but ultimately isolated insights.

More recent studies have partially addressed this gap in the literature by examining government laboratories belonging to major science-based line departments. For example, Rosenblatt (2004) examined three labs of Natural Resources Canada (NRCan) but focussed on research issues at the individual scientist level, while Doern and Kinder (2007) studied laboratories belonging to NRCan and Environment Canada but focussed on a five point policy menu framework. Thus, the aims of both studies were quite different than my purpose here as neither focussed on institutional modes per se and neither developed an explicit institutional design typology to aid public policy analysis. An advantage of the present study is its focus on the institutional variety and design space issues of government laboratories that to date have not received much attention in the Canadian academic literature.

Another advantage and empirical contribution of this study is its use of case studies. Too often, Canadian science policy analysis relies on basic *inputs* data such as S&T funding and personnel statistics or *outputs* data including patent and publication counts and other performance indicators. Since relevant data at the level of individual government laboratories is not collected systematically by Statistics Canada or elsewhere, such analysis must rely on often highly aggregated views of government science that mask the variation that exists. Again, the institutionalists' emphasis on the "whole organization" derives from an acknowledgement of the uniqueness of organizations which implies the need to do case studies. "Because the interchange of structure and function goes on over time, a 'natural history' of an organization is needed" (Perrow 1986, 158). The use of case studies, while imposing other limitations that will be discussed, offers the possibility to explore the rich diversity of institutional roles and designs of government labs.

At a conceptual level, the research contributes to a deeper understanding of government laboratories as institutions, first, by placing them unambiguously at the centre of the analysis and, second, by adapting, extending and applying conceptual tools from institutional analysis as a different and potentially more fruitful way of thinking about public sector research establishments.

Three bodies of literature are reviewed in which scholars have examined and theorized about government science, knowledge-producing institutions and related policy. These are the science studies, economics, and policy/institutional analysis literatures.

This study draws primarily from the institutional stream, particularly to inform the two-part analytical framework discussed below. However, I also extract perspectives and methodological approaches from the science studies literature (especially the sociology and history of science), as well as from the economics discipline, both its neoclassical and evolutionary schools. This literature review makes clear that government laboratories as institutions have only rarely been the central focus of much scholarship. The current study addresses this gap by explicitly focussing on the government laboratory as its unit of analysis.

I also review and summarize the historical policy and institutional context for Canadian government laboratories. Freeman (1988a, 12) contends that “a historical perspective is crucial for any research programme which seeks to understand technical and institutional change, but it must be one which recognizes the importance of qualitative change in the system.” This review traces the evolution and major qualitative shifts in Canada’s science and innovation policy system from its early post-war emphasis on in-house government performance of research, to increasing pressures in the 1970s and 1980s to infuse private sector and market-oriented approaches to government laboratories, to the more recent emphasis on delivering science through policy-induced, formal networks and partnerships.

The literature review and review of the historical context lead me to employ a two-part institutional analytical framework (see Fig. Intro-1). Derived from its application to many realms of society and many policy fields, the institutional literature

suggests an analytical approach of examining institutions through a hierarchies, markets and networks framework. Under the first part of the analytical framework, the case study laboratories are initially examined in an amended framework as a mix of hierarchies, quasi-markets, and networks to bring out their basic institutional characteristics.

Figure Intro-1. Overview of Literature Streams, Two-Part Analytical Framework and Case Studies

As *hierarchies*, the study examines the extent to which the case laboratories are structured, funded and operated along classic Weberian bureaucratic lines, as well as within broader hierarchies of their parent department and the federal government (Weber 1946). As *markets*, what is really being explored here is how the case laboratories have

evolved to become more “market-oriented” through indicators such as the degree of commercial orientation in their mandates, funding, and knowledge products and their use of business-like management practices. In short, the labs are not privately owned but may exhibit *quasi-market* characteristics; hence, the amended version of the first part of the dissertation’s two-part analytical framework. As *networks*, it is important to note that network-based forms of organization are historically common among scientific groups, and government researchers have always been embedded within *informal* networks across the broader scientific community. The focus here, however, is on the increasing use of *formal* network and partnership arrangements. Government laboratories participate in these networks in order to access expertise, leverage additional resources, and, increasingly, to deliver core programs, but such networks also often bring with them increased procedural and reporting bureaucracy associated with hierarchy. The study addresses some of the problems created by these institutional forms, the tensions among them, and their impacts on the labs’ abilities to fulfill their mandates.

A general shift in policy emphasis and preference from hierarchy to quasi-market (in part through “make or buy” policies and later innovation policies) and also to formal network forms of institutional design can be observed over the thirty year period covered by this study. At the same time, however, it is clear that earlier emphases and core institutional features do not disappear. For instance, the case studies make clear the persistence of hierarchies despite years of policy emphasis in other directions. The insights that flow from the first part of the analysis reflect the fact that these discrete

institutional forms are ideal types but also that, even separately, they are complex forms. Further, the case laboratories exhibit a blend of features of all three types, with the specific mix changing over time, but with sufficient variation to suggest that the pursuit of a general amended typology of this kind is useful and not misguided.

The study builds on this initial three-category framework of institutional forms and discusses both its utility and limitations. The analysis makes apparent the need to develop and deploy the complementary institutional design space typology that represents the second and necessary part of the analytical framework and a further major contribution of the study. Employing an institutional design space approach allows for a greater and useful differentiation of the network type, resulting in four general design types, namely hierarchies, quasi-markets, intra-sectoral networks and inter-sectoral networks. More importantly, it makes explicit the more complex and multi-dimensional design space within which policy makers can choose to make, buy or collaborate with respect to Canadian government laboratories. Finally, the study offers an initial exploration of how the institutional design space typology can be applied to guide policy analysis regarding government laboratories.

A clear advantage of such a two-part institutional analytical framework is that it proceeds from no *a priori* assumptions regarding the relative superiority or inferiority of public sector or private sector organizational modes. More fundamentally, this overall approach benefits from the insight that institutions do indeed matter. Crow and Bozeman (1998, 91) suggest that among all the important questions relevant to strategic thinking

about science policy, “the ones most woefully neglected are those pertaining to organizational structure and design.” This is perhaps understandable in that a predominant view among policy analysts is that “structure and design issues are inherently the province of management, not policy” (Ibid., 91). This view leads to an assumption that institutional design is either not important or that laboratory managers can simply “redesign” their organizations to respond quickly to the latest policy dictates. It is little wonder that these expectations are frustrated given the evidence that an organization’s performance is a function of the fit between its structure and environment (Snow and Hrebiniak 1980, Bozeman and Loveless 1987). This study will consider the relationship between a lab’s mandate and its institutional design, and the potential tensions in this relationship that flow from policy-induced reconfigurations of institutional form.

Without a deeper and more differentiated understanding of the institutional nature of government laboratories, policy makers will continue to be frustrated by the apparent lack of responsiveness on the part of these institutions in implementing policy reforms or achieving desired policy outcomes. On the other side, lab managers and researchers will continue to be frustrated by often over-generalized policy initiatives (e.g., sweeping calls for the transfer of government laboratories to other sectors or for the labs to do more to support commercialization) that do not reflect a more nuanced understanding of the diverse institutional make-up of their laboratories. This will be of particular concern when an institution’s budget becomes increasingly tied to its

performance towards these blanket objectives. The results of this study will shed light on how consideration of institutional variety and change, and of the institutional design space, can improve policy analysis regarding government laboratories.

II. DISCUSSION OF THE RESEARCH QUESTIONS AND PROBLEM

Science and technology (S&T) are increasingly central to all facets of life, and S&T policy has become a key concern of the federal government. In Canada, the public expects the federal government to deploy S&T not only to foster innovation in support of a competitive economy but also to protect the health and safety of Canadians and enhance stewardship of the environment. While the S&T conducted in universities and the private sector can make significant contributions to addressing these concerns, government science remains critically important. In Canada, the federal government annually invests approximately \$10 billion on S&T (Statistics Canada 2008b, Table 1-1). Of this investment, over half (approximately \$5.2 billion in 2008-09) is spent for the performance of S&T activities at the federal government's own research institutions (Ibid., Table 6-1).

Yet, while they are the primary instrument through which government science is performed, government laboratories are not, as stressed above, well understood as institutions in public policy. An analysis of four decades' worth of Canadian science policy studies (mainly government studies) suggests a persistent limited and oversimplified understanding of government laboratories as diverse institutions (Doern

and Kinder 2002). By and large, the examined studies exhibited little or no recognition that different government laboratories might fulfill different roles, and that these differences may be reflected in differing institutional designs. Thus, recommendations from these studies for reform and redesign have reflected a very unidimensional understanding of government laboratories; namely, that government laboratories act as surrogates for Canada's inadequate industrial research base. The studies therefore recommend that the labs should be more market-oriented and serve primarily commercial innovation goals (Doern and Kinder 2002 and 2007; see also discussion later in this chapter and in chapter 3).

Nor do some theoretical literatures offer much guidance. For example, neoclassical economic theory, while often enjoying a privileged position in public policy, reduces the rationale for government science to instances of market failure and tends to treat the government laboratory as a *black box* within which policy inputs are automatically converted to desired policy outputs and outcomes, with little or no understanding of its internal structure and relationships.² The relevance of other literatures that approach government science through the lens of individual institutions is often limited by the lack of an explicit public policy focus. In order to develop and implement sound S&T policies, it is necessary to gain a richer understanding of government laboratories as living, breathing institutions in all their diversity and

² In science and engineering, a *black box* is "any device for which the input and output are specified but the internal mechanisms are not" (Hess 1997, 81).

complexity within an analytical framework that can provide guidance about institutional variety to policy analysts.

As stressed above, to begin to understand government laboratories as institutions it is important to locate them within the overall context and evolution of Canadian science policy and of Canadian science as well. This reflects a normal perspective not only that the past can inform the present but that policy makers would be wise to make more effective use of history in decision making (Pyenson and Sheets-Pyenson 1999, Neustadt and May 1986). This history will be examined more thoroughly in Chapter 3; here, I only preview briefly the basic storyline.

While it is generally accepted that the federal government has an important role to play in the Canadian science and innovation system in *funding* S&T activity, the proper role and approach for government in *performing* S&T has long been a subject of debate. Prior to World War II, the relative lack of a research infrastructure in universities and industry meant that a great deal of Canadian S&T activity was funded by and even conducted by government. In the immediate post-war period, federal S&T experienced a remarkable expansion, fuelled in part by an appreciation of its contributions to wartime success. Government laboratories (particularly those of the National Research Council) became key, even dominant, players in Canada's S&T system. Throughout this period, however, the predominant research management model continued to involve exclusive ownership and operational control of the laboratories by a federal government department or agency.

Through the 1960s and 1970s, the national system continued to mature and science policy became a more explicit focus of governments in the industrialized countries. There was an increased questioning of government laboratories, their relevance to the improvement of Canada's economic competitiveness, and the appropriate model for the organization of government science. In 1972, the government introduced a Make-or-Buy policy that directed that essentially all new "mission-oriented R&D" was to be contracted out to private industry. The onus was on federal departments and agencies to make a case for choosing "make" (in-house performance) over "buy" (contracting out). The Make-or-Buy policy was a prime example of the increasing application in this period of market and quasi-market tests to government science.

By the 1980s, policy analyses were highly critical of federal laboratory management, citing for example a "growing atmosphere of irrelevance and an excessively bureaucratic management style" (Task Force 1984, 25). In general, government laboratories were under pressure both to become more business-like in their operations and more market-oriented in order to serve commercial innovation goals more directly (National Advisory Board on Science and Technology 1988a). Expert panels increasingly called for greater use of private sector practices such as management boards, cost recovery practices, contracting in/out, and other business-oriented approaches (Task Force 1984, National Advisory Board on Science and Technology 1990). This emphasis on private sector approaches was, in addition, due to the emergence in this period of the New Public Management (NPM) paradigm, a movement to replace "public sector logics"

with “private sector practices” (de la Mothe 2000, 31). Although the proponents of NPM have a generally favourable view of its application to government activities, it is not at all clear that the specific application of NPM to government laboratories and its effects on the conduct of science in the public interest have been thoroughly examined in Canada.³ As we will see, although primarily associated with the pressure on labs to become more business-like, NPM and its effects can show up in both the hierarchy and quasi-market analytical categories of the three-category framework.

During the late-1980s and 1990s, the science policy context began to shift again in response to increasing scholarship and policy attention to “innovation systems” (Lundvall 1988 and 1992, Nelson 1993), “Mode 2” knowledge production (Gibbons et al 1994), and renewed interest in network theory (Freeman 1991, Nohria 1992, Barabasi 2002, Watts 2003). This literature stressed the importance of collaborative linkages among the various actors in a national science and innovation system, reflecting a growing awareness that no institution, public or private, could “know it all” or “do it all” (de la Mothe 2000). Similarly, the work of Gibbons et al (1994) on the distributed nature of knowledge production suggested the emergence of new network-based forms of organization and greater permeability of knowledge producing organizations. In Canada, such thinking motivated new approaches to promote formal networks and the collaborative performance of publicly-funded S&T. This included the establishment of the Networks of Centres of Excellence (NCEs) (Atkinson-Grosjean 2002 and 2006), the

³ But see Polster (2004), for example, for a critical analysis of the impacts on academic research in Canada of the increasing university/industry interactions since the 1980s.

co-location of government laboratories with universities, and the use of horizontal program funds to supplement traditional Parliamentary direct funding to science-based departments.

By the mid-1990s, the government's efforts to eliminate large budget deficits meant that most government laboratories faced tight budgets and, in many cases, cuts in funding and personnel, some in the order of 40 percent. Later in the decade, when the fiscal position returned to surplus, the government renewed its investments in research capacity. However, these investments were largely directed to other sectors, particularly to universities, rather than to government laboratories whose budgets remained relatively flat. Through new initiatives such as the Canada Foundation for Innovation and the Canada Research Chairs program, the government channelled funding to the universities and other academically-oriented research institutions (e.g., research hospitals, NCEs).

In 2004, for the first time, universities – not government laboratories – were the primary recipient of federal R&D funding, and this trend has continued (Statistics Canada 2007).⁴ This is largely the result of the steady increases in federal funding for academic research since 1997 while funding for federal intramural R&D has remained relatively flat. But it can also be seen as a continuation of a decades-long trend in the post-war period in which the traditional dominance of federal research performers has given way to other performers (Doern and Stoney 2009).

⁴ Although when related scientific activities (RSA) are included, the majority of federal S&T expenditures are still performed intramurally. RSA is defined later in this section.

Throughout this period, the government also provided support to industrial R&D through tax incentives, technical assistance programs, and loans and subsidies. In particular, the Scientific Research and Experimental Development (SR&ED) tax credit program, the Industrial Research Assistance Program and the Technology Partnerships Canada program provided significant direct and indirect support for industrial R&D. These investments, along with the R&D investments made by the universities and the business enterprises themselves, led to a strengthening of the non-government sectors of the Canadian science and innovation system. This, in turn, renewed the debate on the appropriate role for the federal government and government science in the system.

In particular, the debate has centred on what, if any, ongoing role the government should have in *performing* S&T (de la Mothe 2000). Some have called for government's role in S&T to be reduced to that of merely a funder and facilitator, not a performer. For example, Leiss (2000) argues that the "old model" in which government departments engage directly in scientific work which is then applied to policy choices is "obsolete." He calls for shifting the provisioning of science relevant to policy and risk management to independent institutions that are located "at arm's length" from government. By "independent organizations," Leiss has in mind primarily "universities or other entities that draw on the independent expertise resident in universities" (Ibid., 67). The unflattering opinion of the scientific and technical expertise resident in government laboratories and the potential threat to their very existence implied by this viewpoint are obvious. But the argument for this "new model" leaves unaddressed many

challenges, including how the government can ensure it has timely access to the various types of science it needs, how it can ensure that the science conducted by such “independent institutions” is free of bias and conflict of interest (particularly given increasing private sector funding of academic research), and how, without a robust internal S&T capacity, the government can remain an intelligent consumer of the science advice it receives from external sources.

On the other side of the debate, analysts argue that the federal government needs to maintain a strong in-house S&T capacity not only to address these concerns but to ensure the effective functioning of the broader national science and innovation system. In particular, a government role is viewed as essential for the conduct of the science supporting the provision of public goods unlikely to be provided effectively by the other sectors (Council of Science and Technology Advisors 1999, de la Mothe 2000, Moore 2002, Government of Canada 2005). De la Mothe (2000, 44) goes so far as to argue that, “science in the public interest is uniquely the business of government.” Although the intensity of this ongoing debate may ebb and flow, fundamental questions regarding government laboratories and their relationship to other sectors remain a permanent feature and are never far below the surface of any discussion of science policy in Canada.

It is clear, however, that a gradual and important shift has taken place in the policy context for government laboratories. From the early emphasis on in-house S&T performance, policy first shifted to an increased emphasis on industrial support mandates and a basic “make or buy” approach. More recently, this rather simplistic public/private

dichotomy has yielded to increasing recognition of the wide spectrum of alternative arrangements for federal laboratories ranging in principle from fully public to fully private ownership and management, and embracing a variety of formal network-based and partnership arrangements. Simply put, the choices for institutional design of government laboratories have expanded from merely “make” to “make or buy” to “make”, “buy,” or “collaborate” and complex combinations thereof. This central argument, and the problems associated with these choices, will emerge clearly and in more detail throughout the analysis.

The latest indication of the government’s interest in alternative delivery models for government science came in the federal S&T Strategy, *Mobilizing Science and Technology to Canada’s Advantage*, released in May 2007. The Strategy signalled the government’s commitment to consider “alternative management arrangements” for some of the federal laboratories (Government of Canada 2007). In doing so, the government’s stated objective is “to increase the impact of federal investments, lever university and private sector strengths, create better learning opportunities for students, and foster research excellence” (Ibid., 14). In addition, while the government acknowledges that much of federal S&T is in support of “regulatory, policy and operational mandates in important areas such as health care, food safety, and environmental protection,” the Strategy seeks to encourage “innovative new models for S&T collaboration between federal departments and agencies and other sectors” (Ibid., 68 and 70). Clearly, seeking to achieve a greater understanding of government laboratories and their institutional

designs is timely. What is needed is a better understanding of the choices among hierarchies, quasi-markets and networks, and a related typology that incorporates the make, buy and collaborate realities and supports further conceptual and applied policy analysis of institutional design space choices related to government laboratories.

III. APPROACH AND METHODOLOGY

The study is designed to address the key research questions, primarily through case studies but also by drawing on and interpreting the historical evolution of federal S&T policy. The core empirical research consists of case studies of a set of laboratories of Environment Canada, namely: 1) the National Water Research Institute, 2) the Environmental Technology Centre, and 3) the Atmospheric and Climate Science Directorate of the Meteorological Service of Canada. The case studies are developed through the analysis of key documents, supplemented by oral interviews. For each case laboratory, six to twelve semi-structured interviews were conducted with the lab's managers, researchers, technical/support staff, and clients and stakeholders, both internal and external.

A key feature of the research design is the selection of three laboratories within a single federal department rather than, say, a laboratory from each of three different departments. This is done in order to isolate the policy and management contexts of the parent department and their influences on its laboratories. However, this choice may introduce a selection bias if the laboratories selected for analysis are systematically

different from other government laboratories. This potential bias can be mitigated somewhat if the laboratories selected from one department exhibit the breadth of federally-performed S&T and institutional designs, including the use of various alternative service delivery approaches.

Environment Canada is chosen as the parent department and the case studies' home base for two reasons. First, as indicated, most of the scholarly literature has neglected the S&T establishments of Environment Canada in favour of those of the NRC or other natural resources departments (Doern and Lévesque 2002, Rosenblatt 2004, Doern and Kinder 2007). Second, it has a number of diverse S&T institutions from which to choose. Environment Canada requires S&T inputs in support of each of its three primary services, namely, the Environmental Conservation Service (ECS), the Environmental Protection Service (EPS), and the Meteorological Service of Canada (MSC). Its labs exhibit the full range of government S&T activities (although in varying degrees) including research and development (R&D) but also related scientific activities (RSA) as found in many other departments and their laboratories.

Related scientific activities (RSA) are defined as “those activities which complement and extend R&D by contributing to the generation, dissemination and application of scientific and technological knowledge” (Statistics Canada 2008b, 23). RSA is a major component of government science; in fact, it represents the majority of intramural S&T spending and personnel. To the extent that public policy treats all government laboratories exclusively as “research and development” institutions (e.g.,

producers of new knowledge and new applications), it may be poorly designed for laboratories engaged in other important scientific activities and services in the public interest. The limitations imposed by the selection of a single department, in general, and Environment Canada, in particular, will also be addressed later in the dissertation.

IV. DISSERTATION ORGANIZATION

This final section provides an overview of the structure of the dissertation. Part I consists of three chapters and provides the literature review, analytical framework, and historical context. Part II consists of four chapters and examines the three case studies and overall empirical analysis. Conclusions then follow.

Chapter 1 begins with a brief discussion of definitions of “government laboratory” and then proceeds with a review of the various literatures regarding government science, knowledge institutions and related policy. Chapter 2 makes the case for a more explicit focus on government laboratories. It then specifies the two-part analytical framework employed, including the basic hierarchies, quasi-markets, and networks institutional framework and the further institutional design space typology. The chapter concludes with a more detailed discussion of the study methodology.

Chapter 3 provides a more thorough discussion of the historical policy and institutional context by tracing the evolution of government science in Canada and the policy pressures common to federal science departments. Such a contextual analysis is needed, because, as indicated in the brief policy history preview above, institutional

variety and change has been driven significantly by policy change. The chapter also analyzes the departmental context by examining the development of Environment Canada as a department from its origins in the early 1970s to about 2005, the period for which reasonably complete and consistent case study information and data were available.

Chapters 4, 5 and 6 contain the primary empirical content of the study. Each presents a case study of one of the three study laboratories. Each case study provides some context about the origins of the laboratory, a description of its mandate and functions, and a discussion of key institutional trends. Each case then provides an examination of the hierarchy, quasi-market and network elements of the laboratory. Finally, they consider the problems and challenges faced by the laboratory, including the impacts of their changing institutional configurations on their ability to fulfill their mandates.

The results of the case studies are compared and discussed in Chapter 7. The findings with respect to the hierarchy, quasi-market and network characteristics of the case institutions are analyzed across the three laboratories. The value and limitations of this part of the analytical framework are then discussed and why an extended but complementary institutional design space typology is needed. The chapter then examines the institutional design space typology as a complementary aid to policy analysis related to government laboratories. Some initial observations are made about how the typology can be applied both conceptually and empirically.

The final chapter summarizes the purpose, research questions, main arguments and contributions of the study, discusses the limitations of the institutional approach and of this study, and provides suggestions for future research. A bibliography completes the dissertation.

**PART I: LITERATURE REVIEW, ANALYTICAL FRAMEWORK
AND HISTORICAL CONTEXT**

CHAPTER 1

LITERATURE REVIEW

This chapter helps to locate the present study within the broader scholarship on science policy and government laboratories by defining the unit of analysis and reviewing how key literatures have approached it. I begin in the first section with definitional questions surrounding the object of study, namely, government laboratories. The difficulty in getting a precise handle on “government laboratory” illustrates that “top-down” definitional and conceptual approaches to science policy must be balanced with “bottom-up” explorations of the reality of the situation “on the ground” (Doern 2004).

After grappling with these definitional issues, I then proceed in the second section to review three broad bodies of literature in which scholars have theorized about science policy generally and, where available, about government science and government laboratories more particularly. I begin this section in the science studies camp, exploring the perspectives of and approaches used by scholars of the sociology and history of science. This tradition, including its use of “institutional biographies,” encourages us to open the black box to view laboratories as more than mere instruments of science policy but as complex and evolving institutions. I then survey what can be drawn from

economics, both its neoclassical and evolutionary schools. Key concepts emerge including market failure, public goods and linear models of innovation that have shaped so much of science policy and are useful here as well. More recently, the inductive, structuralist approach of the evolutionary economists has provided a more sophisticated view of innovation and the systems of institutions that support it, and informs this study. Finally, and most fruitfully, I examine approaches and concepts from the policy/institutional analysis stream including policy paradigms, principal-agent theory, and institutional design. It is this last body of literature that most directly influences the two-part institutional analytical framework that I have developed/adapted (see more below) and applied in this study, but the first two literatures also provide useful and necessary insights and context, substantively and conceptually.

I. DEFINITIONS

Before proceeding further, it is important to be clear about what exactly is being examined in this study. After all, as the Chinese say, the first step to wisdom is getting things by their right names (Wilson 1998). While I have generally employed the term *government laboratory* to this point, I have only briefly defined the term in the Introduction. It is imperative, however, to be aware of the difficulties of finding a precise yet comprehensive definition of a government laboratory, as well as finding the most appropriate label for this unit of analysis.

According to the Canadian Oxford Dictionary the word *laboratory* derives from the Medieval Latin term *laboratorium* which in turn came from the Latin *laboratus*, the past participle of *laborare* which meant “to labour.” Thus, the term is associated with doing work and has come to mean a place for doing scientific work. Typical dictionary definitions reflect this definitional history, defining laboratory as “a place equipped for experimental study in a science or for testing and analysis” (*Webster’s* 1990), or “a room or building fitted out for scientific experiments, research, teaching, or the manufacture of drugs and chemicals” (*Canadian Oxford Dictionary* 2004).

Early analysts of laboratories tended to conceive of them from the point of view of specific disciplines and were inclusive in terms of the size of the establishment. For example, Munce (1962, 15) writes:

Stated broadly, the basic concept of a laboratory is the provision of a suitable environment for the performance of a specific scientific discipline—this concept being applicable whether the laboratory is but a single room under the control of one person or a complex of differing units housing several hundred scientists.

Similarly, Hiscocks (1956, xii) states that, “a laboratory is a place where practical investigations into natural science are conducted. The word is used variously to connote anything from one room to a large institution....” And Tullock (1966, 167) has written:

Scientists normally do not like to perform their work in the rain or snow. Consequently, they normally work indoors, and the sheltered area in which they work is called, in English, a laboratory. The only thing which laboratories have in common with each other is that they all provide shelter from the elements. Their internal design and equipment and the work done in them vary as much as those of any other type of building. If you visit, successively, the laboratories of a biologist, an organic chemist, and an experimental physicist, the only things that you will normally find in common in the equipment found therein are things you would also find in all sorts of non-scientific surroundings.

For today's policy analyst, there are several problems with these "definitions." First, in emphasizing laboratories as sites for the performance of a specific discipline or of only the "natural sciences" it is apparent that these early scholars did not foresee the emergence of the large multidisciplinary, multiprogram establishments that are common today. For example, in the United States, the "national laboratory" at Los Alamos, New Mexico, employs over 10,000 people working in a broad range of disciplines across the physical, biomedical, computational and engineering sciences. While such "superlabs" are less common in Canada,⁵ one would still prefer a more inclusive conception of laboratory; if for no other reason than to allow for international comparative studies.

Second, by evoking a sense of "bench science" performed at a workbench in a particular enclosed space, all of the above definitions suggest that the laboratory consists primarily of the site and infrastructure of scientific *experimentation*, in which the natural world is deliberately interfered with, under carefully controlled circumstances, in order to investigate the consequences or explore an unknown domain (Ziman 1984). This connotation raises a problem of using the term "laboratory" in the current study in that not all government science is "bench science"; in fact, much of it requires observation or monitoring work performed "in the field," at remote field sites or stations, and away from any central "laboratory." A related problem with the term laboratory is that it is not clear whether the social sciences, which are not usually viewed as bench sciences, are to be

⁵ One could point to the AECL's Chalk River Laboratories and the NRC's Montreal Road complex as Canadian examples.

included. My own inclination is to take the more inclusive view that government S&T includes all of the sciences and technology disciplines. A more satisfactory definition and label for “laboratory” would not exclude these important aspects of the federal S&T endeavour.

Third, as indicated, these definitions are very inclusive in terms of the size of the establishment. Since I have as a central goal the development of higher-order typologies that can guide science policy analysis, the inclusion of the “single room under the control of one person” is probably not helpful. Most analysts of government laboratories seem to focus primarily on institutions greater than some minimum size either in terms of budget or staff level, although the specific threshold varies or is left unstated.

More recently, scholars have employed other terms including “public sector research laboratories” (Beesley et al 1998), “public research organizations” (Dalpé and Ippersiel 2000, Nelson 2000), “government R&D establishments” (Cordell and Gilmour 1976) or “government research establishments” (Boden et al 2004). For my purposes, there are at least two additional problems raised by these labels. First, the studies that employ the term “public research organizations” tend to include all publicly-funded research organizations including university-based laboratories, research hospitals and other publicly-financed research institutes. How the institutional designs and other aspects of government laboratories might differ from their academic counterparts may be obscured in these analyses. To be more useful, a distinction must be drawn between

merely publicly-funded establishments and publicly-owned establishments directly engaged in research, for which the term “public sector research establishments” is sometimes used, particularly in the United Kingdom. However, this language immediately raises a second problem in common with the other labels listed above. Referring to these institutions as “research” laboratories or “R&D” establishments only serves to further elevate the “research” or “R&D” portion of government S&T and obscure the important performance, as discussed in the Introduction, of related scientific activities (RSA) in many of these institutions.

Reflecting on this discussion it is clear that no definition or label is perfect. In an attempt to address all of the concerns raised, I suppose one could refer to “federally owned and funded S&T-performing establishments,” but repeated use of such a phrase would be awkward to say the least. Despite its flaws, I believe the term “government laboratory” remains the best choice given its frequent usage in the literature. But I will conceptualize government laboratory broadly to be an organizational entity within a federal department or agency that serves as a locus for the performance of S&T (R&D and/or RSA), in any of its forms (including theory, experimentation, observation, monitoring, modelling/simulation, prototyping, testing, etc.) and in any of the full range of S&T disciplines (i.e., the natural, health, and social/behavioural sciences, engineering and other technical disciplines). With respect to the size issue, the smallest laboratory considered here employs over 100 people.

II. THEORETICAL BACKGROUND

In considering how to best approach the study of government laboratories it is important to review the many ways science and its institutions can and have been analyzed by scholars in a variety of disciplines. It must be reiterated, however, that government laboratories per se have not enjoyed much scholarly attention. As Boden et al (2004, 2) relate in their study of UK government research establishments (GREs), “the study and analysis of publicly funded research organisations, including GREs has not been a central focus of the science and innovation literature.”

This section will explore the primary theoretical approaches that have been employed within three broad traditions, highlighting their strengths and weaknesses for the purposes of this study. The three broad literatures examined are in the 1) science studies, 2) economics, and 3) policy/institutional analysis literatures. While I ultimately reject situating the current study within any one of these traditions exclusively, this study draws primarily from the policy/institutional stream. Clearly, this literature stream informs the initial choice of the adapted three-category approach to understanding institutions as hierarchies, markets and networks but also, given the limitations of this framework, of the need for an extended but complementary institutional design space typology for government labs, as previewed in the Introduction and as discussed in more detail in Chapter 2. However, I also carry forward conceptual elements and methodological approaches from the sociology and history of science, as well as from the

economics discipline, both its neoclassical and evolutionary schools, to shape the framework used and the empirical case studies in the study as a whole.

Approaches from Science Studies

I will begin this review in the area of “science studies” since, fundamentally, any study of science as an institution including the present study falls within this broad, multidisciplinary domain. As Hess (1997, 3) explains, science studies is not so much a discipline in and of itself as “an interdisciplinary conversation among a wide range of ‘constituent disciplines.’” These constituent disciplines include the early entrants of the history and philosophy of science, which were later joined by the science studies branches of sociology, psychology, economics, and political science, and more recently have come to include anthropology, cultural studies and feminist studies.

To help frame the discussion of how this broad field has variously approached the topic I will draw on the convention of distinguishing between “internalist” and “externalist” perspectives in science studies (Spiegel-Rosing 1977, MacLeod 1977, Ziman 1984). In the “internal” school, sometimes referred to as social studies of science (SSS) or science and technology studies (STS), research questions are generated intra-scientifically and are aimed at resolving cognitive problems—to know how science functions, for example, rather than how science can be governed or directed (Spiegel-Rosing 1977). Thus, scholars will study the historical, philosophical, psychological, and sociological aspects of science as if scientific knowledge were accumulated “for its own

sake” without thought to potential applications in society. Ziman (1984, 4) suggests these scholars have in mind an “academic model of science” because its aim is principally non-instrumental in nature:

The boundary between “science” and “society” is envisaged as a semi-permeable membrane, through which knowledge only flows outward, from the scientific into the technological sphere. The goal of the “internalist” programme is to account for what goes on in the region bounded by this membrane...without reference to a wider world.

While recognizing that “academic science” is far from a complete model of contemporary science, scholars within this perspective seek to understand the internal workings of science and tend to ignore or at least downplay any external forces acting on it.

On the other hand, there is the “externalist” perspective in science studies which is more closely associated with science policy studies (SPS) or science, technology and public policy (STPP). Here, the membrane between “science” and “society” is viewed as fully permeable or even merely an illusion. Science is often examined more in terms of its instrumental aspects, as a driver of technology or a process for solving societal problems. Ziman (1984) discusses how this “industrial science” perspective focuses on science in the service of political, military or commercial forces. Not surprisingly, contributors to this school tend to be based in the disciplines of economics, political science, public administration, and international relations. Analysis within this perspective often proceeds as if science is a black box whose internal mechanisms can be ignored:

In mirror image to the neglect of the socio-political sphere which often characterizes the social studies of science, there is in science policy studies a relative neglect of the internal social and cognitive functioning of science and

technology, however important this may be for their control and direction.
(Spiegel-Rosing 1977, 18)

Again, it is recognized that this “industrial science” model should not be viewed as complete. Nor should it be assumed, despite their labels, that “academic science” is only the purview of universities and “industrial science” the purview of private sector firms; both models of science can be found in both settings. Unfortunately, for my purposes, Ziman’s framework of “academic” and “industrial” science does not make clear how we should understand government science, although one suspects he would see it more aligned with the problem-solving orientation of “industrial” science.

Clearly, in order to obtain a more complete and realistic model of the relations between science and society, these two ways of approaching and perceiving science must be reconciled, and more recent scholarship is focussed at drawing connections between the two (Hess 1997, Fuller 2000). Nevertheless, much of the work remains isolated within its disciplinary boundaries. Thus, science policy scholars become frustrated with the internalists’ preoccupation with epistemological and ontological debates which are not very helpful to policy analysis. On the other hand, the “SSSers” find that science policy studies too often suffer from “black-boxism” or find distasteful the externalists’ emphasis on the instrumental aspects of science.

Since there is not yet a grand unified account within science studies, I will proceed to discuss what can be drawn from the two schools separately, focussing first on the more internalist approaches from the sociology and history of science, and then turning to the more externalist approaches from the policy sciences.

Following Hess (1997) the sociology of science can be grouped into two broad categories: 1) the institutional sociology of science, and 2) the sociology of scientific knowledge. Scholars in both sub-fields often gain insights by looking to laboratories as key sites of scientific activity. I will examine those works that are of relevance to the present study.

In the “institutional” or “Mertonian” (after the influential American sociologist Robert Merton) sociology of science, researchers attempt to understand not so much the social conditioning of the *content* of science but how science works *as a social institution* (Merton 1973). According to Crane (1972, 4), drawing on Storer, “Science is treated not as a body of knowledge or as a set of methods and techniques but as the organized social activity of men and women” engaged in scientific research. “The relationships among these people, guided by a set of shared norms, constitute the social characteristics of science” (Storer 1966, 3).

In 1942, Merton famously identified this set of guiding institutional norms of science --*universalism, communalism, disinterestedness*, and organized *skepticism*, later joined by *originality* – although in the subsequent decades, research has failed to confirm their existence in any pervasive form (Merton 1973, Hess 1997). Consequently, the Mertonian norms have come to be viewed as prescriptive, suggesting how all scientists should behave ideally. In addition, Hess (Ibid., 57) suggests the Mertonian norms might

be reinterpreted as “a description of the legitimating ideology of science...to which scientists may turn as a rhetorical resource in cases of controversy or boundary-work.”

While the norms are clearly oriented to “academic science,” probably all scientists receive this “legitimizing ideology” through their training and take it with them to whatever setting in which they work. Thus, policies toward science that are seen as impinging on these norms may be viewed with suspicion. For example, to the extent that scientists in government laboratories subscribe to the norm of “communalism,” i.e., that science is “public knowledge, freely available to all,” they may resist policies seeking to protect the Crown’s intellectual property. Similarly, the norm of “disinterestedness,” that science is done for its own sake, implies that scientists should not be paid directly for their primary contribution to knowledge. Charging fees-for-service and using contracts for commissioned research can be viewed negatively as contravening “how science is done,” even though it is now generally recognized that these norms are “honoured as much in the breach as in the observance” (Ziman 1984, 8).

Institutional sociologists have also examined informal institutions within the scientific community, beyond the formal organizations such as laboratories, disciplines, and departments. An important area of focus within this stream has been “invisible colleges” or informal networks of specialists that work on similar problems (Price 1963, Crane 1972, Chubin 1983). The work highlighted the small-group nature of much of science, in which efforts are organized via networks more than through large collectivities of individuals such as disciplines (Hess 1997). Hess views the invisible college concept

as an important forerunner of the more recent research on scientific networks and clusters. As stressed in the Introduction, this dissertation emphasizes the more formal policy-induced networks while still being cognizant of the long-standing presence of informal networks discussed in this sociology of science literature.

The second stream in the sociology of science is the sociology of scientific knowledge, in which researchers investigate the social influences on scientific *content*. Of particular interest here are the so-called “laboratory studies” that became popular in the late 1970s and 1980s. In these studies, investigators have often employed quasi-ethnographic techniques, observing scientists in a laboratory setting much like a cultural anthropologist might study a tribal people (Latour and Woolgar 1979, Latour 1987, Knorr Cetina 1995). Much of the work in this stream became quite controversial as it left the door open for a radical relativism to emerge within the field. Those subscribing to the constructivist perspective view science as a process of negotiations among competing interests with scientific “truth” emerging as a mere artifact of a discourse unconstrained by any objective reality. Nonetheless, these studies remind us of the human and social dimensions of laboratories, inviting us to view them as living, breathing organisms and not merely as policy instruments or as boxes on a departmental “org chart.” Unfortunately, few if any of these studies deal explicitly with the unique characteristics of government laboratories.

Despite some fascinating studies in this field, the sociology of science has not for the most part informed the work of the more policy-oriented, externalist scholars. In

part, this is due to its internalist perspective; these scholars are not concerned with providing guidance to the policy realm.⁶ In addition, much of the field became distracted over the last two decades by the so-called “science wars.” The “wars” began as a backlash from the positivists and the natural sciences community against some of the more extreme views of the radical relativists, cultural constructivists and feminists within parts of the science studies community (Gross and Levitt 1998). The debate quickly digressed into particularly intense attacks in which the entire field was often dismissed as a “hotbed of postmodern irrationalism” (Hess 1997). Not surprisingly, science policy scholars have largely steered clear of close association with the field. As Boden et al (2004, 5) put it:

The advent (and domination) of the relativist platform shook the blind belief in the, a priori, infallibility of science. This questioning led sociologists to lose their influence in wider discussions. ... Following from its main epistemological assumptions it was impossible for the sociology of knowledge to provide the expertise needed by policy makers. Somebody had to fill the gap, and the economists were only too happy to oblige.

Before we turn to economics, however, I will briefly explore the offerings from the history of science.

History of science

Historians of science have long been interested in the creation and development of the various communal institutions of science, including learned societies, universities

⁶ This is not to say, however, that the studies’ findings could not, with additional work, be applied to inform policy. For example, sociological studies of status attainment in science and of scientific productivity could provide a basis for assessing affirmative action policies and other personnel management issues (Hess 1997).

and disciplines (Pyenson and Sheets-Pyenson 1999). Some of the history of the rise of organized and professionalized science is recounted in the next chapter as context for today's government science and its laboratories. Here, I am more interested in what conceptual or methodological features can be usefully drawn from the historiography of science.

Some scholars of the history of science observe the evolution of government science through the lens of individual institutions by providing what can be referred to as "institutional biographies." Canadian examples in this category include Bothwell (1988), Cook (1977), Eggleston (1978), Haskins (1984), Vodden (1992), and Zaslow (1975). American examples include Crease (1999), Furman (1990), Heilbron and Seidel (1989), and Holl (1997) to name just a few.

According to Crease (1999), such works typically emphasize a) the science advanced by an institution, b) the personalities of key individuals and their influence on the institution, or c) the institutions' major research instruments (e.g., reactors, accelerators, telescopes). Many of these works are official or quasi-official histories, or of the "memoirs" variety written by someone long associated with the institution and often with a tone bordering on reverence. To that extent, they are more institutional hagiography than biography and are often limited in their potential for objective or comparative analysis.

More analytically rigorous institutional histories also exist and can be very useful to the policy analyst. For example, Hahn's (1971, ix) history of the Paris Academy

conceives of the institution “as something more than the sum of the accomplishments of its illustrious members, however famous they were as individual creators.” His study illustrates:

the extent to which scientific institutions are shaped by the requirements of both science and society. In writing about scientific institutions as something more than a chronicle of discoveries or the social history of its members, there is a need to recognize that they are the main instrument for the formulation and the transmittal of scientific norms, and that these norms must harmonize with the dominant nonscientific modes of the time.” (Ibid., x)

Hahn concludes that “major institutions deserve their histories no less than leading scientists, although the task may take longer and the interpretation may be more complex” (Ibid., xiii). Similarly, Peterson (1980, 134) has written that “the history of scientific laboratories is...an important part of the history of Canadian science, and the biographies of laboratories are as important as the biographies of scientists.” Indeed, these institutional biographies can yield important insights on the characteristics of public laboratories. For example, Castonguay (2000) highlights the important role some Canadian laboratories have played in advancing fundamental knowledge and in the training of researchers, particularly within new fields of study.

I will conclude this section on science studies by summarizing the benefits and deficiencies for my particular study. On the positive side, the field encourages us to open the black box of science in order to “see what’s inside.” By doing so, the social studies of science help us to understand the norms and ideologies that shape the self-perception of the scientific community, to examine the ways scientists network and collaborate, and to view laboratories as more than mere instruments of policy but as complex and evolving

institutions. With some additional work, the policy analyst can use insights from science studies to improve the design of science policies, as well as their acceptability and effectiveness.

On the other side of the coin, I find that for my purposes most of the work of the field is deficient both substantively and methodologically. Given their internalist perspective, most of the studies are handicapped in their relevance to science policy analysis by their lack of an explicit policy focus and by the controversies over their relativistic and reflexive tendencies. The field tends, for the most part, to insist on placing the scientist as “actor” at the center of analysis. For my purposes, I prefer to see the government laboratory as more than the sum of the individual scientists and their relationships, and as a more profitable unit of analysis for the focus and application of public policy. Within the historical stream, the emphasis on individual institutions (particularly on the National Research Council in the case of Canada) provides important but ultimately isolated insights. The sheer number of government laboratories militates against an approach to public policy that would require detailed historical case studies of each and every laboratory.

Approaches from Economics

In this section, I examine approaches from economics regarding the study of science and government laboratories. Both neoclassical and evolutionary economics sub-fields are discussed briefly.

Neoclassical Economics

Until relatively recently, the mainstream economics discipline did not provide much analysis of science and technology institutions. This is not surprising given that neoclassical economics, the dominant school of thought, “tends to promote a view of economic growth in which technological change is either static or exogenous” (de la Mothe 2000, 40). According to this view, technical change is “not unlike manna, raining down from heaven to permit economic growth” (Scherer 1999, 29). Given this stance, science and technology have not, for the most part, been key considerations within the traditional model of economic growth. Crow and Bozeman (1998, 28) summarize the standard neoclassical argument as, “...free markets are the most efficient allocators of goods and services and, left to its own devices, an unfettered market will lead to optimal rates of science production, technical change, and economic growth.” And Joly and Mangematin (1996, 902) add, “Relying on Mertonian sociology, economists thought for a long time that research laboratories were governed by behavioural norms which were independent of economic rules. Scientific production was thereby excluded from the economic field.” There was, it seemed, no need for the economist to understand the institutions of science.

Within this paradigm, government intervention in the market is generally viewed as an undesirable distortion. The rationale for a government role, in S&T or otherwise, is reduced to instances of *market failure* “which prevent the attainment of Pareto equilibria by violating one or other of the conditions for perfect competition”

(Metcalfe 1997, 269). The theory of market failure suggests that within a market system there can be a role for government when markets are not capable of producing efficient outcomes. Market failures occur when there are externalities, when transaction costs are extremely high, when information is either unavailable, costly or distorted so that market signals are weak, or in the provision of public goods (Crow and Bozeman 1998, Browning and Browning 1992).

Inefficiencies or market failures can occur when price signals are distorted due to externalities. These occur when some of the benefits or costs of a good or service are not reflected in its price or sources used (Bozeman 1987). Pollution is a prime example of a negative externality (external cost); knowledge spillovers are typically a positive externality for society (external benefit). Both types of externalities have implications for this work. Producers tend to ignore external costs such as, for example, the pollution effects on human or ecosystem health and thus their prices reflect only their private costs. Consequently, pollution-generating goods tend to be underpriced and overproduced. The government employs regulation to, in effect, internalize these costs to the producer. In doing so, the government seeks to ensure its interventions are based on sound science with respect to the extent and effects of the externality.

In the presence of positive externalities the opposite situation pertains. Private market decisions result in the underproduction and overpricing of goods and services that generate external benefits because the value to society exceeds the price individuals are willing to pay when they are uncompensated for these broader benefits. A common

example is influenza immunizations. Individuals tend to ignore the broader societal benefits of their getting a flu shot and so are less likely to get immunized than is socially optimal. Knowledge spillovers are another key example. Private sector firms will tend to underinvest in the advancement of knowledge since they can not appropriate all of the benefits that accrue from the creation and dissemination of knowledge (Nelson 1959). Government thus has a role in encouraging research and development, which it does through grants to university researchers and tax credits to research-performing firms. In addition, government has an internal role to play in advancing knowledge by conducting in-house S&T activity in support of “public goods.”

One reason Public goods are goods where shared consumption is possible (non-rivalry) but where consumers can not be excluded from accessing the benefits of the good once provided (non-exclusivity). Because of this non-exclusive characteristic, people will automatically benefit from the good, regardless of whether they pay for it. This is the basis for the “free-rider” problem and it makes the provision of public goods unattractive to private producers. The fact that competitive markets cannot efficiently provide public goods is the major justification for their provision by government. Common examples of public goods and services include national defense, cancer research, and police protection. In the context of this study, the federal government’s provision of weather forecasts, its development, monitoring and enforcement of environmental regulations and pollution standards, and the establishment of standard weights and measures constitute

public goods.⁷ As a shorthand, I occasionally refer to the S&T that supports the provision of these types of goods as “public goods science,” since this is a major part of what government laboratories do but not all of what they do.

The market failure paradigm has guided much of S&T policy (Bozeman and Sarewitz 2005). Indeed, at least in the United States, Crow and Bozeman (1998) argue that it has been dominant, with minor concessions for government R&D to support particular public missions (so-called “mission-oriented” research). But the policy prescriptions that result from this market failure paradigm caricature the complexity of the science and innovation process as well as the roles ascribed to the various players. One reason for these shortcomings is the linear model of innovation inherent within the paradigm.

While it has many variants, at the core of the linear model is the assumption that basic scientific research leads inevitably to applied research and technology development, which in turn ultimately result in the commercialization of new products, processes and services. Returning to Ziman’s terminology, innovation is conceived as flowing unidirectionally from “academic science” to “industrial science” as university researchers produce new ideas that industrial laboratories pick up through the open scientific literature. Such a perspective has the advantage of simplifying the requirements for policy intervention. Namely, government should support academic research and provide

⁷ Similarly, in the late 1950s Musgrave (1987) introduced the concept of a “merit good” as a commodity judged to be important to have on the basis of societal need, rather than individual ability or willingness to pay. Due to externalities, a merit good would tend to be underconsumed (and under-produced) in the free market. Government science would seem to exhibit the characteristics of a merit good.

incentives and intellectual property protections to innovating firms. But as de la Mothe (2000, 40) points out, this model tends “to reduce the driver of economic activity to R&D, ignoring all the tacit skills and RSA that are required” for the entire national system to flourish. And it has nothing to say about government laboratories. Freeman (1988b, 3) contends that “the main weakness of this [equilibrium] theory has been inadequate attention to social learning processes, particularly technological accumulation and the institutions affecting these processes.” Moreover, Metcalfe (1997, 274) concludes that “[w]hile market failure virtually defines the equilibrium approach to policy-making, the very ubiquity of market failure in an innovation economy limits its practical insights and limits its role to providing a general policy rationale.” As a result, in recent decades, some economists began developing an alternative approach.

Evolutionary Economics

As science policy became a more prominent concern of governments, economists began to more closely examine the relationship between science, technology and economic growth (de la Mothe 2000). In doing so, they became increasingly aware of the shortcomings of their traditional neoclassical, market failure approaches and the linear model of innovation (Rosenberg 1991). Recognizing the limitations of the neoclassical approach, some economists began to revisit “institutional economics” and to develop an “evolutionary economics.” Here, unlike in neoclassical theory, technological change is treated as endogenous and the focus is not on static equilibriums but the

dynamics of the real world (e.g., Nelson and Winter 1982, Clark and Juma 1988, de la Mothe and Paquet 1996, and Foster and Metcalfe 2001). Following the paths suggested by Schumpeter (1934, 1939 and 1942) and others, these economists realized that innovation lay at the centre of economic development—not just innovation leading to new products and processes but also the opening of new markets, the development of new supply sources, and, importantly, the creation of new organizational forms (Scherer 1999, McGraw 2007).

For institutional and evolutionary economists “institutions matter” and they attempt to, in effect, open up and explore what is inside the institutional black box (Rosenberg 1982 and 1994). Consequently, they operate on a different methodological terrain than neoclassical economics. In place of mathematical formalism, much of the work makes use of Nelson’s insight that “quite complex causal arguments can be gained by using *appreciative* stories (i.e., told by those who appreciate the details)” (Rycroft and Kash 1999, 12).

From an early emphasis on human capital, intellectual property rights and knowledge spillovers, economists have more recently examined what role a nation’s institutional environment might play in supporting innovation (Scherer 1999). Emerging from the work of the evolutionary economists and from the rejection of the linear model of innovation is the notion of innovation being fostered by a “national system of innovation” (NSI). This idea came to dominate science policy debates in the Organization for Economic Cooperation and Development (OECD) member governments

and in Canada over the last two decades (Lundvall 1992, Nelson 1993, de la Mothe 1994, Freeman 1995, Edquist 1997, Niosi 2000). The “innovation system” is an institutional concept that focuses on the complex network of agents, policies, and institutions supporting the process of technological change in an economy. According to de la Mothe (2000, 34):

An “innovation system” approach allows us to move towards more accurate descriptions of how knowledge actually leads to growth, underpins our economic and social union, and how institutions adapt to rapidly changing circumstances. This embraces the reality that no institution – firm, research lab, or government agency – can “know it all” or “do it all.”

The early emphasis on *national* innovation systems has given way, particularly in Canadian scholarship, to *regional* and *local* innovation systems (de la Mothe and Paquet 1998, Holbrook and Wolfe 2000, 2002 and 2005). Much of this work has been coordinated and advanced by the Innovation Systems Research Network (Holbrook and Wolfe 2005). A focus at the regional level reflects a recognition that “attempts to develop policy exclusively at the national level in a country such as Canada may flounder on the diversity of the Canadian innovation system” (Holbrook and Wolfe 2005).

Whatever the level of focus, the innovation system concept is centred on knowledge flows that imply social interactions between organizations. The institutions that govern or influence these relations, therefore, are of particular interest in the analysis of innovation systems (Dalpé and Ippersiel 2000). Holbrook and Wolfe (2005, 110) write:

Both bodies of literature share the critical insight that the institutional aspects and formal organizations of the innovation system, and the presence or absence

of social or civic capital, play a critical role in influencing the climate for innovation and economic growth in cluster-based regional and local economies.

Analysts thus study the development of partnerships, networks, and collaborative arrangements of many kinds, in funding, in the exchange of information and knowledge, and in decision making processes (de la Mothe 2000). The studies often focus on formal policy-induced networks.

Applying the innovation systems approach allows policy makers to address not only market failures, but systemic failures, i.e., “the sources of success and failure within the broader mix of institutions that facilitate or inhibit the process of innovation, as well as specific structural gaps in the innovation system” (Holbrook and Wolfe 2000, 4). Unfortunately, innovation systems scholars have not paid much attention to government laboratories, *per se*.⁸ In most of this literature, firms are placed at the centre of the analysis with “universities and government agencies and policies” positioned as “supporting institutions,” part of the system’s “knowledge infrastructure.”

In addition, as discussed in this study, government laboratories have many S&T functions including the provision of public goods science that does not directly support innovation (at least in its narrower sense of commercialized new products or services). To the extent public policy analysis considers government labs only through the lens of their contributions to an “innovation system,” there is the potential to compromise the labs’ more public science functions. As a partial response to this concern, in this study I

⁸ Canadian exceptions include Niosi 2000, Niosi and Bas 2000, and Niosi 2002.

tend to refer to Canada's broader "science and innovation system" as opposed to the narrower concept of its "innovation system."

Evolutionary economics and the innovation systems paradigm has much to offer over neoclassical economics in terms of shaping government science policy. From this more structuralist theory, we draw the lesson that institutions matter and the success of a policy is not determined solely by its design; success partly depends on the specific context in which the policy is implemented. That is, good policies are designed with the specific institutional context and organizational competencies in mind. Evolutionary models and inductive approaches are favoured over the deductive paradigm of full-information and global maximisation which no longer seems fully adequate.

Despite these advantages, evolutionary economics does not provide a sufficient framework within which to understand the full diversity of government science and its institutions. De la Mothe (2000, 41) argues that while a market rationale may be legitimate in some aspects of government S&T, "as a broad rationale, it falls short." Bozeman and Sarewitz (2005, 119) contend that, "In science policy, market-based arguments and outcomes dominate political thinking and action, despite the fact that science and technology hugely influence public values in ways that are independent of the marketplace."⁹ The authors go on to argue that "pervasive use of market valuation, market-failure assumptions and economic metaphors shapes the structure of science policy in undesirable ways" (Ibid., 120).

⁹ The authors further write that "scholars in disciplines ranging from economics of technology to history of science have been documenting a 50-year increase in the influence of the marketplace on the agendas of public science" (Ibid., 120).

Similarly, the impact of the “innovation systems” literature has been clearly felt as governments have developed a systems view of science and a more sophisticated view of innovation (Boden et al 2004). This is reflected in how the policy discourse has shifted from “science and technology policy” to “innovation policy.” But by privileging innovation and economic growth rationales, the greater portion of government S&T—public goods science and RSA—and the institutions that seek to provide it are left both theoretically homeless and underappreciated in public policy.

Approaches from Public Policy and Institutional Analysis

In this final section of the literature review, I examine key concepts and theories from the policy/institutional analytical stream of literature. As will be seen in the next chapter, the analytical approach employed in this study draws significantly from this stream by adapting it to produce my two-part analytical framework. The discussion here is kept at a fairly high level because as Guston (2000, 15) has noted, “we need some understanding of the broader structure of policy making in order to understand the specific structure of science policy making.” The more specific discussion of how I build on and adapt these literatures to create the two-part institutional analytical framework is found in the next chapter.

Policy Paradigms

In 1975, political scientist Harvey Sapolsky argued that science policy is under-theorized (Sapolsky 1975).¹⁰ Many involved in the field believe this remains a problem today. Guston (1996, 229) writes that much of science policy is ad hoc and empirical and, despite some attempts to provide a political economic theoretical foundation, “no sustained effort at theory-building for science policy has emerged.” Rather, what has passed as theoretical underpinnings for science policy are policy paradigms and metaphors (Hall 1990).

Since the end of the Second World War, science policy has been framed within a “social contract” paradigm. This “social contract” metaphor captures the basic relationship between science and the state and consists of two fundamental tenets. First, public goods science delivers benefits that advance a wide range of national goals and is thus deserving of strong federal government support. Second, given the inherent uncertainty in the paths of scientific advancement, scientists themselves are in the best position to judge what is good science and, by extension, what science should be funded. Put simply, the social contract states that government agrees to fund the research that the scientific community deems worthy of support (as determined through peer review) and scientists agree to conduct science that will advance knowledge leading to a constant stream of new technologies that can be applied to the improvement of the nation’s health, security, and economy (Guston and Keniston 1994).

¹⁰ see also Sklair (1973, 48) who refers to “the theoretical naiveté of much of science policy studies.”

Thus, the social contract for science is a policy paradigm specifying an overarching *idea*—science as a public good; the broad policy *goals*—improved health, security, and economic prosperity; and the legitimate policy *instruments*—a high level of public spending on science, scientific autonomy with respect to its distribution, and accountability through self-regulation and peer review. As to the appropriate *institutions*, the social contract is largely silent. A reading of the key proponents of the paradigm, however, makes clear that the social contract was guided by a linear model of innovation in which public monies spent in university laboratories would ultimately, and inevitably, lead to new industrial technologies and societal benefit (Bush 1945, Polanyi 1962). The specific role for government laboratories was murky at best, but was generally couched in terms of supporting various public missions in agriculture, defense, public health and safety, etc. (Downs 1967).

This social contract for science was negotiated in the wake of the Second World War, when academic scientists who had been drawn into the government's war efforts were eager to get back to their universities and reassert their independence. Their preoccupation with autonomy was shaped by the Nazi and Soviet counterexamples and the concern that direct state interference could produce distorted, even ideological, accounts of the natural world. However, over time the perceived threat to scientific autonomy has shifted from the state to other sources:

By the 1980s and 1990s, the threat to autonomy appeared to come more from private capital and the increasingly permeable boundary between universities and industries such as biotechnology and information technology. In this context, state intervention may actually play a democratic role by providing a

mechanism for the public to be involved in setting broad research agendas that reflect general values rather than specific industrial interests. (Hess 1997, 58)

Left unexplored by Hess is the role that government laboratories can play along similar lines—i.e., as a mechanism for providing science in the public interest.

*Principal-Agent Theory*¹¹

As Guston and Keniston (1994) relate, this “social contract” metaphor is useful for a number of reasons. First, a contract implies two parties, each with distinct interests, who come to a formal agreement on some common goal. Second, it implies that the parties arrive at an agreement through a series of negotiations in which each tries to secure the most advantageous terms. Third, use of a contract metaphor suggests the possibility of conflict or at least of a disparity of interests. Finally, contracts can be renegotiated if conditions change. In recent years, the science policy communities in many of the industrialized countries, including Canada, have debated the need to renegotiate the post-war social contract for science. Most of this analysis, however, has not rested on robust theoretical foundations.

In attempting to help lay those foundations, Guston (1996 and 2000) hypothesizes that the key problem in science policy is one of delegation. That is, “How

¹¹ Also known as “ideal contracting theory.” To the extent principal-agent theory emerges from and is informed by organizational economics this discussion could have been positioned as an economics approach in the earlier section. However, as Guston (2000) points out, principal-agent theory borrows from transaction-cost economics to take a contractual approach to explaining organizations. “As such, principal-agent theory has been an aspect of the so-called ‘new institutionalism’ in both sociology (Powell and DiMaggio 1991) and political science (Alt and Shepsle 1990, Weimer 1995)” (Guston 2000, 18fn6). Given its links to institutional analytical approaches, and the natural tie-in with the previous section’s discussion of the “social contract” metaphor that guides so much of science policy, I have chosen to discuss principal-agent theory here.

do nonscientists get scientists to do what we all, as citizens, have decided?” By focusing on, as he puts it, the “how?” of science policy rather than the “how much?” of research funding, Guston is attempting to step away from the traditional lens of science policy analysis to develop a theory of the structure—the institutions and the processes—of science policy that goes beyond the typical focus on inputs (funding, personnel, etc.), outputs (publications, patents, etc.) and historical accounts of the outcomes of budgetary battles.

In my view, Guston (1996 and 2000) has advanced science policy scholarship by applying principal-agent theory to examine the problems of government-to-science delegation. This approach is productive for understanding science policy at a number of levels. At the highest, most abstract level of the science policy system the state is the “principal” that requests the “agent,” science (i.e., managers and professionals in scientific institutions), to perform certain tasks because the principal is not capable of performing them directly. As Guston (1996, 230) explains, “The agent performs the delegated task, out of self-interest, but with some of the consequential benefits accruing to the principal as well.”

At a more concrete level, the system consists of actual institutions such as legislative bodies, departments and agencies, and a range of public and private S&T-performing institutions including government laboratories, universities, research hospitals, and firms. At this level, the federal science-based departments serve both as agents to the legislative/executive principal (Parliament or Cabinet), and as principals to

their research performing agents. At the finest level of resolution, the theory also accommodates the individual relationships embodied in actual grants and contracts between institutions and scientists. The principal-agent approach clearly contrasts with the Mertonian or sociological approach which understands science as a social activity of peers guided by community norms. Given the pervasiveness of principal-agent relationships in the state-science nexus, the theory is particularly helpful for the policy analyst more interested in the policy of science than in the social conduct of science.

This principal-agent approach is particularly useful in framing two problems associated with government-to-science delegation: “adverse selection” and “moral hazard.” In the “adverse selection” problem, the principal has difficulty selecting the most appropriate agent because of a lack of expertise or information. Guston (1996, 231) states, “It is difficult and costly for the principal to discover which agent most completely shares the principal’s goals.” With respect to the “moral hazard” problem:

the delegation by the principal provides not only an incentive to perform the required task, but also an incentive to cheat, shirk, or otherwise act unacceptably. It is difficult and costly for the principal to know whether the agent will continue to pursue the principal’s goals after the principal has made the delegation of authority. (Ibid., 231)

To combat these problems, principals can engage in the joint and public formulation of goals in order to enhance the selection of agents who share their goals. Furthermore, to reduce the information asymmetry and combat the potential for opportunism, the principal can require monitoring and reporting of the agent’s performance (Lane 1997).

While the general notion of a “social contract” has long been a guiding metaphor in science policy, Guston is one of a few scholars who have explicitly introduced principal-agent theory to the analysis of science policy. His initial work translated the theory’s fundamental concepts into the vocabulary of science policy and demonstrates how many key science policy issues, including who should conduct public research, can be reformulated by adopting a principal-agent approach. Of particular relevance here, Guston considers the theory’s impacts on organizational structures and policy instruments in the debates about intramural vs. extramural performers, mission-oriented vs. discipline-based research, and the selection of research performers through peer-review vs. ear-marking (“pork-barreling”). Unfortunately for my purposes, his subsequent work has not focussed on the implications of the theory for government laboratories per se.

Building on the work of Guston and others, Van der Meulen (1998) extends the use of principal-agent theory by employing game theoretical approaches to test his hypothesis of national differences in the way the relationship between state and science is institutionalized. Like Guston, Van der Meulen begins by identifying the important features of the principle-agent relationship within science policy. First, agents have their own professional objectives that may conflict or only partially overlap those of the principal. Second, a major problem for the principal is the information asymmetry between principal and agent. Third, while the principal has the right to monitor the performance of the agent he does so at a cost. Fortunately for the principal, there is an

incentive within science for agents to monitor each other since scientists are consumers, as well as producers, of scientific output. Finally, Van der Meulen highlights the role of trust in creating the stability necessary for productive long-term relations.

Van der Meulen's treatment is much richer than Guston's initial exploratory piece because he conceptualizes the social contract for science not just as a principal-agent relationship but as a repeated principal-agent game. In such a dynamic context, the contract that mediates the principal-agent relation evolves as the preferences of the actors change based on outcomes of previous interactions and the emergence of rules, norms and trust between the actors. Van der Meulen examines the importance of institutional structures in stabilizing the government-science relationship. Importantly, however, he demonstrates empirically that there is no unique equilibrium—no one right institutional arrangement that stabilizes the science policy game. He believes stabilization of the state-science relationship through specific institutional structures has profound consequences for the development of science policy:

As institutions structure the set of rational strategies of actors and the ongoing interactions, the development of science policy and the possibility for changes depend on the nature of the institutions. In other words, we might expect science policy to be path dependent if the existing stabilization cannot be changed, but against high costs, and if new policy schemes reproducing the existing institution are possible and rational. (Van der Meulen 1998, 409)

Van der Meulen demonstrates that path dependency exists in his three case countries so that changes to the stable institutional structure are possible but at a cost. For Canadian science policy analysts, Van der Meulen's analysis demonstrates the importance of

considering carefully the path dependency implications of institutional structures of government science when introducing policy experiments (such as New Public Management) from other jurisdictions. While he and others have extended the use of principal-agent and game theory in science policy, I will now turn to other approaches from the institutional literature.¹²

Institutional Typologies and Institutional Design Approaches

Inherent in the mission-based policy paradigm is that ownership alone determines institutional design, purpose and behaviour. Under the mission-based policy paradigm, once a public need is identified that requires S&T inputs that the private sector is unlikely to provide (for the public good reasons discussed earlier), this mission is assigned to the appropriate public department or agency and it proceeds to deliver on this mandate. The assumption, then, is that this mission alone is determinative of the institutional characteristics of the laboratories that are “owned” by the department, in the sense of belonging to it organizationally. But this leaves unexplored the role of policy on the laboratory agents themselves. While recognizing that policy making at the strategic level will most likely continue to be guided principally by the sorts of high-level abstractions provided by policy paradigms, metaphors and sector-based stereotypes, some scholars have considered how policy analysts working just below this highest level (a level which is, nonetheless, of great significance) might be guided by something richer.

¹² For more on principal-agent and game theory as applied to science policy see especially Van der Meulen (2003), Braun and Guston (2003), and Devine and Webb (2004).

In the Canadian context regarding government labs, Doern and Lévesque (2002) address this shortcoming by applying an explicit three-category hierarchies-markets-networks framework to the study of the National Research Council. Their study demonstrates the usefulness of applying an institutional lens to government laboratories and their basic framework has been essentially adopted, with modifications regarding quasi-markets, as the first part of the two-part analytical framework for this study. The framework will be discussed in much more detail in the next chapter as will the methodological issues and boundary problems in determining what constitutes empirical evidence for inclusion in each of the hierarchy, market and network categories.

As indicated, however, Doern and Lévesque's focus on institutes of the NRC may provide limited insights into the institutional characteristics of government laboratories from other departments, especially those that have regulatory and other RSA functions that are not significant features of the NRC.

In a broader international and comparative context, a key contribution in this area is the study by Joly and Mangematin (1996). They stress that:

There is a paucity of papers dealing with the system characteristics of laboratories or, put in another way, the *institutional character* of research organizations. Neither R&D economics nor the sociology of science, as traditionally conceived, has made much headway in providing insight into sets of R&D laboratories and their evolution. (Ibid., 901, italics added)

Drawing on their empirical study of the relationships of public research laboratories within the plant breeding and biochemical industry, the authors present a typology of public laboratories which is based on three dimensions: scientific production and

visibility, type of funding (public or private) and homogeneity of research themes. Three lab types emerge from their analysis with each type developing specific kinds of relationship with private sector partners. Indeed, their main purpose is to study the dynamics of industrial partnerships of public laboratories. This is a shortcoming of their study for the purposes here, given that government labs have many other functions in the science and innovation system. Nonetheless, Joly and Mangematin's study and their empirical approach greatly inform the present study by underscoring the need for and potential characteristics of more complex institutional typologies for government laboratories to complement existing approaches.

Another major work of particular relevance is by Crow and Bozeman (1998). The authors have developed and proffer an "institutional design" approach to understanding government laboratories. At the analytical core of their approach is an "environmental context taxonomy" of laboratories within the U.S. system. Their work is premised on insights from organization theory that organizations adapt to their environmental context as a means of ensuring their survival and that the dominant influences affecting these adaptations are external (Crow and Bozeman 1998). The authors make the assumption that "laboratories, like other organizations, are influenced by a mix of economic and political authority," and that these influences are only partially explained by the formal sector of "ownership." They therefore see the need to go beyond mere sector-based stereotypes about these organizations.

The taxonomy developed by Crow and Bozeman maps laboratories within a matrix which has as one axis the level of “government influence,” and as the other axis the level of “market influence.” As indicators of public sector influence, the authors look at variables such as the percentage of the laboratory’s R&D budget provided by the government and the percentage of scientific equipment and facilities financed directly or indirectly by the government. These are primarily “inputs” variables. Market influence, by contrast, is determined by looking at the extent to which a laboratory’s effectiveness is measured by commercial, as opposed to scientific, success. This is indicated by looking at the laboratory’s core “outputs”—its knowledge and/or technology products and the extent to which their effectiveness was judged by commercial criteria (e.g., patents, licences, royalties, prototypes, etc.) or scientific criteria (journal publications, conference presentations, technical reports).

Along both axes, laboratories are classified as having either high, moderate, or low levels of government and market influence, resulting in a 3 by 3 matrix of nine possible classifications for R&D laboratories. Not surprisingly, a large number of government labs tend to cluster within the category of high government influence/low market influence, while industry laboratories are highly represented in the opposite category. But, importantly, Crow and Bozeman’s study shows that the story is more complicated since other cells of the matrix also have representatives from both sectors. Again, sector-based stereotypes are not wrong, only incomplete. For the purposes of my research, there is a need to build in a specific treatment of network influences. This is

done in both parts of my two-part analytical framework. In particular, in the second part, different categories of networks are included as will be discussed in Chapter 2.

The above analyses clearly inform the present study of government laboratories and the two-part analytical framework in that they explicitly put government laboratories at the centre of analysis and develop an institutional taxonomy, albeit different kinds, for the purpose of guiding policy and analysis. The major shortcoming of these works is that two of them focus on only two institutional forms, hierarchies and markets, while the other includes networks but with the category not sufficiently explored to reveal the complex types and varieties of networks. Tensions and spillovers among this trio of institutional forms also often do not receive the detailed treatment they need and deserve.

CONCLUSIONS

This chapter has located the present study within the broader scholarship on science policy and government laboratories by defining the unit of analysis and reviewing how three key approaches and literatures have directly or indirectly viewed science and government laboratories. The chapter began with an exploration of the difficulty in defining precisely the study's major unit of analysis, the government laboratory, and has reviewed the scholarship that exists pertaining to this institution. In this study, I define *government laboratory* broadly to be an organizational entity within a federal department or agency that serves as a locus for the performance of S&T (R&D and/or RSA), in any of its forms and in any of the full range of S&T disciplines. But the more important point

flowing from this analysis is the need to balance definitional approaches to understanding government laboratories with more fulsome study of them as institutions.

The second part of the chapter reviewed three broad approaches and streams of literature that variously comment on science and its institutions: 1) science studies, 2) economics and 3) policy/institutional analysis. I began with a review of the science studies literature, exploring the perspectives and methodologies from scholars of the sociology and history of science. This literature stream partly contributes to the present study by emphasizing the need to view laboratories as more than mere instruments of policy but rather as complex and evolving institutions. In addition, the study's methodology was informed by the use within this literature stream of case studies to build institutional biographies that go well beyond a focus on key scientists.

I next surveyed what can be drawn from economics, both its neoclassical and evolutionary schools, given the discipline's historical importance in informing public policy. Mainstream neoclassical economics has been heavily influential in shaping science policy and the section examined core concepts such as market failure, public goods, and the linear model of innovation. From the evolutionary school of economics, I build on the innovation systems approach by focussing on S&T institutions and their inter-relationships, including the importance of formal networks.

Finally, and most fruitfully, I examined ideas from the policy/institutional analysis stream including policy paradigms, principal-agent theory, and institutional typologies and institutional design approaches. These literatures are even more directly

relevant given their more explicit focus on science policy and government laboratories. The institutional typology approaches of Joly and Mangematin (1996), Crow and Bozeman (1998) and Doern and Lévesque (2002) have most directly influenced the direction of this study and the choice of the two-part institutional framework. This framework will be further set out and explored in the next chapter.

CHAPTER 2

THE RESEARCH FOCUS, ANALYTICAL FRAMEWORK, AND METHODOLOGY

This chapter details the study's overall design and approach to addressing the key research questions by discussing the research focus, the analytical framework and the methodology. The first section further makes the more detailed case for a more explicit focus on government laboratories. It also begins to address their multiple mandates and the tensions that can arise between diverse mandates and policy-induced institutional designs. Building on this discussion and the literature review of the previous chapter, the second section then specifies the two-part institutional analytical framework employed and how and why it emerged in this adapted form and is needed to advance the nature of research on government laboratories. Applying the two-part institutional analytical framework in the context of institutional mandates helps use see how problems are likely to and do arise as the preferred institutional modes shift to quasi-markets and networks but with hierarchies still being a major presence in government laboratories.

As noted earlier, the first part of the analytical framework, my adapted three-category typology of hierarchies, quasi-markets and networks, is used to examine the laboratory case studies in Chapters 4, 5, and 6 and to explore the problems that arise and

hence help answer the second research question. The second part of the analytical framework, the institutional design space typology, is introduced in this chapter but is drawn out more fully in Chapter 7. Chapter 7 also discusses, based both on the logic of the framework and the evidence of the case studies, why the first part of the two-part analytical framework is not sufficient and needs to be extended and complemented by the second part, the institutional design space typology, which emphasizes the multi-dimensionality of institutional forms. That is, the design space typology gets us out of a discrete category framework and allows us to examine the spectrum of more complex and varied kinds of institutional modes, particularly regarding networks, and the problems related to them. The concluding section of this chapter reiterates the research questions and discusses the study methodology.

I. THE DETAILED CASE FOR A GOVERNMENT LABORATORY FOCUS

The Importance of Government Science

A focus on government science makes sense given the importance of the federal S&T investment, both from the perspective of the federal government's share of the nation's overall scientific enterprise and in terms of the share of the federal budget allocated to S&T. In 2007, Canada's gross domestic expenditures on R&D totalled approximately \$28.9 billion (Statistics Canada 2008a, Table 1-1). Of this amount, the federal government funded approximately \$5.3 billion or 18 percent of the total (Ibid., Table 1-2). Much of the federal support for R&D passes through various mechanisms to

extramural performers in the private sector and universities; indeed, extramural funding has been an increasing proportion of the total in recent years. Nonetheless, almost half of federal R&D expenditures, or about \$2.5 billion, supports intramural efforts within government laboratories (Ibid., Table 1-2). Federal intramural R&D represents, therefore, approximately 9 percent of Canada's total expenditures on R&D. This share has declined steadily from about 36 percent in 1965 but is comparable to the current average among OECD member states (Organization for Economic Cooperation and Development 1969, Statistics Canada 2008a, Government of Canada 2003).

Furthermore, the discussion above does not include the government's major support of so-called related scientific activities (RSA). I have referred to RSA previously and it will now be useful to elaborate on what it is. RSA is officially defined as "activities that complement and reinforce R&D efforts by contributing to the generation, dissemination and application of scientific and technological knowledge" (Statistics Canada 2008b, 23). But, as Doern and Kinder (2007) have pointed out, this definition underplays the significance of RSA by relegating it to a kind of residual category of S&T, as everything that is "not R&D." Yet, many of the important services and risk management functions associated with government, from weather forecasting to science-based regulation of public health, security and the environment, are supported by RSA. For example, RSA includes regulatory science activities such as pre-market approval and post-market monitoring of drugs, medical devices and other S&T-intensive products. Indeed, Doern and Kinder (2007, 167) argue that "RSA is the quintessential core of

government S&T...necessary if the state is to regulate and monitor in the public interest.” According to a former senior federal S&T official, “the public looks to government for these [RSA-supported services] but there’s a sense that they haven’t received the attention they warrant” (Henderson 2003a). I would suggest that any examination of government S&T that focuses on R&D to the exclusion of RSA amounts to staging *Romeo and Juliet* without a Juliet.¹³

To account for this important activity, the Government of Canada refers to its “science and technology” portfolio as the total of its R&D and RSA investments. In fiscal year 2007-08, the government’s total investment in S&T (i.e., R&D + RSA) reached almost \$10.2 billion, and represented about 4.4 percent of the total federal budget (Main Estimates) (Statistics Canada 2008b, Table 1-1). Government *intramural* S&T amounted to approximately \$5.2 billion in 2007-08, representing over 51 percent of the total federal S&T spend (Ibid., Table 3-2). Thus, whether viewed through the lens of a) the federal government’s intramural contribution to Canada’s total R&D performance, or b) the S&T portion of the Government of Canada’s annual budget, federally-performed S&T is not insignificant in Canada.

Another set of indicators illustrating the relative importance of government science draw on personnel data. According to official data, in 2007-08 the Government of Canada employed over 35,500 people (full-time equivalents) engaged in S&T activities, with over 13,500 of these engaged in R&D and over 19,500 engaged in RSA

¹³ I wish to acknowledge my debts to Paquet and Shepherd (1996) who, in a completely different context, referred to staging *Hamlet* without the Prince of Denmark.

(Statistics Canada 2008c, Table 4-1).¹⁴ Approximately 16,000 of the S&T total were in the “scientific and professional” occupational category, of which about 6,300 were directly engaged in conducting R&D, and over 9,000 in RSA (Ibid., Table 4-2). In 2005 (the most recent year for which inter-sectoral data is available for comparison), federal personnel engaged in R&D represented 7 percent of the Canadian total (Statistics Canada 2008d, Table 1-1).

And within the specific arena covered by this study’s case labs, Environment Canada reports that “over 40 percent of Canada’s environmental research capacity lies within the federal government” (Environment Canada 2006a, 22). In 2007-08, Environment Canada had almost 3,600 personnel engaged in S&T activities, or about 10 percent of the total federal S&T personnel (Statistics Canada 2008c, Table 4-9). As indicated by these funding and personnel data, government laboratories represent a significant component of Canada’s scientific enterprise.

The indicators related above constitute “input” measures; they describe key inputs to the science system such as funding and personnel. Government science and its importance can also be characterized using “output” measures. Common output indicators employed by the S&T policy analyst include measures related to scientific publications and patents. For example, Table 2-1 shows the federal share of Canada’s total publications in various specialty areas during the last two decades of the 20th century. The data indicate that government laboratories are a major source of Canadian science, contributing from a third to a half of all Canadian publications in key public

¹⁴ Note: the remainder were engaged in the administration of extramural S&T programs.

stewardship domains such as food and the environment. Much use is made of such input and output indicators in characterizing the government science system but it must be stressed that they can provide only a partial picture.

Table 2-1. Federal Share of Total Canadian Publications in Top Specialty Areas, 1980-97

Specialty	Federal % of Total
Oceanography and Limnology	51.1%
Agriculture and Food Science	47.7%
Meteorology and Atmospheric Science	46.3%
Entomology	44.8%
Environmental Science	40.2%
Dairy and Animal Science	38.7%
Marine Biology and Hydrobiology	38.2%

Source: Robitaille and Godin (2002) drawing on data from Observatoire des sciences et des technologies (2000)

Obtaining a complete picture of the system of government laboratories is made difficult by the fact that there is not even general agreement on which establishments should be included in mapping the system. Industry Canada maintains a list of 102

“federal government research facilities” and the Federal Partners in Technology Transfer program maintains a list of 114 “federal labs” but even a casual look at these lists show them to be inconsistent, inaccurate and incomplete (Industry Canada website, Federal Partners in Technology Transfer website). Niosi (2000), in his examination of the Canadian innovation system, estimated there were 110 government R&D laboratories. While it is not essential to this study to nail down a firm number, it seems fair to say that there are on the order of 100 key government laboratories. More to the point, the lack of a consistent official list of government laboratories demonstrates that they have not been viewed as strategic assets within Canada’s science policy making.

Government Laboratories: Purposes and Pressures

The federal government laboratories, functioning within larger science-based departments and agencies (SBDAs), deliver on a wide range of roles while facing numerous contemporary pressures. As Table 2-2 illustrates, various attempts have been made over the years to delineate these roles. It is evident that while a single, comprehensive list of roles is difficult to obtain, common themes do emerge. Similarly, the particular stresses faced by government laboratories vary in intensity and impacts but general policy pressures are evident. As stressed in the Introduction, this study is not focussed on roles per se. The focus is on institutional forms and varieties, expressed mainly in the context of hierarchies, quasi-markets and networks. But some discussion of roles is needed as background and context both in this chapter and in the case study

chapters. They are also subsumed in the discussion in Chapter 3 of the evolution of S&T policy as it affects the labs.

Broadly speaking, government laboratories must support important and increasing regulatory, policy and risk-management objectives and processes through the provision of public goods science and technology. This role is critical for the effective functioning of Canada's knowledge-based economy and society by, for example, ensuring public confidence in key consumer commodities such as food and drugs. Fulfilling this role is becoming ever more complicated by global trade rules and international requirements that rules and assessments be based on sound science (Browne 2000). International acceptability of national regulatory regimes will be influenced by perceptions of how these systems ensure the integrity of their underlying science (Jarvis 2000). Doern (2000, 295) writes, "To have a voice that will be heard at the growing number of international tables, a small or medium-sized country has to bring a good science-based view, or else it will simply not be a credible player in complex negotiations."

Table 2-2. Various Takes on the Roles of Government Science

A federal laboratory may have one or more of six primary rationales for conducting R&D:

- where *security implications* are thought to make it unsuitable for a private organization;
- where it is needed to assist a *regulatory function*, there being no private R&D institution available which is independent of the firms being regulated;
- where the R&D required by a department is deemed to be *otherwise inappropriate to private industry, or where there may be no existing industrial capability* and it is not judged worthwhile to create one;
- in connection with primary, secondary, and consumer *standards*, including their relationship to international standards;
- to permit *intramural monitoring of the technical state-of-the-art*, without which the parent department may miss opportunities or mismanage its contract research; and,
- in support of intramural capital facilities provided to meet the *research and testing needs of Canadian industry*.*

Government carries out S&T activities in order to:

- provide *technical assistance* to SMEs;
- pursue *development of new technology* where firms could not afford solo development;
- *establish and negotiate standards* to protect Canadians and provide a favourable business climate, and to harmonize Canadian standards with international regimes;
- undertake *testing and approval* in areas such as drugs, biomedical devices, food and other consumer products (a pre-market role);
- *regulate and monitor compliance* in similar areas (a post-market role);
- undertake *environmental monitoring* both in terms of protecting the ecosystem from emerging threats, as well as *survey work and stock assessments* to support natural resource management;
- support *emergency preparedness* for natural disasters;
- support *policy* in a broad range of departments and agencies; and
- conduct *basic research* in order to keep government current with the latest advances, keep vibrant an external research network that can be called upon in support of government science, and promote an attractive career path for current and prospective employees.
- provide S&T-based *information and statistical services* including weather forecasts, census data, geographical information, etc.**

The government requires the capacity to deliver four core public good S&T roles:

- *support for decision making, policy development and regulation*
- *development and management of federal and international standards*
- *support for health, safety and security, and environmental needs*
- *enabling economic and social development****

* adapted from Cordell and Gilmour (1976)

** adapted from de la Mothe (2000)

*** adapted from Government of Canada (2005) and Council of Science and Technology Advisors (1999)

In delivering this public goods science, government laboratories must contend with what Doern (2000) describes as the growing tension between “patient science”—the

type of anticipatory science that proceeds steadily based on the internal dynamics and natural progress of the research as judged by the scientists involved—and “science on demand” in which the laboratories must respond to external priorities flowing from non-scientists such as Cabinet ministers, the media, and other interests. According to Doern (Ibid., 288), “science on demand is growing and displacing patient science.” He suggests that this is due to the department’s ever-expanding mandate despite the budget and personnel cuts of the mid-1990s, and the revolving door of ministers who stay on average only 15 months and must play “the short game” (Ibid., 287-8). Given this context, one departmental scientist suggested that there is less “freedom to roam...in launching new research initiatives based on the instincts of scientists as opposed to the dictates of existing policies and commitments” (Ibid., 293).

Government laboratories are also expected to support broader policies and processes to foster innovation in a knowledge-based economy. These pressures reflect a longstanding concern that R&D performance in Canadian industry has been persistently weak compared to its foreign competitors. Government science policy has long called for federal laboratories to help compensate for industry’s deficiencies. This is perhaps understandable in that frustrated policy makers have latched on to one of the few policy levers at their disposal. However, it has been argued whether this approach actually helped or hindered industrial R&D performance in Canada (Smith 1983). Nonetheless, government laboratories continue to be cast as key catalytic players in both national and

regional systems of innovation whose purpose is to foster and support commercial innovation and economic development.

While this role may make sense in the context of some government laboratories, its blanket application reflects a simplistic mode of thinking that fails to differentiate sufficiently among laboratories and their various mandates. For example, this perspective fails to recognize that the emerging regulatory and risk management pressures may quite properly be pushing some government laboratories to act less as contributors to economic development and more as guardians of public confidence (Doern and Kinder 2002, Farina 2001).

At the same time, government laboratories are under pressure to adopt new institutional arrangements and to network with partners in the private sector, the voluntary sector, academe and the rest of the government (Government of Canada 2002 and 2007). As noted in the Introduction, Gibbons et al (1994) describe the emergence of a new mode of knowledge production that has implications for government laboratories. In this new, more socially-distributed mode of knowledge production, successful institutions must become more permeable and create new channels of communication.

The authors assert that:

Large university-based institutes with tenured faculty, or government laboratories for fulfilling specific functions as well as permanent research units with tenured research staff set up for specific monocultural research, will not be the policy models of the future. Such organizations have become too expensive and inflexible to meet the needs of distributed knowledge production. (Gibbons et al 1994, 161)

In response, policies and management strategies seek to increase the permeability of these institutions and the linkages among them.

Government laboratories also face challenges with respect to maintaining and renewing their scientific and technical capacities (in terms of personnel, capital infrastructures, etc.) in order to grapple with newly emerging and complex science-based issues. One major pressure on the federal government's intramural capacity is the aging of its workforce. Just as with the university sector, the federal government has a large cohort of researchers nearing retirement and is in direct competition with universities for the next generation of researchers to refresh their ranks. However, with the increasing funding being channelled into academic research and with high-profile programs such as the Canada Research Chairs making academic research very attractive to top researchers, government laboratories face stiff challenges in attracting the best and brightest.

Regarding physical infrastructures, Munce (1962, 36) observed that "laboratories by their very nature are one of the most likely of all building types to become obsolescent." Because scientific advancements are continually pushing back the frontiers of what is possible, government laboratories must contend with a continuing obsolescence of their equipment and physical infrastructures. Government laboratories are often the custodians of unique national S&T facilities and this function is often key to their role in Canada's science and innovation system.

Finally, government labs are under pressure to develop new performance indicators and accountability systems to measure and evaluate their research processes

and impacts (Rappert 1995, Rhodes 1997, Doern 2008). These and other pressures create the context in which government laboratories operate today. In this changing context, and with the sharp increase of research capacity in universities and industry relative to government, the roles and institutional designs of government laboratories are evolving.

Government Laboratories as the Focus

The literature review presented in Chapter 1 examined three approaches and related literature streams that have been used to analyze government science and its institutions. Despite its importance, I have stressed that it is not at all clear that the “government laboratory” as an institution has been examined systematically by Canadian scholars.¹⁵ In fact, very often policy studies refer only to a concept of “government science” disembodied from the institutions in which it is performed. Such an approach underestimates the degree of variation that exists across government laboratories. The need to think about government laboratories in a more explicit way, involving a wide range of institutions performing a diverse set of functions, is critical if the full range of government science policy goals are to be successfully met.

¹⁵ There have certainly been many analyses of Canadian science policy including Royal Commission on Government Organization (1963), Mackenzie (1964), Lithwick (1969), Organization for Economic Cooperation and Development (1969), Senate of Canada (1970), Doern (1972), Hayes (1973), Task Force (1984), Dufour and de la Mothe (1993), Doern and Reed (2000) and de la Mothe (2000), as well as numerous relevant reports of various science advisory bodies such as the Science Council of Canada (1968 and 1979), the National Advisory Board on Science and Technology (1988a, 1988b, 1990, 1993 and 1995), and the Council of Science and Technology Advisors (1999, 2001, 2003 and 2005). There are also many examples of case studies of individual science agencies or establishments such as Thistle (1966), Zaslow (1975), Eggleston (1978), Bothwell (1988), Jarrell and Gingras (1991) and Vodden (1992). More relevant to the present study are important contributions such as Cordell and Gilmour (1976), Anderson and Dalpé (1991), Anderson and Davis (1993), Doern and Kinder (2002), Doern and Lévesque (2002), Rosenblatt (2004) and Doern and Kinder (2007).

As noted earlier, while some studies, particularly those within the “innovation systems” literature, often do refer more specifically to “public research organizations,” this term usually includes publicly-funded university laboratories as well as government laboratories (e.g., Dalpé and Ippersiel 2000, Nelson 2000). The problem is that, by conflating university and government laboratories, these studies do not examine the differences between the two types of institutions. Given the large number of government laboratories that collectively spend over \$5 billion annually, it would seem that they deserve more attention. An important advantage of this study is that it places government science at the centre and focuses on the government laboratory as the unit of analysis.

Where government laboratories have been examined in their own right, within the Canadian literature, the focus has typically been on the role that government laboratories have played and should continue to play in the realm of technology transfer and commercialization, industrial innovation, and economic development (e.g., Cordell and Gilmour 1976, Niosi 2000 and 2002). In their important early work, Cordell and Gilmour provide a comprehensive overview of the federal S&T complex and amply illustrate the diversity of Canadian government laboratories:

They are remarkably diverse in size, character and orientation. A tour of all government establishments would exhaust the energy and powers of memory of the most tireless and thorough investigator...A structure as complex as this must be conceptually simplified in order to be understood. (Cordell and Gilmour 1976, 152)

However, they do not develop a simplifying institutional typology and their study is not focussed on issues of institutional design but rather on technology transfer from government laboratories to the manufacturing sector, a key concern in that period.

Niosi has used patent data to highlight the role played by laboratories of the National Research Council as “entry attractors” or “competency agglomerators” within industrial clusters or regional innovation systems (Niosi 2002, Niosi and Bas 2000). But how their industrial relations and related S&T functions impact and potentially put at risk other public good roles of government laboratories has not been adequately explored. In addition, while patent counts provide a readily accessible, quantitative measure favoured by many analysts, the use of patent analysis downplays the importance of other, less market-oriented knowledge products and policy and regulatory advice of government laboratories.

Thus, government laboratories have tended to be treated unidimensionally with no notion that some laboratories might function well in some roles (e.g., technology transfer to industry) while others might perform well in fulfilling different roles (e.g., directed basic research, regulatory science), or, in fact, that often such a range of roles exist within the same laboratory. Hence, my repeated emphasis on the observation that, as organizations, government laboratories have been treated far too much as “black boxes” with little examination of their institutional makeup, their internal and external structures, roles, and relationships.

Canada is not alone in this regard. A study of the U.S. innovation system revealed that while public policies affecting research laboratories typically treat them as simple, homogeneous, and stable there is, in fact, a remarkable diversity and complexity in these institutions (Crow and Bozeman 1998). The authors describe how the dominant framework for S&T policy-making has been based on sector of ownership—government, industry, or university—with long-standing stereotypical roles ascribed to the laboratories in each sector:

Universities are seen as the bastion of fundamental research, industry as the home of commercially related, applied, and development research, and while the government lab stereotype is a bit more murky, government labs are often viewed as sites for supporting national research missions, especially in weapons, energy, space, and agriculture. (Ibid., 14)

The authors do not contend that this sectoral distinction is no longer reasonable or useful, only that much more is needed. Linkages across sectors and among formal networks of laboratories are becoming increasingly evident and important. Some of the labs are “hybrids” where public and private ownership and sources of funding are so complicated as to defy classification by overstretched sector-based categories. Examples include the so-called GOCO laboratories which are government-owned but contractor-operated, or the company-sponsored laboratories on university campuses (these examples are found particularly in the United States) (Crow and Bozeman 1998, Whelan 2000, Georghiou 2004).¹⁶

¹⁶ Although there are exceptions, most government laboratories in Canada are government owned and operated. This contrasts sharply with the situation in the United States where many laboratories as well as the more arms-length federally-funded research and development centres (FFRDCs) are government owned, contractor-operated laboratories (GOCOs) managed by universities (e.g., Los Alamos National Laboratory, until recently), university consortia (e.g., Fermilab), industrial contractors on a not-for-profit

This classification problem is not a new phenomenon. As far back as 1956, in an analysis of the ownership and control of government and industrial laboratories, Hiscocks (1956, 24-5) observed that:

Whether an institution is operated on public funds or not does not...seem to be a sound method of classification, because there are amongst the former a whole range of degrees of government control, just as there is, in effect, government supervision of some of the work of industrial laboratories which are engaged upon government contracts—especially defense contracts.

He went on to categorize laboratory types that span a spectrum of degrees of government control or influence, which I will illustrate with Canadian examples. At the most “public” end of the spectrum we have departmental laboratories such as those of Environment Canada that will be studied here. In the next category would fall “extra-civil service organizations” such as the National Research Council laboratories that are subject to somewhat less government control.¹⁷ Further out, there are research organizations of nationalized or quasi-nationalized industries (e.g., the Chalk River Laboratories of Atomic Energy of Canada, Ltd.) and industrial sector research associations funded or influenced by government (e.g., PAPRICAN).¹⁸ Finally, there are private sector laboratories that conduct research supported by federal loans and subsidies

basis (e.g., Oak Ridge National Laboratory) and independent non-profits (e.g., Draper Laboratory) (U.S. National Academy of Engineering 1993).

¹⁷ For example, the NRC enjoys greater flexibility in human resources management than departmental laboratories that fall within the core public service.

¹⁸ Since 1950, the Pulp and Paper Research Institute of Canada has been an independent non-profit institution. Historically, however, it was influenced by the federal government through, for example, the appointment of some of the members of its Board of Directors (Organization for Economic Cooperation and Development 1969). PAPRICAN is now part of FPInnovations.

or subject to government contracts and agreements (e.g., through Technology Partnerships Canada).

Even among the purely public sector laboratories there is a remarkable degree of institutional diversity. According to a study of the British system:

There is an enormous diversity in the types of organizations which could be referred to as “public sector research laboratories” in the UK science and technology system. This diversity covers not only the areas of specialism but also factors such as size, ownership details, locations, organizational issues and relationships with industry and with other parts of the S&T infrastructure. (Beesley et al 1998, 129)

II. THE TWO-PART INSTITUTIONAL ANALYTICAL FRAMEWORK

Based on the findings of the literature review, and the discussion in the previous section, the need to conceptualize and analyze government laboratories as institutions in a more focussed, explicit way is paramount. To this end, Canadian government laboratories are examined using a two-part institutional framework: first, an adapted hierarchies, quasi-markets and networks typology, and then through a complementary but necessary second part, an institutional design space typology and approach.¹⁹

Under the first part of the analytical framework, the case laboratories are initially examined as a mix of hierarchies, quasi-markets, and networks to bring out their basic institutional characteristics and the problems associated with delivery of the labs’ mandates, as the labs have moved towards the greater preferred use of quasi-market and

¹⁹ It should be noted that use of the term *design* is not meant to include the literature related to the architectural design and physical layout of laboratories—see for example Munce (1962) and Guy (1962). While this literature provides useful guidance to the laboratory designer (even going so far as to recommend workbench dimensions!), they provide little of relevance to the policy analyst.

network institutional forms. I then build on this initial three-category framework of institutional forms to develop an institutional design space typology that represents the second complementary but necessary key part of the overall analytical framework.

Employing an institutional design space approach in particular highlights the existence of four general design types, namely hierarchies, quasi-markets, intra-sectoral networks and inter-sectoral networks. It also makes more explicit the multi-dimensional design space within which policy makers can choose to make, buy or collaborate. Among other benefits, the institutional design space approach can assist the policy analyst in understanding the potential tensions between the mandates and institutional designs of government laboratories.

Analytical Framework - Part I: Hierarchies, Quasi-Markets and Networks

Institutions can be defined and viewed in many ways and are studied by many academic disciplines. At the broadest level they can be seen as entrenched systems of behaviour centred around strong beliefs, cultures, values, norms, conventions, routines, procedures, roles and organizational forms (March and Olsen 1989). Edquist and Johnson (1997, 49) define institutions as “a set of common habits, routines, established practices, rules or laws that regulate the relations between individuals or groups.” And, Streeck and Thelen (2005, 13) define institutions as “building blocks of social order” representing “socially sanctioned (i.e., collectively enforced) expectations with respect to the behaviour of specific categories of actors or to the performance of certain activities.”

While there are important differences among these definitions and among institutional theories more generally, for my purposes, the key injunction from the institutional school is “to analyze the whole organization” as a living entity with a “natural history” (Perrow 1986,157-8). This notion of an organic, evolving organization emphasizes the importance of understanding how it adapts to changes in its environment, and also often resists them, as revealed in part by analyzing the configurations and reconfigurations of its structural forms. Increasingly within the evolving institutional theoretical literature, a basic typology of institutional forms as hierarchies, markets, and networks has come to the fore (Williamson 1975 and 1985, Powell 1990, Thompson et al 1991, Nohria and Eccles 1992, Peters 1999, Benkler 2006).

Institutions as Hierarchies

Institutions as *hierarchies* refers to organizations constructed along classic Weberian bureaucratic lines. Max Weber, the great German sociologist, was one of the most prominent early theorists on the nature of bureaucracy as legal-rational and hierarchical organizations (Weber 1946). Hierarchies are characterized by a division of labour based on functional specialization. Authority is exercised through primarily vertical superior-subordinate relationships, often referred to as a “chain of command,” within a ranked structure of office holders each subordinate to the level above it (Starling 1986). These levels consist of salaried officials holding permanent positions based on qualifications and competence. Knowledge flows within hierarchical organizations are

primarily vertical and impersonal and they engage in primarily written modes of communication to ensure accountability (Hood 1998, Pollit and Bouckaert 2000).

Through its system of rules and standard procedures, a hierarchical organization is also intended to produce reliably predictable behaviour, a highly valued capacity especially when linked with responsible government (Lane 1997, Doern and Kinder 2002).

On the other hand, critics of hierarchical organization contend that the rigidity of the command-and-control operational mode and the inward-looking culture make it particularly ill-suited to addressing the complex challenges facing governments, problems that often transcend organizational boundaries (Goldsmith and Eggers 2004). According to Goldsmith and Eggers (Ibid., 7):

In the twentieth century, hierarchical government bureaucracy was the predominant organizational model used to deliver public services and fulfill public policy goals. Public managers won acclaim by ordering those under them to accomplish highly routine, albeit professional, tasks with uniformity but without discretion. Today, increasingly complex societies force public officials to develop new models of governance. . . . One-size-fits-all solutions have given way to customized approaches.

With respect to institutions as hierarchies, the study will examine questions such as:

- To what extent do government laboratories exhibit characteristics of hierarchies?
- How have the laboratories changed as hierarchies functioning within other hierarchies (e.g. their own hierarchy; their parent department as a hierarchy; the Government of Canada as a hierarchy)?

- How do hierarchical and related procedural characteristics impact the labs' abilities to fulfill their mandates?

Institutions as Markets or Quasi-Markets

Markets are a form of organization emphasizing modes of exchange, in which goods and services are traded on a voluntary basis. Markets are greatly facilitated by widely acceptable mediums of exchange (such as money), property rights, and where contracts can be developed and enforced (Thompson et al 1991). De la Mothe (2004) has suggested that while markets are effective at exchanges of physical commodities they are less successful at handling “non-commodities” such as knowledge and information.

While government laboratories are not markets, they often exhibit *quasi-market* or market-like characteristics. The longest-term pressure on the government laboratories in Canada has been that they should be more market-sensitive themselves and that they should serve industrial and innovation policy goals (de la Mothe 2000, Doern and Kinder 2002). Canadian government laboratories are usually publicly owned but they are often no longer wholly funded by taxpayers. Partly under the New Public Management banner, but also under the logic of innovation policy, they are expected to adopt private sector business practices. In quasi-market type laboratories, external relationships are largely contractual or governed by formal partnership agreements in which the assignment of intellectual property rights is often of central concern. It is important to understand the extent and impacts of market-oriented behaviour and practices, including the use of new

institutional arrangements such as special operating agencies; the use of revenue-generation, cost recovery, contracting, or other business-like approaches; intellectual property protection and revenue streams; and roles in local or regional clusters of economic and social innovation (Dalpé 1997b, Dalpé and Ippersiel 2000). Key questions here include:

- What market behaviour or market-like attributes are government laboratories exhibiting?
- How have these changed during the study period?
- What impacts are these having on the labs' abilities to fulfill their mandates?

Institutions as Networks

In contrast with hierarchies and markets, *networks* are a way of organizing that involve more horizontal exchanges of information and expertise, shared authority and mutual accountability, and relations based primarily on trust and collegiality rather than rules, command-and-control, or monetized transactions and contractual obligations (Powell 1990, Thompson et al 1991, Rhodes 1997, Kickert et al 1997, Benkler 2006). In this era of continuous change, networks are viewed as more flexible than traditional hierarchies. According to Paquet and Shepherd (1996, 59), the forces of globalization have weakened the traditional nation-state and “have called for a more distributed form of governance: large private and public organizations have had to reorganize into networks

of autonomous units that are agile, and better able to adapt to ever-changing circumstances.”

According to Nohria (1992, 4), “all organizations are in important respects social networks” and should be analyzed as such. Following Laumann et al (1978, 458), a social network can be defined as “a set of nodes (e.g., persons, organizations) linked by a set of social relationships (e.g., friendship, transfer of funds, overlapping membership) of a specified type.” But this definition does not go far enough. What is missing is a sense of the dynamic connections and interactions inherent in networks, especially policy-induced formal networks. A network requires active engagement and the potential for reciprocity. To be successful, networks must have conventions about how trust-based exchange is maintained and enhanced (e.g., they must develop rules about how to treat opportunistic behaviour) (Breton and Wintrobe 1990, Hood 1998, Lane 1995).

Also, as stressed throughout this analysis, networks can be either formal or informal. Rycroft and Kash (1999) point out that network relationships often begin as informal linkages that evolve toward more formal structures. And Freeman (1991, 503) adds that “behind every formal network, giving it the breath of life, are usually various informal networks.”

Networks, although much in vogue these days, should not be viewed as universally positive. According to Cohen and Prusack (2001), they can become clannish, insular and idiosyncratic as suggested by the negative connotation of “old boys network.” Networks can sometimes become so enthralled with doing “their own thing” that their

work may no longer be of much relevance to the participating organizations. A delicate balance must be maintained between creative vitality and self-indulgent “group think.” Greater permeability of the network can address these problems (Cohen and Prusack 2001).

As Chapter 1 has shown, informal networks are common among scientific and professional groups. Federal laboratories, as scientific institutions, were network-based historically, both internally and externally, long before formal networks became managerial fashion. In fact, Benkler (2006, 323) documents how market-based approaches to key scientific activities such as journal publication are giving way to commons-based and network-based approaches: “The existing market structure is quite odd in a way that likely makes it unstable. Authoring and peer review, the two core value-creating activities, are done by scientists who perform neither task in expectation of royalties or payment.” Given the rapidly escalating costs of journal subscriptions, non-proprietary solutions are beginning to emerge such as Public Library of Science and ArXiv.org, an online repository of working papers in the physics. Benkler (2006, 325) argues that the success of these approaches is due to the small, specialized nature of the networked user community where the “reputation effects of poor publications are likely immediate.”

With respect to the importance of internal networks, Nohria (1992, 4) quotes Lincoln (1982, 26), “To assert that an organization is not a network is to strip of it that quality in terms of which it is best defined: the pattern of recurring linkages among its

parts.” Nevertheless, the pressure to organize and operate through more formal, external networks has increased in recent years, and these will be the primary focus for this study. The study will examine what kinds of partnerships and other horizontal relationships are fostered with the labs’ key external stakeholders and S&T actors in the broader Environment Canada matrix, other government departments, provincial and municipal governments, universities, business and industry, non-governmental organizations, local communities, as well as internationally (Dalpé, 1997a). Important questions include:

- How do government laboratories operate as and within networks?
- How have labs changed in terms of the ways in which they network?
- How have formal networking and partnering impacted the labs’ abilities to fulfill their mandates?

To “Make” or “Buy” or “Collaborate”

Thinking about these institutional forms has been aided by the use of transaction cost analysis from the institutional analysis literature and its accompanying calculus of how and why one organizational mode might be chosen over another (Williamson 1975 and 1985, Coase 1991, Doern and Levesque 2002). Such analysis focuses on explicit and implicit contracting and on how to overcome both the procurement costs of inputs and the costs of exchange. Facing these “transaction costs” produces a series of “make” or “buy” or “collaborate” decisions that imply a choice (or a series of choices) between hierarchies, markets and networks (MacDonald 2000, Doern and Levesque 2002). Thus, overall, if

there is a greater movement to network forms, for example, there are likely to be benefits but also transaction costs of both an informal and formal bureaucratic-procedural kind.

According to Williamson (1975, xi) “market transactions involve exchange between autonomous economic entities” while “hierarchical transactions are ones for which a single administrative entity spans both sides of the transaction, some form of subordination prevails, and, typically, consolidated ownership obtains.” Although networks were not part of Williamson’s framework, we can draw on Fukuyama (1997, 4) to view network transactions as exchanges among “a group of individual agents that share informal norms or values beyond those necessary for ordinary market transactions.” Transaction cost frameworks have been applied mainly to understanding firms and economic organization, but increasingly they are being applied to any sector that faces choices among modes of operating (Doern and Levesque 2002). Such analysis has been applied to understanding choices in government not only in service delivery but also in how organizations structure their choices for obtaining inputs for policy making (MacDonald 2000, Doern and Levesque 2002).

Another way to explore and understand institutions as hierarchies, markets and networks is to examine differences in how they access knowledge and in their investment emphases (see Table 2-3). Hierarchy-based organizations seek to internalize the resource inputs they require to produce or “make” their outputs. They therefore tend to concentrate their investments in developing their *human and physical capital* resources, ensuring they have in-house the necessary expertise, personnel and facilities.

Organizations emphasizing market-based modes of operation must by necessity emphasize *financial capital* in order to ensure they have the revenue with which to “buy” what they need to meet their objectives. Emphases include cost recovery and fee-for-service provision, contractual employment, and enforcement of revenue-generating intellectual property rights and other non-appropriations based revenue streams.

Finally, network-based organizations that “collaborate” to deliver on their mandates must pay special attention to developing their *social capital*. “Networks are key and critical components of any organization’s stock of social capital” (Cohen and Prusack 2001, 60). Organizations invest in networks and network participation because they provide access to power, information, knowledge, funding, and, importantly, access to other networks. In accessing knowledge, the importance of tacit knowledge in S&T suggests a requirement for higher degrees of interaction (i.e., networks / collaboration), not just appropriation (markets / contracts) (de la Mothe 2004). Wolfe (2002a, 13) writes, “Competitive advantage is not limited to the acquisition of codified knowledge and capital that are available worldwide; it is dependent on the institutional and social capital that fosters the acquisition and utilization of codified and tacit knowledge.” Network-based organizations invest in “learning by interaction” through spatial proximity and even co-location with collaborators to facilitate face-to-face meetings, through collaborative research and technology development, and by providing the rewards and recognition that legitimizes and encourages networking activity and social learning among its employees, not just to gain access to information but to acquire new skills,

build new capacity and develop new competencies (Wolfe 2002a, Gertler and Wolfe 2002).

Table 2-3. Differences in Operating Mode, Knowledge Access and Investment Emphasis

Form	Operating Mode	Knowledge Access	Investment Focus
Hierarchies	Make	Hire	Human/Physical Capital
Markets	Buy	Contract	Financial Capital
Networks	Collaborate	Social Learning	Social Capital

The first part of the framework applies the three-category typology of hierarchies, quasi-markets and networks to explore the institutional features of government laboratories. Table 2-4 summarizes the specific characteristics under each category that will be examined in the case study laboratories. In addition, as noted earlier, the case studies will discuss the laboratories' mandates and the challenges they face, particularly those associated with the policy pressures to reconfigure their institutional designs.

Table 2-4. Aspects of Hierarchies, Quasi-Markets & Networks in Government Labs

Hierarchy	Quasi-Market	Network
<ul style="list-style-type: none"> - Vertical layers of reporting and superior-subordinate relations in lab as a public bureaucracy - The lab as a unit lodged within "hierarchy of hierarchies" (departmental and the federal government) - Traditional public sector management strategies and styles; emphasis on written modes of communication; nature and timeframes of macro-planning, budgeting, etc. - Evolution in systems of budgetary and allocative control (Program Review, budget cuts, revenue raising, Vote-netting etc.) - Prescribed policies and rules linked to S&T funds and programs with varying eligibility features - Procedural bureaucracy to ensure accountability on inputs, outputs, and results-based performance to multiple stakeholders - Support for core Public Service values and traditions of lab but also potential for inertia - Consistency sought in managerial levels, span of control, concern for getting the org chart right - Human resource practices conditioned by traditional Public Service practices; emphasis on permanent positions; formal career system and merit-based performance; rigid occupational categories; low mobility - Government-wide policies on intellectual property 	<ul style="list-style-type: none"> - Extent of commercial orientation and links to markets; extent of lab's role in supporting and brokering within key industrial sectors - Extent of adoption of quasi-markets (e.g., cost recovery, user fees) and business-like methods - Shift from discipline-based divisions to technology groups - Use of external boards of directors or advisors and review mechanisms - Use of revenue generation, partnered funding, performance targets as proxies for market relevance - Greater presence of private sector personnel in labs or co-location of firms and lab (clustering) - More autonomy in human resources practices including special hiring authority outside the Public Service; greater use of on-site contractors and term appointments - Greater attention to intellectual property rights, strategies and revenue streams - Privatization of functions or creation of "spin-off" companies - Greater emphasis on "commercialization" effort 	<ul style="list-style-type: none"> - Horizontal relationships of trust and exchange of information, knowledge and support - Links with universities, firms, NGOs, provincial/local governments, communities, and other federal departments, "networks of networks" - Internal networking and collaboration within and across the lab to integrate across former divisions or disciplines - Complementing predominantly informal discipline-based networks with more formal issue-based and even service delivery networks - Scientific peer review networks used in granting, refereed publication process and performance evaluation - Participation on domestic and international committees and working groups as sources of networked advice - Labs functioning as critical nodes within local/regional innovation networks - Increase in policy funds requiring levered and partnered funding intended to foster networks - Greater flexibility in organization structure; "inconsistencies" embraced; greater emphasis on interpersonal factors, tacit knowledge, and verbal or face-to-face forms of communication - Human resources focus on hiring internally shifts to accessing expertise externally - Participation in global networks in science and innovation.

Source: Table adapted from Doern and Lévesque (2002).

Analytical Framework - Part II: Institutional Design Space

As indicated, the case studies will employ the first part of the framework to examine the institutional characteristics of the labs. But the basic hierarchies, quasi-markets, and networks approach that emerges from the generic institutional literature does not sufficiently capture the richness of the institutional design space for government institutions. The second part of the conceptual framework will be briefly set out here but will be developed in significantly more detail in Chapter 7, as will the discussion of why the first part of the analytical framework needs to be extended and complemented by the second part, the institutional design space typology.

The important work by Goldsmith and Eggers (2004) is particularly relevant in elucidating the two-dimensional space within which governments operate today. The authors provide a deeper look at the rise of “governing by network.” In their 2 by 2 framework of governance models, one axis maps the traditional public/private continuum from low to high degrees of private sector delivery. Along the second, orthogonal axis, they map the government’s “network management capabilities” from low to high. This yields a four-quadrant matrix of “models of government”: 1) traditional “hierarchical government” in the low market/low network quadrant, 2) “outsourced government” in the high market/low network quadrant; 3) “joined-up government” in the low market/high network quadrant; and 4) “networked government” in the high market/high network quadrant.

Goldsmith and Eggers describe how the traditional debate has been between the first two modes of governance, namely hierarchical government and outsourced government, but argue that “discussions about government innovation rarely centre on outsourcing versus bureaucracy anymore. The pressing question has become how to manage diverse webs of relationships in order to create value” (Ibid., 21). This leads to their examination of network management capabilities and “joined up” and “networked” governance. By “joined up” Goldsmith and Eggers are referring to “the joining up of various levels and agencies of government to provide more integrated services” (Ibid., 15). With “networked” government, these linkages and partnerships extend beyond the public sector agencies to include performers and delivery agents in other sectors.

In similar fashion, the institutional design space typology developed in Chapter 7 seeks to go beyond the basic three-category world of hierarchies, quasi-markets and networks to complement and better capture analytically the multi-dimensional *space* within which government labs operate, particularly by capturing more complex network modes. It places the conventional public/private continuum along one axis and the degree of network engagement along the other. This yields a 2 by 2 matrix that splits the simple network category from the first part of the framework into two types: intra-networks and inter-networks.

By *intra-networks*, I am referring to organizations that exhibit network characteristics but where the members and other characteristics of the network are still predominantly within a single sector (in this case, the federal S&T community). In this

context, intra-networks involve the joining up of government laboratories from different federal departments and agencies to collaborate on research, share a common campus, be funded from a horizontal policy fund, etc. *Inter-networks*, on the other hand, refer to the situation where organizations are enmeshed in more complex, inter-sectoral collaborations and networks. The institutional design typology thus consists of a four quadrant space, albeit with very fuzzy boundaries, that can be used to better map a government laboratory's design elements as hierarchies, quasi-markets, intra-networks or inter-networks. It is argued that this institutional design space typology can enable more nuanced and effective policy interventions related to government science.

III. RESEARCH QUESTIONS AND METHODOLOGY

Research Questions

To reiterate, the study seeks to address the following key research questions:

1. How have the institutional forms of government laboratories been reconfigured during the period 1990-2005?
2. What are the laboratories' mandates and how do these reconfigurations affect the labs' abilities to fulfill their mandates?
3. How might Canadian science policy analysis better take account of the importance, diversity and complexity of government laboratories?

The two-part institutional analytical framework described in the previous section is employed to address these questions through an analysis of the three case study labs but

also through a broader historical and contextual awareness of how federal science policy has evolved, more details of which are examined in Chapter 3. The first part of the analytical framework helps reveal the reconfigured nature of the labs in terms of their evolving mix of hierarchies, quasi-markets and networks. It also helps show conceptually and then in the case studies empirically what kinds of problems might emerge and have emerged as the preferred modes have shifted to quasi-markets and networks but with the still strong staying power of hierarchy. The second part of the analytical framework helps provide a basis for answering the third research question.

Methodological Issues

Case studies

The discussion to this point has revealed a need for a bottom up approach to understanding government laboratories as diverse and dynamic institutions to complement the top down definitional or high-level theoretical abstractions that tend to guide science policy related to government laboratories. Two approaches present themselves for obtaining a more empirically-based understanding of government laboratories: statistical analysis and case studies. As Anderson (1998) makes clear, statistical approaches are currently hampered in Canada by the lack of data at the organizational or functional unit level. She argues that what is required are standardized taxonomies of both organizational and functional structures and a standardization of the

terminology used to describe types of linkage. Until these are developed, Anderson (1998, 405) contends:

It will not be possible to monitor statistically the trends and changes to the actors who comprise the [national innovation system], nor to the interactions between these actors. We will have to rely ... on detailed case studies for understanding transformations, without being able to provide a global overview.

Following Anderson's suggestion, this study employs detailed case studies to inform the development of, in her term, "standardized taxonomies."

The study provides case studies of three laboratories of Environment Canada, namely: 1) the Environmental Technology Centre (Chapter 4); the Atmospheric and Climate Science Directorate of the Meteorological Service of Canada (Chapter 5); and the National Water Research Institute (Chapter 6). The cases, though in-depth, are not intended to be exhaustive organizational analyses. Rather, they seek to explore those organizational characteristics and trends that illuminate the key issues of institutional variety and institutional design space, as discussed above. The case studies are meant to be illustrative of the nature of these institutional features, not formal evaluations of each lab's performance.

As highlighted in the Introduction, a key feature of the study is the selection of three laboratories from a single department, Environment Canada, rather than the selection of one laboratory from each of three different departments. This is done initially in order to isolate the policy and management contexts of the parent department and their influences on its laboratories. However, there clearly is the risk that a selection bias is introduced by this choice. It cannot be argued that three Environment Canada labs

are fully representative of the breadth of federal labs. Although this issue can be mitigated somewhat by selecting laboratories that exhibit a breadth of federally-performed S&T and institutional designs, there will clearly be a need for additional empirical work to validate the institutional design space typology developed further and discussed in Chapter 7.

Labs of Environment Canada are chosen for two reasons. First, as indicated, most of the scholarly literature has neglected the laboratories of Environment Canada in favour of those of the NRC or other natural resources departments (Doern and Lévesque 2002, Rosenblatt 2004, Doern and Kinder 2007). Second, it has a number of diverse laboratories with differing mandates and institutional characteristics. Its labs exhibit a reasonable range of government S&T activities (although in varying degrees) including research and development (R&D) but also an emphasis on related scientific activities (RSA) that can be found in many other departments.

Case studies can provide a kind of “ground truthing” and this is a rationale behind employing them in this study. But as Crow and Bozeman (1998, 238) caution, in case study approaches “more is known, but about less.” The limitations imposed by the use of case studies and by the selection of labs from Environment Canada will be addressed further in the concluding chapter.

Data collection and empirical evidence boundary issues

This section will detail the approach taken to collect data in support of developing the case studies. According to Salter (1988, 15):

Case study research depends for its rigour upon a systematic review of all available documentary materials produced within and concerning any aspect of the situation being studied, upon interviewing as many people as possible, upon interview techniques that encourage dialogue and the expression of points of view, and upon detailed field notes from participant-observation.

The case studies are developed through the analysis of key documents of the kinds listed below:

- relevant federal statutes
- government policies relating to the laboratories and relevant government-wide policies
- department and laboratory strategic plans, annual reports and budget documents
- laboratory evaluations, bibliometric analyses and management studies
- laboratory marketing materials, including website content
- reports of advisory bodies
- relevant academic studies
- media reports

The analysis of documents provides an important starting point for understanding the descriptive features of the laboratories and their institutional variety. However, it must be stated how surprisingly little lab-specific documentation is publicly available, at least in some cases. In particular, the fact that not all of the labs consistently

provide annual reports that detail organizational data such as budgets, personnel levels, and research emphases was a surprise to this researcher. Nor is lab-specific data available in the standard department-level reports to Parliament such as the annual Report on Plans and Priorities and Departmental Performance Reports which tend to report at a higher level of aggregation. Consequently, the case studies often have to rely on dated, incomplete or inferred information, particularly with respect to lab budget data.

In addition, public documents issued by the institutions often do not sufficiently convey the key pressures, problems, and dynamics of change that the laboratories have faced and continue to face. Therefore, while a review of documents is the primary source of information, this is complemented by a set of oral interviews with laboratory scientists, administrators, and policy makers, as well as with some of the laboratories' primary internal and external partners, clients and stakeholders.

Interviews were conducted on a confidential, not-for-attribution basis with protocols approved by the Research Ethics Board at Carleton University. They were based on a "semi-standardized" format covering predetermined topics but also allowing for more open-ended probing of topics of relevance to the particular interviewee. The interviews sought a mix of objective and opinion data regarding the lab's characteristics under the three-category framework, as listed in Table 2-4. It is important to reiterate, however, that the interviews were a secondary component in the methodology that served to complement and fill gaps in the documentary evidence.

network. There are some boundary issues regarding empirical evidence and its use in the hierarchies, quasi-markets and networks analytical framework. These will be commented upon as the analysis proceeds in the case studies and elsewhere. For example, some aspects of the New Public Management (NPM) can be cast as either evidence of the presence of hierarchy or quasi-markets. Moreover, levered funding can also be analyzed under multiple categories in that political authorities are ordering that funding take different forms but these same new rules can be devices to induce or require the formation of extended networks and partnerships.

Time Frame

In terms of time frame for the study, although Chapter 3 provides an overview of the entire 150-year history of Canadian government science for contextual purposes, the focus of the study is roughly the three-decade period from the creation of Environment Canada in the early 1970s to the early 2000s (with the case studies based on reasonable comparative data and information up to about 2005). As will be shown in Chapter 3, the 30-year period is segmented for discussion purposes into periods roughly consistent with the Trudeau, Mulroney, and Chrétien/Martin Governments. Some reference has already been made to the Harper Government policies but the Harper era has not been captured at the level of the lab case studies. The time frame captures the general shift in policy and institutional emphasis from hierarchy to quasi-market to formal

network forms of institutional design, and the issues and problems associated with these policy preferences and institutional varieties.

IV. CONCLUSIONS

This chapter has detailed the overall study focus, analytical framework and methodology. A more detailed discussion of the research focus on government laboratories has been presented, as well as a detailed account of the two-part institutional analytical framework and an examination of methodological issues associated with the study.

The first section set out, from multiple perspectives, the more detailed case for the importance of government science and its institutions. The importance of government science in Canada's overall science and innovation system is evident from its scale, its unique roles, and its contributions to knowledge in key public policy and stewardship domains. Further, the centrality of government laboratories in the system suggests the need for understanding their diversity, complexity and the contemporary pressures they face.

In the second section, I specified and discussed my adapted two-part institutional analytical framework employed in this study. Building on the literature review in Chapter 1 and the discussion in the first part of this chapter, the study's framework has two parts, the first centred on a hierarchies, quasi-markets, and networks typology, and the second on an institutional design space typology. Given my focus on

public laboratories, I emphasize quasi-markets rather than pure markets. Constituting the first part of the study's analytical framework, this three-category typology of hierarchies, quasi-markets, and networks suggests differences in the ways institutions operate, access knowledge and invest. It will be used to examine the institutional characteristics of the case laboratories in Chapters 4, 5, and 6.

The section went on to initially discuss the institutional design space typology that provides a needed complement for examining institutions, and which represents a further major contribution of the study. Moving beyond a basic, discreet three-category world, the institutional design space typology explores the multi-dimensional space within which the analyst can map a government laboratory's design elements as degrees of hierarchies, quasi-markets, intra-networks or inter-networks. It is argued that this typology provides the analyst with better understanding of these institutions and of the make, buy or collaborate choices available to the policy maker or lab manager. Informed by findings from the case studies, the institutional design space typology is further developed and examined in Chapter 7.

To complete the discussion of study design, the third section reiterated the research questions and discussed the study methodology and related issues. The reasons for adopting a case study approach in this study have been set out. The empirical work relies primarily on document analysis but is supplemented with oral interviews. Limitations imposed by the methodology will be discussed further in the final chapter.

CHAPTER 3

GOVERNMENT SCIENCE, SCIENCE POLICY AND ENVIRONMENT CANADA IN HISTORICAL CONTEXT

Some of the historical context for science policy and government science was previewed briefly in the Introduction. In this chapter I provide the more detailed historical policy and institutional context for government science in Canada and for Environment Canada, the parent department of the three case study laboratories. The purpose is to explore how this context has influenced the development of government science over time to today's situation in which its institutions serve multiple purposes to an increasing extent. The primary focus of the analysis, the institutional mix of government laboratories as hierarchies, quasi-markets, and networks, is ultimately found in Part II of the dissertation. However, as stressed in previous chapters, these institutional configurations are also the result of cumulative policy changes which alter, shape and influence the labs' mandates and their ability to fulfill their mandates, and hence both seek to solve some problems but inevitably also create others.

Accordingly, I begin the chapter with a review of the evolution of government science in Canada and the policy pressures common to federal science departments and their laboratories. This history shows that over the entire period government science and

science policy were positioned to support many common policy purposes, both economic and social broadly defined. The common policy purposes are evident from the policy debates and public decisions regarding government science and have shaped the mandates and designs of the laboratories, though not necessarily consistently. These range from public purposes such as early nation-building (agriculture, fisheries and minerals) through to national defense, health, industrial development and, later, environmental protection, product safety and public protection of various kinds. While there are some common themes overall, successive periods, as we will see, have provided particular emphases and thus the impact on the labs' institutional configurations can be diverse and complex. This is even more the case when policy influences no longer arise from simple science policy rationales but also from policies related more broadly to S&T and innovation policy as well as in response to broader policy contexts such as budget cuts, New Public Management, or concerns about intellectual property in the knowledge-based economy.

In the second section, I examine the specific departmental context of the case laboratories by briefly examining the emergence and development of Environment Canada as a department from its origins in the early 1970s to the early 2000s. This will highlight how the department's evolution reflects the more general evolution of government science, of its mandates and of the institutional design emphases for government laboratories, from hierarchies to quasi-markets to networks.

Overall, the chapter begins the process of addressing the first two research questions regarding how the institutional forms of government labs have been

reconfigured and how these reconfigurations impact the labs' ability to fulfill their mandates. The first of the general arguments in the dissertation is also borne out, namely that the traditional "make or buy" and related quasi-market lens on policy analysis related to government labs does not adequately capture the increasingly formal network-based approaches regarding the labs. As well, this historical review will provide support for the dissertation's second main argument that Canadian science policy has not adequately reflected the remarkable diversity of mandates and institutional features that exists among government laboratories.

Why should we care about history? Without a basic understanding of the historical forces and choices that have shaped the current context, we will fail to fully appreciate how this larger part of the empirical story both conditions and constrains current policy options for government science and its institutions. As two historians of science have written, "history may help us see clearly today" (Pyenson and Sheets-Pyenson 1999, xiv).

But one might also ask, if the goal is to understand the government laboratory as a general entity, why review the particular history of Canadian government science. After all, isn't science the pursuit of universal truths that are not bounded by any national context? It is true, as we have seen in Chapter 1, that science is often studied from the perspective of its universality, its pursuit of knowledge that is "valid in every context" (Bocking 2002). But as Bocking has commented, "borders do matter" and comparative

studies of science have demonstrated that, while scientific knowledge may ultimately be universally valid, different nations generate distinctive approaches to science.

The history of Canadian government science is no less distinctive. According to Bocking (2002, 5-6), it has been shaped by:

institutions such as the Geological Survey of Canada, the National Research Council and the federal research granting agencies; the evolving relationship between Canadian scientists and a natural environment of unusual biological and geographical diversity; and recent shifts in science policy, from the building of an autonomous scientific community to the formation of a “national system of innovation” focussed on science as an economic instrument.

A basic appreciation of this history is thus necessary for a complete understanding of Canada’s government laboratories, the roles they have played and continue to play within this country, and the changing institutional forms they have revealed. Focussing as it does on the historical context for government science and government laboratories, this chapter does not examine the important scientific achievements of these institutions—of which there have been many—but rather traces the evolving policy and institutional context that has influenced the mandated roles and designs of the institutions that contributed to those achievements.

Before continuing, and to aid our understanding of the evolution of the “government laboratory” as an entity, it is useful to very briefly recall the history of the emergence of organized science and some of the overarching themes that characterize that history. While science and technology have perhaps always been a part of the human story, the organization of scientific research into specific institutional settings that we know as government laboratories is a relatively recent phenomenon.

State support for organized science dates at least to the classical period in institutions such as Plato's Academy, Aristotle's Lyceum, and Ptolemy's Museum of Alexandria (Pyenson and Sheets-Pyenson 1999). This classical period of science was characterized by an ideal of "pure inquiry" which rejected practical utility as a legitimate end of natural philosophers (Stokes 1997).²⁰ This classical elevation of pure inquiry influenced the course of science for centuries and survives today in the commonly held view of the superiority of pure, basic research over more applied science. As we will see later in this chapter this tension between basic and applied research has also influenced the evolution of government laboratories in Canada.

By the late Roman imperial period, the schools of higher education stressed literary studies over natural sciences. And by the sixth century even these institutions had faded or were "extinguished by Christian fanaticism or barbarian neglect" (Pyenson and Sheets-Pyenson 1999, 32-3). It was in Constantinople and various eastern cultures that organized science survived and it was not until the thirteenth century that Europe began to emerge from its "dark" period. New universities began to flourish in Oxford, Paris, Bologna and Padua. However, with their emphasis on the classical trivium—grammar, rhetoric and logic—the focus of these new centres of scholarship was not necessarily on expanding the frontiers of knowledge about the natural world.

With the Scientific Revolution in the sixteenth century we begin to see a movement of research activity towards what could be considered the forerunners of

²⁰ An important exception were the Hippocratic physicians whose vivisection of criminals enabled them to develop medical and surgical approaches to the treatment of diseases and injuries. (Stokes, 1997)

modern government laboratories. Examples include the Paris Academy of Sciences and Paris Observatory in France, and in Britain the Royal Society and, later, the Royal Institution. Indeed, Berman (1978, xxi) believes the establishment of the Royal Institution in 1800 was a watershed event in the history of organized science: “Prior to the founding of the Royal Institution research was a matter of arbitrary interest and private initiative...” He argues that this “gentleman amateur tradition” in British science was highly congruent with the world of the landed aristocrat. Thus the break from this tradition during the Industrial Revolution towards expertise and professionalism was a significant development (Ibid., 155).

While the amateur scientist tradition survived well into the 20th century (Ibid., xxiii)²¹ the institutionalization of science increasingly became the norm. The latter part of the nineteenth century saw the advent of the industrial research laboratory, of specially designed research laboratories on the campuses of universities and, by the turn of the century, national governments had also begun to invest more substantially in science and to construct their own scientific laboratories (Bernal 1971, Pyenson and Sheets-Pyenson 1999). Of particular concern were laboratories for the establishment of standard weights and measures and other physical constants.²² This growth in organized science continued

²¹ Thomas (1988, xiv) highlights the famous example of Lord Rayleigh, who, “after establishing one of the foremost laboratories of physics in the world – the Cavendish Laboratory at the University of Cambridge – opted to set up a laboratory in his baronial home at Terling, Essex.” See also Conant’s (2002) “biography” of Tuxedo Park, the home laboratory of amateur scientist Alfred Loomis.

²² As examples, the Board of Trade Laboratory in 1869 and the National Physical Laboratory in 1900 in Britain, the Physikalisch-Technische Reichsanstalt in Germany in 1887, and the National Bureau of Standards in the U.S. in 1901.

to the point where, since the Second World War, the role of amateur scientists has virtually disappeared and organized science and the “corporate” laboratory enjoy uncontested dominance.²³ Midway through the 20th century Hiscocks (1956, 2) observed: “During this century we have seen the ‘patriarchal’ laboratory centred on the intellectual drive of one great researcher, give way to the institutional laboratory employing hundreds and sometimes thousands of workers.”

This brief overview makes clear that the government laboratory, as understood today, is a relatively recent phenomenon in the history of science, emerging as it did in the nineteenth century and becoming predominant only in the twentieth century. For the purpose of tracing the remarkable growth and development of government laboratories, and their evolving policy contexts, I now turn to the particular case of the evolution of government science and science policy in Canada.

I. THE EVOLUTION OF GOVERNMENT SCIENCE AND SCIENCE POLICY IN CANADA

In order to fully understand the current context for government laboratories it is important to locate them within the history of science in Canada and the federal government’s evolving policy role within that history. In this section I trace the history of Canadian government science and science policy, generally, by looking at key stages such as: its 19th and early 20th century nation-building beginnings; the post-World War II expansion through to the 1960s; the first emergence of actual science policy in the 1960s

²³ Exceptions remain in, for example, astronomy and ornithology where amateurs still can and do make fundamental discoveries (such as the discovery of Pluto) or contributions to studies of avian migratory patterns and population trends (Mims 1999).

and 1970s; the enunciation of the mid-1970s “make or buy” policy; the rise of NPM and budgetary policies in the 1980s and 1990s, and policies related to innovation and the transition to a new century.

In the last section of the chapter I pay particular attention to the evolution of the federal environment department and its mandates in order to set the particular historical/institutional context for the three case study laboratories. This historical review is organized through a review of changes in the Trudeau, Mulroney, and the Chrétien/Martin prime ministerial periods.

Three decades ago, J. Bruce Sinclair (1980) wrote that Canada does not have a coherent science policy because it is unconscious of its science history; to a large extent this remains true today.²⁴ Many pieces of the overall story have been written but a comprehensive history of Canadian government science has yet to be written. All that can be accomplished here is a brief recounting, drawn mostly from secondary sources.²⁵ For the sake of the narrative I have divided this history into six sections corresponding to

²⁴ However, I would be remiss to not acknowledge the efforts of the Canadian Science and Technology Historical Association and others to rectify this situation.

²⁵ There is a danger, of course, that by relying chiefly on secondary sources I will fall victim to the received wisdom of Canadian science history and contribute to the perpetuation of “myths” that some analysts have identified, particularly with respect to the role and performance of industrial R&D in Canada in the pre-World War II period (see e.g., Phillipson 1983, Hull and Enros 1988; see also footnote 37). Hull and Enros (1988, 22), for example, summarize “the extent to which scientific networks involving industry, government, and university had penetrated by 1939 (as well as the extent to which the process has remained undocumented).” Their evidence argues against the received policy narrative that portrays government science as overwhelmingly predominant in this period. Although one could counter that the minimal extent of the system prior to WWII and the general correlation of the standard narrative with the actual post-WWII situation provides it some legitimacy, the point of these myth-busting analyses is well made. In response, I can only offer that to the extent that the history described below has become part of the standard policy narrative of Canadian government science it is important to understand the narrative and how it has shaped science policy. I leave it to others to provide a firmer foundation based on the historical record.

major shifts, although the most appropriate periodization of Canadian science policy history remains open to debate.

Nation-Building: Early History to the Second World War

The early history of Canadian government science overlaps extensively with the history of science in Canada generally, in that government was the major patron and a primary performer of science in the period prior to the Second World War (de Vecchi 1984b). In his history of Canadian invention, J. J. Brown (1967) reminds us that until the turn of the twentieth century Canada was a frontier country of pioneers. In such a harsh environment, the pursuit of scientific activity was largely neglected in favour of the more immediate task of satisfying basic needs. Nor was science a major concern of Canada's founding fathers. De Vecchi (1984a, 112) explains the relative lack of interest in science on the part of the nation's leaders: "...no political career was helped (and much less threatened) by matters connected with the relations between science and government."

To the extent that government supported science in the nineteenth century it was largely what Zeller (1987) refers to as "inventory science" targeted at "nation-building" activities in support of expansion and development of the young country.²⁶ Zeller (1987, i) writes, "Victorian science offered a means to assess and control nature as a rational alternative to retreat from nature's harshness. It also helped develop a sense of Canada's past and brighten the prospects for a transcontinental future." At the time, "science" was

²⁶ In his discussion of the creation of the Canada Food Inspection Agency, Prince (2000) demonstrates that "nation-building" remains a guiding rationale even today.

viewed among many lay persons, including politicians, as predominantly concerned with the collection of “scientific” facts (i.e., statistical information).²⁷ This emphasis had grown out of the statistical inventoring tradition of the Scottish Enlightenment which aimed to improve the quality of life through detailed “fact-gathering” (Zeller 1987). According to de Vecchi (1984a, 122), “the systematic collection of data coincided...with the natural need of a largely unexplored country to find out about its physical geography, climatic characteristics and strategic potential.”

Consequently, the initial emphasis of government investments in science was on the inventory of natural resources and on their utilization. In particular, the Geological Survey of Canada founded at Montréal in 1842, the Magnetic and Meteorological Observatory founded at Toronto in 1840, the Marine Biological Stations founded initially as a floating station at St. Andrews, New Brunswick in 1899 and later as permanent stations elsewhere, and the Dominion Experimental Farms begun in 1886 that conducted agricultural research on behalf of the small and medium-sized farms that grew up along the western railroads are usually cited as the key focal points of Canadian government science in the nineteenth century (Dufour and de la Mothe 1993 and 2001, Niosi 2000, de Vecchi 1984a and 1985).

Although the scientific programs receiving support in this early period led to many advances in fundamental scientific knowledge, it is clear that support for government science was based primarily on pragmatic motives. In one of its earliest

²⁷ According to de Vecchi (1985), it was only after Canadian universities, influenced by the German model, took on the professionalization of scientists that a new and more sophisticated understanding of the nature and purpose of scientific research emerged.

forays into the support of science, the federal government commissioned William Logan to make a comprehensive geological survey of the Dominion. As Logan makes clear the Geological Survey was dominated by economic, not scientific objectives:

The object of the Survey is to ascertain the mineral resources of the country, and this is kept steadily in view. Whatever new scientific facts have resulted from it have come out in the course of what I conceive to be economic researches, carried out in a scientific way.²⁸ (Adams 1939, 15-6)

According to de Vecchi (1985, 103-5), the transfer of the Geological Survey's salaries to the civil service in 1883 "seemed to mark the beginning of an era when it would be possible to have a formal and proper career in the scientific branches of government" and the Survey soon acquired the reputation of being a very good training institution.

Interestingly, de Vecchi (Ibid., 105) illustrates how the Survey's increasing scientific reputation tended to raise suspicions on the part of government about whether its true motive was not pure science: "Not much that politicians would recognize as practical could come from men who not only chose and pursued an ill-paid career but also accepted the ban on any consulting activity."

The mandate of the Fisheries Research Board (originally, the Board of Management of the Marine Biological Station of Canada and later the Biological Board of Canada) was similarly oriented to pragmatic objectives, namely the "...conduct and control of investigations of *practical and economic problems* connected with marine and

²⁸ On the other hand, Zeller (1987, 51) points to the dual nature of Logan's task: "to facilitate the location and exploitation of 'economic' mineral deposits in Canada, while at the same time advancing scientific knowledge." She argues that Logan was well-suited to such a dual mission: "Logan's training as a businessman enabled him to shift his frame of reference easily between the practical and the theoretical poles of geological thought" (Ibid., 54).

fresh water fisheries, flora and fauna...” (Anderson 1984, 151; my emphasis). It is interesting to note, however, that between 1898 and 1925, the biological stations had no permanent employees but rather merely provided research facilities for academic researchers and their students—volunteers who served without remuneration except for travel expenses (Anderson 1984, Johnstone 1977).

Organized meteorology began in Canada at the Toronto Observatory on New Year’s Day in 1840, but it was only under the leadership of George T. Kingston, who served as director from 1855-1880, that Canadian meteorology really matured. Generally regarded as the “Father of the Canadian Meteorological Service,” Kingston is described as:

a man who almost single-handedly brought Canadian politicians and bureaucrats of the 1870s to believe in the importance of meteorology. Kingston also had a remarkable grasp of the necessary structure and organization required for a national scientific service. (Thomas 1991, 44)

By 1880, there were 176 active observer stations reporting monthly to Toronto; interestingly, some of these stations were staffed by volunteers.

As the nation grew, so too did the amount of regulatory legislation and the organization of government departments to administer it. According to Gillis (1980, 60-1), “forestry programs, irrigation work, regulation of water-power, wildlife conservation, and national parks all grew to be important aspects of Dominion policy during the first two decades of the twentieth century.” The need for government science was also being driven by international treaties; for example, the Migratory Birds Convention of 1916

between the U.S. and Canada required the federal government's involvement in wildlife conservation.

The need for growing numbers of civil servants with higher levels of education and technical expertise to administer these increasing technical and regulatory functions created a demand for scientifically trained personnel. This demand helped to stimulate the Canadian science system. Nonetheless, it is important not to overstate the extent of government science in this period. Simply put, Canadian investment in science prior to the First World War was minimal, at least by subsequent standards.

The Great War of 1914-18 spurred the creation of the National Research Council, probably the single most important institution in the history of Canadian government science, if not of Canadian science generally. Initially created as the Honorary Advisory Council on Scientific and Industrial Research, the Council was given the role of advisor to the government on science matters related to the war effort. In fact, the NRC was able to contribute little prior to the Armistice. At the time, this impotence was attributed to Canada's serious shortage of scientific manpower and infrastructure. This recognition led, in turn, to the NRC's early heavy emphasis on building the nation's science capacity, and, some years later, to the establishment of its own laboratories. The NRC was expected to support Canadian industrial research and, in the early years, it was thought that contract research would account for much of its work. In the late 1930s, in what may have been the first instance of contracting in, Imperial Oil Ltd. funded the NRC to hire an extra chemist to work on problems defined by the company (Phillipson 1983).

As Doern and Lévesque (2002) have reported, the beginnings of the NRC laboratories were quite modest, emerging as they did during the lean years of the Great Depression when there was little demand for research on the part of manufacturers. Nonetheless, by 1939, on the eve of the Second World War, the NRC had about 300 employees and government science was positioned to take on a vastly expanded role (Ibid.).

Expansion: World War II to the 1960s

The Second World War marked a major turning point for science in Canada. According to E. W. R. Steacie, who served as president of the NRC during 1952-1962, “In a real sense Canadian science came of age during the war” (Babbitt 1965, 126). Steacie attributed this maturation of the Canadian science system to two factors. First, Canada’s traditional scientific isolation was broken by its inclusion in the Allied efforts to mobilize science on behalf of the war effort. Second, the war provided facilities and research capacity that had been sadly lacking in Canada. Steacie believed that “it was only after World War II that the Canadian universities really came into their own as centres of research and graduate education” (Ibid., 163). Thus, the government was forced to create the necessary research capacity. Federal government R&D expenditures (in current dollars) increased sevenfold between 1938 and 1945 with the bulk of the increases going, not surprisingly, to military research (Organization for Economic Cooperation and Development 1969).

Another factor during this period that analysts have pointed to is the relationship between C. D. Howe, the wartime Minister of Munitions and Supply, and C. J. Mackenzie, President of the NRC (Doern 1972, Avery 1998). Mackenzie did not have the ear of Prime Minister Mackenzie King but his close personal relationship with Howe afforded him and the scientific community a privileged access to political power that it had not enjoyed previously (nor perhaps since) (Avery 1998, 260).²⁹ Two decades later, when Dr. Mackenzie was asked to advise Prime Minister Pearson on the organization of government science, he clearly sought to reproduce such an intimate advisory relationship through the creation of a science secretariat within the Prime Minister's Office (Mackenzie 1964, Doern 1972).

During the war Allied science demonstrated its worth (Avery 1998, Eggleston 1950). Avery (1998, 260) notes that "Canada's achievements were most notable in the fields of explosives and propellants, atomic energy, and chemical and biological warfare, while Canadian research and development in aviation medicine, radar, and the proximity fuse were also important to the total Allied war effort." In the afterglow of victory, science was viewed with awe as the source of new possibilities for achieving the nation's peacetime goals. The post-war reconstruction period was characterized by rapid economic growth, full employment and an open economy heavily reliant on resource exports and with a tendency toward continental integration (Albo 1994).

²⁹ For more on the Howe-Mackenzie relationship see Porter (1965, 430-2).

To meet these new expectations the federal government's science system expanded significantly through the early postwar decades and important new institutions and facilities emerged. The NRC's responsibilities for defence science, atomic energy and medical research were spun off to new agencies—the Defense Research Board (in 1947), Atomic Energy of Canada Ltd. (in 1952), and the Medical Research Council (in 1960) respectively. In addition a licensing agency, the Canadian Patents and Development Ltd., was created in 1946. Its mission was “to transfer to private industry the commercially useful results stemming from public research” (Niosi 2000, 40).³⁰ By signing arrangements with other federal laboratories it became a central agency for the federal government's intellectual property.

In addition, the postwar period witnessed a geographical decentralization of government science as an increasing number of laboratories were set up outside the Ottawa region. As examples, Niosi (2000) highlights the Prairie Regional Laboratory set up in 1948 in Saskatchewan to conduct research on the industrial use of agricultural waste, and a Maritime Regional Laboratory created in Halifax in 1952 to perform R&D in marine research, industrialization of local agricultural produce and steel-making processes.³¹

³⁰ In addition, the National Research Council Act of 1946 provided authorization for NRC to enter the marketplace by building and operating pilot-scale industrial plants. According to Phillipson (1983), however, the NRC's experience in this regard was a financial disaster.

³¹ These two institutions have since been reconstituted as the Plant Biotechnology Institute and the Institute for Marine Biosciences, respectively (Niosi and Bas 2000).

Throughout the early postwar period, the federal government remained a dominant actor in Canada's science and innovation system, with the government continuing to house a large share of Canada's S&T infrastructure and expertise (Science Secretariat 1967, Council of Science and Technology Advisors 1999).³² In 1959, about half of the total national expenditure on R&D went to the federal government's intramural performance (Organization for Economic Cooperation and Development 1969).³³ By 1960-61, the federal S&T workforce had grown to almost eighteen thousand people, consisting of almost five thousand scientists and engineers plus additional technicians and support personnel (Ibid.). This workforce was operating in an expanded set of science-based departments and agencies with significant research portfolios (see Table 3-1). In 1967, it was recognized that:

For many years to come industries will turn mainly to the government laboratories for help with problems beyond their immediate capabilities. Furthermore, these laboratories will also be the guardians and maintainers of the fundamental standards, which are so necessary in a developing industrial economy. (Science Secretariat 1967, 83)

And it was not until 1979 that the private sector supplanted the federal government as the sector spending the most on R&D (Gualtieri 1994, Niosi 2000). Clearly, in the first couple of decades following the Second World War, government science in Canada was

³² According to a report of the Science Secretariat (1967, 82-3): "The research done in government laboratories has earned international recognition and has attracted many distinguished scientists to Canada. For a long time practically all Canadian research was done, and done well, in such laboratories. The present strength of our university research and the growing strength of our industrial research stems from the earlier work in government laboratories and still depends to a considerable extent on a continuation of such in-house research."

³³ The government's share of R&D performance has declined steadily since to less than 9 percent of the national total today (Statistics Canada 2008a, Table 1-1).

expanding and generally enjoying a predominant role in Canada's science and innovation system (Doern 1970b).

Table 3-1. Ten Largest Federal Government S&T Organizations, 1969

Rank	Department	Laboratories	Scientists and engineers
1	Department of Agriculture	2	847
2	Department of Fisheries and Forestry	6	841
3	Department of Energy, Mines and Resources	10	711
4	National Research Council	13	677
5	Atomic Energy of Canada, Ltd.	4	588
6	Department of National Defence	17	362
7	Department of National Health and Welfare	6	166
8	Department of Communications	2	102
9	Department of Transportation	15	100
10	Department of Indian Affairs	4	83
	Total:	79	4,535

Source: adapted from Niosi (2000, 43) based on official data from Dominion Bureau of Statistics.

But What's the Policy? 1960s to 1970s

This vast postwar expansion of Canada's government science was achieved apparently without any guiding statement of national science policy along the lines of that provided by Vannevar Bush in the United States.³⁴ In 1944, President Roosevelt asked his science advisor to prepare recommendations on how, in peacetime, the government could continue to engage the scientific community for the pursuit of national goals. Bush's report, *Science: The Endless Frontier*, was issued in 1945 to President Truman following the death of Roosevelt and is widely regarded to be the single most influential document shaping U.S. science policy in the second half of the twentieth century (Bush 1945, Barfield 1997). The report offers an image of science as an "endless frontier" which could replace the physical frontier of the American West as a driving force for economic growth, improved standards of living, and positive social change (Guston and Keniston 1994).

The Canadian scientific enterprise, meanwhile, seemed to be operating under an unwritten or "hidden policy" of laissez-faire governance (Organization for Economic Cooperation and Development 1969, Senate of Canada 1970, Drury 1975). Without an explicit science policy, Canada exhibited a Polanyian "republic of science" policy paradigm. This paradigm held that government investments in science, if left in the control of scientists, would inevitably lead to economic prosperity and social benefit

³⁴ Although Atkinson-Grosjean (2006) points to the Massey Commission's (1951) articulation of the linear model.

(Polanyi 1962). Although the empirical evidence for a link between R&D investment and economic growth was rather sketchy,³⁵ Canada and other countries that followed the American lead in the postwar period seemed convinced that making large investments in science and technology, while providing the scientific community a high degree of autonomy for allocating those investments, was a strong prescription for national well-being.

The 1960s witnessed an increasing questioning of the laissez-faire approach to science policy, both in Canada and around the industrialized world. Voyer (1999, 278) pinpoints the transition from the early postwar period:

Decision-making in this earlier period was largely informal and based principally on personal relationships between the elites of Canada's scientific community and senior politicians and government officials. There was very little public scrutiny or even interest in the scientific activities funded by the public purse. Given the success of science and technology in supporting the war effort in the Second World War, this faith in the scientific establishment continued to go unchallenged until the report of the Royal Commission on Government Organization appeared in 1962.

The Royal Commission on Government Organisation (the "Glassco Commission") was established in 1960 and charged with reporting on the organization and operating methods of the whole of the Canadian government. As part of its broad examination, the Commission undertook what many analysts agree was the first comprehensive review of Canadian government science and science policy (Royal Commission 1963, Bachynski 1973, Impact Group 1999). The Commission's findings

³⁵ In fact, it still has not been conclusively demonstrated empirically; see for example Godin (2004) for a summary discussion of the issue.

and recommendations address the government's high-level science policy machinery and the need to reorganize the intramural federal science effort.³⁶

The Commission found that 82 percent of federal S&T expenditures was spent intramurally (compare with about 50 percent today), but that this in-house activity was subject to no overall scrutiny or supervision. The Commission was concerned that the existing arrangements for central science policy decision making were too ad hoc. It followed that in the Commission's view Canadian science policy was merely the resultant of rapid post-war expansion and budget growth rather than of any well-considered policy design (Royal Commission 1963).

Another policy pressure from this period was the "government efficiency movement" that began with the Glassco Commission and was implemented through various Government Organization Acts. According to Anderson (1984), this movement had a profound effect on the Canadian government in the 1960s and 1970s. In this period the Treasury Board implemented its Planning, Programming and Budgeting (PPB) approach to resource allocation and management which emphasised hierarchical controls: "Planning, as conceived by this approach, required centralization of control and annual accountability" (Anderson 1984, 154). There were concerns about whether such a government-wide, top-down approach was appropriate for research management. Certainly Dr. Steacie, a key science policy figure in the postwar period, exhibited an aversion to anything that smacked of "planning" or "coordination" of science:

³⁶ Skinner (1978, 37) states that the Glassco Commission report was the "first organized attack on substantive questions of science policy as well as related institutional structures."

The problem is that those who are trying to make science efficient do not know what it is, and are trying to apply the normal criteria of cost accounting. This inevitably leads to enthusiastic attempts to “plan” science, and I think that such planning is probably the greatest danger facing science today. (quoted in Babbitt 1965, 178-9)

Steacie’s obvious preference for pure, “academic science” heavily influenced the direction of the NRC’s work, and eventually led to criticisms that the agency had become a “university without students” and had drifted from its original mandate to support industrial research (Jarrell and Gingras 1991, 8; see also Doern and Levesque 2002).³⁷

It was also in this period that the OECD took a greater interest in science policy. Following years of rapid budget growth, science had become a major category of national expenditure in the industrialized countries. Given this and its impressive accomplishments in the postwar period, it is not surprising that science finally “got noticed” as a key policy field for OECD analysis. In 1962, the OECD Committee on Scientific Research decided “to give more emphasis in the future to the economic aspects of scientific research and technology” (quoted in Godin 2004). As part of the industrialized world’s “push for growth” in the 1960s, the Committee suggested that national governments link S&T to economic growth and productivity, and assess the contribution of the former to the latter (Albo 1994). The OECD proceeded to conduct

³⁷ Phillipson (1983) criticizes this line of argument as the “Steacie Myth,” arguing that much of the historical narrative on which it is based derives from the flawed historical material in the Glassco and Lamontagne studies. He accounts for the perpetuation of this myth to the fact that these studies constituted “an admired and politically influential body of science policy literature” which appeared “before professional historians had begun to grapple with the history of science in Canada, or at least published much” (Ibid., 117).

reviews of the national S&T systems of member countries, including Canada in 1969 (Organization for Economic Cooperation and Development 1969).³⁸

Challenging the state of Canadian science policy, the Glassco report initiated an active debate as indicated by the numerous studies conducted in the ensuing decade, including those of the Science Council and Senator Lamontagne's committee (Bachynski 1973, Drury 1975, Mackenzie 1964, Science Council of Canada 1968, Senate of Canada 1970), as well as by international interest in science policy as focussed through the OECD. In the years that followed, Canada experimented with various science policy coordination mechanisms, including the Science Secretariat in the Privy Council Office and later the Ministry of State for Science and Technology (MOSST). However, most of this "machinery" has not survived. Interestingly, many of the issues examined by the Glassco Commission remain key concerns of government science to this day.

To Make or To Buy, That Is the Question

In the absence of an overall national science policy, there was the potential for particular policies to have major impact on government science and its laboratories. Of particular importance in this regard was the 1972 Make-or-Buy policy (Meyboom 1974, Smith 1974, Skinner 1978). The aim of the Make-or-Buy policy was to ensure that

³⁸ To frame its analysis of Canadian federal S&T activities, the OECD study used a simple classification that organized federal S&T departments and agencies into four main categories: (1) those concerned with renewable resources; (2) those concerned with non-renewable resources; (3) those concerned with collective needs; and (4) those concerned with research in general. This classification scheme is unhelpful for my purposes because by operating at the level of the parent department, it implicitly suggests that a department's laboratories can be treated as homogeneous and it does not help us understand issues of institutional design at the laboratory establishment level.

procurement of S&T requirements fostered the growth of scientific activities throughout the economy, “increasing industry’s potential for autonomous technological innovation and avoiding fragmentation of scientific resources where a capability exists in other sectors” (Drury 1975, 29). This policy was a tangible example of the increasing policy pressure to contract out government science as a means to get a larger proportion of the nation’s R&D done in the private sector (Anderson 1984).

On February 10, 1972, Cabinet established a policy that new mission-oriented R&D, with the exception of that conducted by the Atomic Energy of Canada, Ltd., was to be contracted out to private industry. The directive was later extended to include all existing R&D “wherever possible.” Supapol and McFetridge (1982) argue that the policy was a direct response to the Lamontagne Committee and the view that contracting out would increase the private sector’s awareness of the opportunities for exploiting commercially the results of R&D funded by the federal government. But the general principle can be traced back to Glassco which stated that “...decisions to ‘make’ rather than ‘buy’ should only be taken on the basis of conclusive evidence of the unavailability on reasonable terms of the goods and services from outside the government” (Royal Commission 1963, II-319).

In 1973 the Treasury Board issued guidelines to assist departments with the implementation of the Make-or-Buy policy. This document contains a list of criteria for in-house R&D. The onus was on departments and agencies to demonstrate a valid reason for choosing “make” over “buy” based on the criteria listed in Table 3-2.

In his analysis of the policy and its implementation, Skinner (1978, i) argued that “the dynamics of bureaucratic behaviour in the Canadian public service are not generally conducive to the contracting out of government R&D work to industry.” He tested the prediction that responses to the policy would depend on the degree of conflict perceived by officials between departmental and agency goals and the broad objectives of Make-or-Buy. Perhaps not surprisingly, his results were generally consistent with this hypothesis.

Table 3-2. Make or Buy Criteria

national security	where questions of security prohibit industrial involvement
lack of industrial capacity	where the R&D requirement needed to perform the mission of the department is inappropriate to industry, or where no suitable industrial capacity exists and it would not be of benefit to Canada to create one
regulatory science	where the R&D requirement is essential to provide direct support to a regulatory function and associated planning activities, and where no private establishment independent of the firms being regulated can be found or created, e.g., certain aspects of research associated with food quality, narcotics control, transportation safety regulations and communications
standards	where the R&D requirement is essential to the development and maintenance of a set of national primary standards and, in some cases, secondary and consumer standards including their relationship to international standards
maintaining in-house capacity	where the conduct of research and development is essential to establish and maintain a limited in-house competence sufficient to assess the opportunities represented by the current state-of-the-art, to enable the operating department to perform its mission and manage its contract research in industry
national facilities	where the conduct of research and development is necessary to the effective support and operation of in-house capital facilities which provide central testing and research services which are agreed, after appropriate consultation, to be necessary to Canadian Industry

Source: Government of Canada (1973, 4-5).

On the other hand, in an economic analysis of the policy, Supapol and McFetridge (1982, 94) reached the ironic conclusion in 1982 that “the make-or-buy directive has not increased contracting-out in areas where there are potential benefits and has increased it in areas where there are not.” The authors found that, by and large, those departments (such as Communications, Energy, Mines and Resources, and Defence) that were most likely to produce commercial spinoffs were already demonstrating close ties with the private sector, and the Make-or-Buy policy did not have an appreciable effect on their level of contracting out. On the other hand, those departments (such as National Health and Welfare, Environment and Agriculture) whose scientific portfolios were less likely to have commercial relevance had increased contracting out but with little real impact on industrial R&D.

While conceding that Canada tended to perform a greater proportion of national R&D within government than a number of other “similarly situated” OECD countries, Supapol and McFetridge (1982, 90) advised against the universal application of the policy:

While it is possible that Canada has failed to exploit the potential benefits of contracting-out, it is not necessarily the case. Indeed, it is one of our principal conclusions that a universal contracting-out policy such as the make-or-buy directive is not necessarily conducive to more effective use of our research resources.

With respect to Environment Canada, the analysts concluded, “In sum, the R&D activities of the Department of Environment appear to be characterized by an absence of spin-offs. As a consequence there appears little to be gained from the application of the make-or-

buy directive to this department” (Ibid., 66). Nonetheless, the Make-or-Buy policy was broadly applied and was a prime example of the increasing policy pressure to apply quasi-market tests to government science. This general thrust was a precursor to a more general government reform movement in the 1980s and 1990s that came to be called New Public Management.

Science and Technology Policy and the New Public Management: 1980s to 1990s

By the late 1970s and early 1980s, the policy agenda was being driven largely by the energy crisis and economic stagnation. With respect to government science, these problems translated into an increasing concern about its relevance to improving Canada’s economic competitiveness:

Canada remained ‘trapped’ as an exploiter of natural resources; the quality and number of new jobs in this sector was limited. A trade surplus in manufactured goods was central to maintaining high employment levels and more regionally balanced job growth. But this was blocked by the American-dominated, branch-plant industrial structure. ... [N]ationalists asserted...a national industrial strategy was required....and selected high technology sectors should be targeted to develop strong research and development capacities and world trading enterprises. (Albo 1994, 318)

As scholarly understanding of the innovation process evolved and filtered into the thinking of policy officials, the earlier almost exclusive emphasis on science and science policy gave way to a complementary interest in technology and technology policy.³⁹ Consequently, the policy focus shifted and the field came to be referred to as “science and technology policy.”

The administrative reforms associated with the so-called New Public Management (NPM) also gain prominence throughout this period and were extended to Canada's federal S&T system. A product of debates about the appropriate role of the state, NPM seeks to reform traditional bureaucratic approaches by importing private sector management techniques and market concepts into the public sector in order to improve efficiency and effectiveness (Aucoin 1997, Aucoin 2008, Doern 1994, Ferley et al 1996, Bellamy and Taylor 1998). Proponents of NPM argue that this managerialism addresses the classic pathologies of bureaucracies by reducing hierarchies and introducing market-based approaches and private sector management styles and instruments (Kettl 2000 and 2002). Others observe that NPM introduces new forms of hierarchy and procedural bureaucracy (e.g., in the form of new and more extensive performance reporting requirements) (Aucoin 2008, Doern 2008, Flinders 2001). As we will see in the case study chapters, government laboratories were not immune to these pressures.

NPM is often associated, tangentially at least, with the demise of the postwar welfare state and the rise of the New Right political movement in the 1970s and 1980s which sought to de-regulate, "downsize" and, in some cases, privatize portions of the state.⁴⁰ By the 1990s, there was "strong ideological support for...a general opening-up of social and economic arrangements to the logic of 'free' competitive markets" (Streeck and Thelen 2005, 5). NPM proponents generally support a role for the state but argue that

³⁹ See, for example, Science Council of Canada 1979, Government of Canada 1983, Stoneman 1987, Voyer 1999.

⁴⁰ It must be noted, however, that NPM reforms were initially introduced by parties on the left in New Zealand and Australia (Lane 1995).

public bureaucracies must be restructured to increase their focus on service delivery to customers/citizens and downplay their traditional focus on top-level policy development. Elements of the NPM movement include establishing explicit client-contractor relationships, devolving authority to lower levels of government and sharing governance functions with other actors, and adopting new accountability mechanisms that place more emphasis on performance and results and less on bureaucratic lines of authority (Boden et al 2001, Ford and Zussman 1997, Barberis 1998). There is virtually no area of government activity that has not ultimately come under the scrutiny of NPM reformers, and S&T functions, including science-based regulation, are no exception (Jarvis 2000).

Under the NPM banner, countries such as the United Kingdom, Australia and New Zealand altered their government science structures quite profoundly, including a high degree of outright privatization of government science institutions (Beesley et al 1998, Boden et al 2001, James et al 2005). New Zealand shifted its government science into Crown Research Institutes and the UK progressively moved much of its intramural science first into separate agencies and then often into the private sector. Australia pushed government departments to find alternative revenue streams by setting a 30 percent external earnings target.

In the United States, government science departments came under pressure to “re-invent” themselves and “do more with less” (Osborne and Gaebler 1993, Marceau 2001). The Government Performance and Results Act (GPRA) imposed NPM-style

performance requirements to which U.S. laboratories had to conform.⁴¹ And the NPM phenomenon is not limited to the developed world. In Gupta et al (2000, 289), the authors examine how government laboratories in developing countries are “under tremendous pressure to re-orient their research focus from serendipity or supply side to become market driven.”

Canada is usually cast as having adopted a more selective approach of encouraging “alternative service delivery” (ASD) mechanisms (Borins 2002, Ford and Zussman 1997). In the S&T context, Canada’s involvement with ASD includes the creation of high-profile, arms-length foundations, “special operating agencies,” and Crown Corporations. Examples of these arms-length entities include the Canada Foundation for Innovation and the Canadian Institutes of Health Research which exhibit higher degrees of independence from government (Ford and Zussman 1997). Guston (2000) attributes the emergence of such “boundary organizations” to their capacity to provide a space for the negotiation of stable partnerships between science and politics. Even within the traditional line departments, NPM has created pressures for different approaches.

⁴¹ Greenberg (2001, 31-2), however, makes a case for the durability of government laboratories in offering a contrarian viewpoint with respect to the impact of NPM in the U.S. context: “Starting in 1981 with the Reagan administration [and continuing under subsequent administrations], ‘downsizing’ was enshrined as a managerial goal in the federal government, but the number of government laboratories has actually changed very little over the long span of years before and after the Reagan presidency. In 1969, according to the National Science Foundation [NSF], the federal government owned 723 ‘R&D installations.’ In 1996, the General Accounting Office...reported that the roster had expanded to 736 ‘laboratories,’ a figure that included ‘satellites’ of other laboratories.” Greenberg cannot guarantee complete equivalence between the two lists but cites an NSF analyst who states that they appear to be equivalent.

Concerns about government performance rose to the top of the agenda during the 1980s in Canada. “In 1984, the Government changed from Liberal to Conservative and the S&T policy debate became even more attuned to economic imperatives” (Voyer 1999, 280). The Mulroney Government created the Nielsen Task Force to examine and explore ways in which government could operate more economically, efficiently, and effectively (Paquet and Shepherd 1996). Policy analyses in this period were highly critical of federal laboratory management, citing, for example, a “growing atmosphere of irrelevance and an excessively bureaucratic management style” (Task Force 1984, 25). The National Advisory Board on Science and Technology (NABST), which reported to the Prime Minister, called for greater use of management boards, cost recovery, contracting out, and other business-oriented approaches. (see for example NABST 1988a, 1988b, 1990, and 1993) “With the focus shifting to innovation policy in the 1980s, S&T became more integrated into economic policy considerations.... This put increasing pressure on academic and government researchers to justify their activities in economic terms” (Voyer 1999, 281).

In 1990, the government liquidated the Canadian Patents and Development Corporation and “shifted responsibility for transferring technology from the public laboratories to industry onto each laboratory and its supervising government department” (Niosi 2000, 54). This responsibility was later supported by the creation of the Federal Partners in Technology Transfer, a program that enrolled thirteen federal departments and

agencies to promote commercialization of publicly produced technology (Ibid.). Niosi's analysis is worth quoting at length:

Funding programs changed, as did the mandates, missions, evaluation procedures, and effectiveness criteria of government laboratories, where technological cooperation became key, to increase both revenues and visibility. The evaluation of public research institutions, traditionally conducted via publications and citations, is now increasingly based on the overspill on the economy, particularly on employment and production. (Ibid., 53)

Although Lindquist (1997, 48) argues that public sector reforms in this period did not go as far in Canada as in Australia, New Zealand, and the United Kingdom, he nonetheless agrees that the Canadian reforms "can broadly be characterised as 'managerialist' in nature." In general, government laboratories were under pressure both to become more market-oriented and business-like in their operations and revenue streams, and to serve commercial innovation goals more directly.

Innovation Policy, Deficit Fighting and the Transition to the New Century: 1990s to early 2000s

During the 1993 election campaign the Chrétien Liberals signalled in the Red Book their intention to place innovation at the centre of their agenda. Innovation was also a core concept in the Chrétien government's main microeconomic policy paper (Industry Canada 1994). Not long after taking the reins of power, however, the policy agenda quickly gave way to fiscal realities, and the ensuing cuts in program spending and personnel were particularly severe for many of the science-based departments and agencies, including Environment Canada. In their second mandate, with the return of

some fiscal flexibility, the Chrétien Government increased investment in R&D but this funding was primarily targeted to other sectors, particularly the universities. With respect to government science, Ottawa in the 1990s became a Dickensian “city of two tales”—the first being “the worst of times” during the Liberals’ first deficit-fighting mandate, and the second, during the budget surplus mandate that followed, being better but still not the “best of times” for most government laboratories.

As part of its innovation agenda, the new Government sought to re-examine the role and performance of government with respect to S&T (Meisel 1998). A further impetus for a major S&T review were three chapters of the 1994 report of the Auditor General of Canada that offered a rather scathing assessment of federal S&T management (Auditor General of Canada 1994). Lindquist and Barker (2000, 345) also point to the impact of this report in extending the NPM agenda to government science:

[The Auditor General] introduced themes, such as a focus on results, performance management, horizontal management, and producing better information for Parliament and citizens that would influence the S&T community in the medium term. Such themes, though a staple of the auditor general, were relatively new for Ottawa’s science establishment.

This report raised concerns at the highest political and administrative levels and it, along with high-level interest in S&T on the part of John Manley as minister of industry and Paul Martin as minister of finance, led to focussed attention on federal S&T (Lindquist and Barker 2000).

The story of the S&T Review is well known (de la Mothe 1996, Meisel 1998) and I will not dwell long on it here. Launched in mid-1994, the comprehensive internal

and external review was quickly overtaken by the fiscal imperative to reduce the federal budget deficits. But the consultation process proceeded and in March 1996 the government released *Science and Technology for a New Century: A Federal Strategy*, along with a set of action plans outlining how each department would implement the strategy.

The potential for the S&T Review to produce a guiding policy framework was to a large extent pre-empted by the broader Program Review and its associated cuts. Nonetheless, the Federal Strategy seems to have changed the tone of the debate somewhat. Its overall message was that the government should evaluate and justify federal laboratory activities against strategic needs in order to determine whether others might better perform them. In this, the strategy was continuing an old theme. But to a greater extent than in the past, government science was viewed in the context of its role as a critical part of a “national innovation system”—a concept that had become fashionable among scholars of innovation. Government science had something to offer, but rather than simply serving industrial clients, government laboratories would collaborate as partners with other sectors. The Strategy emphasized that “what matters most is the exchange of knowledge and information; cooperation among governments, business and universities; and the forging of partnerships for mutual benefit” (Government of Canada 1996, 4). With its emphasis on mutual exchange, cooperation and partnerships, we begin to see the emergence of a “network” approach to government science (although traditional “hierarchy” and “market” pressures remained important);

hence, my first overall argument about the need to go well beyond the simpler “make or buy” choices and dynamics.

Clearly, the budget constraints and personnel reductions during this deficit-fighting period damaged the morale, if not the effectiveness, of government scientists and science managers. For many within the federal S&T community, the mid-1990s were the worst of times. Their outlook was not much improved in the last part of the decade when, after the return to budget surplus, research spending resumed its flow but through new channels. These new channels, including for example the Canada Foundation of Innovation, were often new forms of funding instruments that were not directly accessible by government laboratories.

Indeed, the constraints on federal investment in government S&T made it necessary to find new ways of operating. Government laboratories came under greater pressure to leverage funds by collaborating with researchers in other sectors. At the same time, the complex issues that government S&T was expected to address demanded multidisciplinary and multi-sectoral approaches. It became increasingly recognized that the organization of government S&T within vertical hierarchies, focussed on finding solutions to specific departmental missions, was not an appropriate means of addressing the complex challenges of such horizontal issues as climate change, sustainable development and national security. In partial response, the Assistant Deputy Ministers responsible for S&T within the major S&T-performing departments and agencies came

together to create the ADM S&T Integration Board. The Integration Board seeks to foster interdepartmental collaboration on horizontal S&T issues.

In recent years, the traditional departmental organization of government science has been complemented by a growing number of interdepartmental programs and resource funds. These include, for example, the Climate Change Action Fund, the Program of Energy Research and Development, and the Toxic Substances Research Initiative. Although typically managed by one or two lead departments, such programs seek to foster collaborations across many government departments and with non-government researchers to focus on emerging issues not adequately addressed by existing research programs within vertical “stovepipes.”

Since the mid-1990s Program Review, organization by policy-induced networks has become increasingly fashionable. As emphasized from the outset, network-based forms of organizing research are not new in that scientists have always worked through informal networks and “invisible colleges” to pursue the advancement and adjudication of knowledge. Even with respect to more formal policy-induced networks the Canadian government has experimented with research networks at least as far back as 1988, with the creation of the Networks of Centres of Excellence program (Atkinson-Grosjean 2002 and 2006). But out of the frustrations of their inability to “make the case” for government science in the 1990s, and building on the theoretical insights emerging from work on innovation systems and network theory, government science managers became

increasingly interested in formal network approaches as alternatives to traditional hierarchical and quasi-market-based approaches, including “make or buy” approaches.

One further model that was proposed was the Federal Innovation Networks of Excellence (FINE) (Henderson 2002, Kinder 2003). The purpose of the FINE initiative was to increase the capacity of government laboratories to conduct public good science in support of national policy goals. Drawing on the lessons learned from previous and existing science initiatives that employed horizontal, collaborative governance models, FINE was to establish research networks that would integrate the resources and expertise of the various science-based departments and agencies, universities, and the private sector to address specifically identified priority themes. In essence, these networks led by government laboratories would be an analog to the university-based NCEs. And while the government did not ultimately go forward with FINE, it signalled its intention to pursue new formal network-based approaches to government science. For example, the government’s 2002 Innovation Strategy stated:

In addition to providing traditional support for government science, the Government of Canada will consider a new approach to investing in research in order to focus federal capacity on priority, emerging science-based issues. New investments in scientific research would ensure that sound science-based policies are adopted to support environment, health and safety objectives. The government would build collaborative networks across government departments, universities, non-government organizations and the private sector. This approach would integrate, mobilize and build on recent government investments in the universities and the private sector. Funding would be competitive, based on government priorities and informed by expert advice. (Government of Canada 2002, 52-3)

We have probably not yet seen the full emergence of the “formal network” era for government science.

II. ENVIRONMENT CANADA AS AN S&T DEPARTMENT

This section provides the historical and contemporary contexts of the federal environment department, Environment Canada. Other scholars have produced excellent histories of the department (Brown 1986 and 1992, Conway 1992, Doern 1992, 2000 and 2002, Doern and Conway 1994, Toner 1994 and 1996) and so the account here can be brief. On the other hand, much of the existing scholarship has tended to examine the department through the lens of its role in the broader environmental policy context. These works examine how the department navigates the complex political-institutional power relationships among various actors, both governmental and non-governmental, concerned with the environment and, more recently, sustainable development and innovation. Thus, the department has been analyzed primarily with respect to its position as a policy department, not as a science department (with Doern 2000 being a notable exception).

It is true that within the definitive work on the department, Doern and Conway (1994) do acknowledge a dual policy/science dynamic within their framework. This framework brings S&T into the discussion by considering, for example, the problems of dealing with scientific uncertainty, risk assessment, and the limits and controversies around the use of science in regulatory decision making. Their analysis thus deals with

“science in policy” but does not delve much into “policy for science” within the department, nor does it look specifically at the department’s laboratories or the institutional aspects of the science dynamic within Environment Canada.

Von Moltke (1996, 219) has written, “Environment Canada is a ministry with limited executive functions. Consequently funding of environmental research to support Environment Canada’s mission represents one of its most important activities.” Indeed, in 1999 S&T expenditures represented 80 percent of the Department’s total budget (Environment Canada 2000). It is also one of the primary science-performing departments of the federal government, behind only the NRC and Statistics Canada in terms of its intramural S&T budget (Statistics Canada 2008b, Table 6-2). In this study I will examine the department using this different “science-based” lens. In addition, I will highlight how the department’s evolution reflects the more general evolution of institutional design emphases across government science, from hierarchies to quasi-markets to networks.

The Trudeau Era: Empire Building, but Get the S&T Out

Some of the key science-based functions of the contemporary environment department (such as meteorological science and wildlife research) not only pre-date the creation of the department but, in fact, date to the earliest periods of organized science in Canada. But these efforts were not yet viewed under the umbrella concept of “environmental science.” Prior to the Second World War, what limited environmental

regulation as existed in Canada was administered primarily by public health authorities and was geared not so much at protecting the natural environment but to limit the spread of infectious disease (Macdonald 1991).

During the 1950s and 1960s, the federal and provincial governments began to expand their legislation and administrative mechanisms in the area of environmental regulation, providing themselves more far-reaching powers than those invested in health authorities (Ibid.). Still, the federal government did not play a large role in environmental protection, except in the context of its jurisdiction for international concerns (e.g., boundary waters, migratory birds). According to Macdonald (Ibid., 138), “Since there was little political pressure surrounding the issue, the governments of John Diefenbaker and Lester Pearson were happy to leave regulation in the hands of provincial and municipal governments.” By early in the Trudeau era, however, forces converged to push the environment onto the political agenda.

As Anderson (1984) has argued, the emergence of a federal environment department followed a turbulent period at both the policy and organizational levels. In particular, she identifies three “movements” that converged to give birth to and shape the early development of Environment Canada. These were 1) the environmental movement, 2) the efficiency in government movement, and 3) the science policy movement. By 1970, an environmental movement had clearly begun to emerge as evidenced in part by the passage of the *Clean Water Act* and the first observance of Earth Day in that year. Increasing public concerns about pollution and resource scarcity led to a growing

recognition of human/nature interdependencies and the need to manage resource use (Toner 1994). This was accompanied by a shift in focus from individual concerns within fisheries, forests, etc., to a more explicit “resource management” approach.⁴²

Secondly, as has been discussed, there had been a growing movement since the Glassco Commission pushing for “government efficiency.” This was reflected in the large amount of organizational reshuffling during the late 1960s that first created a Department of Fisheries and Forestry and then subsumed it and a host of other entities within a Department of the Environment. The consolidation of these wide-ranging organizations into a new environment department was justified largely on efficiency grounds: “The bringing together of a wide range of formerly diverse policy areas was rationalized by the minister in terms of more efficient resource management” (Anderson 1984, 153).

Finally, there was a general science policy pressure to reassert a philosophy of “science for government” over “government for science.” For example, in testimony before the Lamontagne Committee in 1968, the Treasury Board offered a view of the role of government science that clearly reflects the spirit of the times:

In the eyes of the Board, science is not regarded as a thing in itself, but rather as a means to an end. In general, particular scientific projects are not examined on their own merits but rather as components of programs which have defined objectives. (Simon Reisman, quoted in Anderson 1984, 154)

⁴² Doern (2002) has argued, however, that the more remedial “end-of-pipe” cleanup approach was preferred at Environment Canada at least until more recently when the rise of the sustainable development paradigm elevated the more preventative and systemic resource management approach.

This movement, as we have seen, would soon place heavy emphasis on getting a larger proportion of research done in the private sector.

In response to these various pressures and evolving understandings, the Trudeau government began to take action. The Department of the Environment was created in June 1971 by assembling a mix of “organization orphans” drawn from no less than six other departments throughout the federal government:

- the existing Department of Fisheries and Forestry;
- the Atmospheric Environmental Service (formerly and currently the Meteorological Service of Canada) from the Ministry of Transport;
- the Air Pollution Control Division and the Public Health Engineering Division from the Department of National Health and Welfare;
- the Water Sector from the Department of Energy, Mines and Resources;
- the Canada Land Inventory from the Department of Regional Economic Expansion; and
- the Canadian Wildlife Service from the Department of Indian Affairs and Northern Development.

According to Whittington (1980), it was left to the new department to bring some coherence to this melange. The initial organization led to the following seven components of the new department:

- Atmospheric Environmental Service
- Environmental Protection Service

- Lands, Forests and Wildlife Service
- Fisheries Service
- Water Management Service
- Policy, Planning and Research Service
- Finance and Administrative Service

Even without the federal responsibility for national parks or pesticides regulation, this created a massive new bureaucratic structure with more than 10,000 employees including 29 percent of all federal personnel in the natural sciences. The department's budget of \$179 million for 1971-72 grew to \$239 million a year later, the vast majority of which (\$225 million or 94 percent) was for in-house work. Indeed, with research centres in Ottawa, Hamilton, Winnipeg, Edmonton, Toronto, and Vancouver, the Environment Canada research "empire" rivalled that of the National Research Council (Calamai 1971).

While this initial phase of department-building can be viewed as a classic example of institution as hierarchy, the general pressures of the era to get more of the research work done extramurally was also almost immediately evident. For example, the overall science policy of the new department was suggested in remarks made by Jack Davis, the new Environment Minister, early in 1971:

The Science Council believes that we should contract out more of our research work. Less development should be done 'in-house' and more should be done in company plants and graduate schools. I agree with this. We in Ottawa have tended to be too inbred. Too much of our work has been done behind closed doors, and too many studies have been filed away without being read by people who could make some practical use of them....The Science Council says we should concentrate on certain areas of research and avoid spreading ourselves too thin. I agree with this also. I agree that more of our work should be mission-oriented. I agree that it should be tailored to suit Canada's particular

needs. I agree that our environmental endeavors should fit our own Canadian situation. (quoted in Calamai 1971, 10)

The primary S&T policy pressure in this period was to get a larger proportion of the national scientific effort done in the private sector and the federal intramural effort was a favoured target. Anderson (1984, 155) has written, in the context of the Fisheries Research Board (one of the organizations ultimately affected by the creation of Environment Canada), that “the Lamontagne attack on government science and plans to implement the so-called make-or-buy policy both put in question the very foundations of the principle underlying the Fisheries Research Board which was the building up of in-house expertise.”

However, there were critics of the relevance of the Make-or-Buy Policy, at least in the context of Environment Canada. Dr. Roots, a science advisor to the department, contended in a brief to the Lamontagne Committee:

...the application of the ‘make-or-buy’ policy, namely that transferring government scientific work from in-house laboratories to industry will stimulate industrial innovation and technology transfer, and thus lead to more competitive and profitable Canadian industry—has little relevance in many cases for many of the scientific activities of the Department of the Environment Although there are conspicuous exceptions, such as with our program of pollution abatement technology, by and large the scientific activities of the Department of the Environment are not the type that are directly relevant to the immediate development of marketable products, and the contractor who provides scientific services to the department is very rarely able to turn around and find a large number of national or international customers for his new knowledge. (both passages quoted in Supapol and McFetridge 1982, 65)

In Dr. Roots' view, "not very much of the contracted science can be expected to have industrial spin-offs of the type envisaged in many statements that have been made to justify the [Make-or-Buy] policy in general" (Ibid., 66).

The Mulroney Era: From Blais-Grenier to the Green Plan

Following its early period of high-level policy attention and profile, Environment Canada suffered a loss of institutional clout as other policy concerns gained centre stage. In particular, the Mulroney era began quite badly for S&T at Environment Canada. In 1985, the new Conservative Minister Blais-Grenier voluntarily offered up the Canadian Wildlife Service for 25 percent cuts. Although her tenure was short-lived, Doern (1992, 359) observed that "the Blais-Grenier period had left federal environmental management at its lowest ebb ever." More budget and personnel cuts followed under Minister McMillan (Doern 1992). These cuts were not necessarily associated with reductions in mandate. For instance, passage of the Canadian Environmental Protection Act (CEPA) in the 1987-88 period increased the department's emphasis on a "cradle-to-grave" approach to regulating toxic substances and requires key S&T inputs.

At the same time, however, the decade witnessed major environmental disasters globally including at the chemical plant in Bhopal, India, the Chernobyl nuclear accident, and the Exxon-Valdez oil spill, as well as increasing domestic concerns about acid rain and the PCB warehouse fire in St-Basile-le-Grand, Québec. These all contributed to placing environmental concerns at or near the top of public opinion polls by the late

1980s, and the Conservatives belatedly realized they might be vulnerable on the environment. By December 1990 they had found the political will to create and fund the mammoth Green Plan. Initially budgeted at \$3 billion, the Plan was almost immediately cut as the economic recession deepened in 1992-93 (Toner 1994). Nonetheless, the Green Plan represented a major expansion in funding and mandate and represented a huge departure for the Conservatives.

Doern's (1992) discussion of the Green Plan highlights what the Mulroney years were principally about. For example, he argues that the Green Plan's emphasis on traditional regulatory instruments was a reaction to the criticisms of a weakened federal government that were being voiced with respect to the free trade agreement, the Meech Lake process and the Conservatives' general pro-market agenda:

The big, regulatory and therefore quite interventionist Green Plan, which runs counter to the otherwise pro-market 'free trade-deregulation-privatization' thrust of the larger Mulroney agenda, was partly the product of a desire by the Mulroney entourage to counteract the Opposition's growing case that the Mulroney regime was systematically weakening the federal government and Canadians' sense of national unity. (Ibid., 354)

He continues, "The main paradox of the Green Plan in relation to the larger eight-year Mulroney agenda is its puzzling failure to openly support the use of market-based instruments of policy" (Ibid., 369).

The high water mark of the late Conservative era was probably the Rio Earth Summit in June 1992 and, with the infusion of Green Plan funds, Environment Canada's total budget peaked in 1992 at \$1.14 billion. The following years witnessed a downgrading of the influence of Environment Canada with continual turnover in its

ministerial and deputy ministerial ranks, the elimination of the Cabinet Committee on the Environment, and the transfer of Parks Canada (with a 40 percent reduction of Environment Canada's employees and resources) to the new Department of Canadian Heritage (Toner 1994, Environment Canada 2000, Doern 2002). This was followed by "real" cuts (i.e., beyond the transfer of Parks Canada) in the mid-1990s as a result of Program Review.

The Chrétien Era: Down and Out and Across

Environment Canada was among the departments hardest hit by the budget and staffing reductions following Program Review. The department's overall allocation fell from its post-Parks budget of \$737 million in 1994 to \$507 million in 1997. The net effect were cuts to the department's expenditures of 31 percent and to staff on the order of 20 percent (Gualtieri 1994, Environment Canada 2000, Doern 2002). Focussing on S&T only, the department's expenditures fell from a high of \$663 million in 1993-94 to \$424 million in 1999-00, a 36 percent reduction. According to Toner (1996), these latest cuts to Environment Canada were more difficult to absorb than those associated with earlier reorganization exercises because the department experienced a reduction in resources but not a reduced mandate. "Indeed,...the environmental mandate has continued to expand while resources have withered" (Toner 1996, 100).

However, Toner (1996) goes on to highlight that cuts were not the only outcomes of Program Review. The Review proposed a number of changes in each of

Environment Canada's core mission areas. With respect to the department's Science mission, the Review proposed:

- a shift to an ecosystems approach;
- a focus on research in areas requiring core capacity to address policy-based issues;
- replacing fully-funded, non-directed external research with more highly leveraged initiatives;
- modest increases in socio-economic research; and
- pursuing opportunities for commercialization of research facilities.

Under the department's Policy mission the Review proposed, among other things, focussing technology development capability on catalyzing a vibrant environmental industry sector. And under the Service mission it stressed providing good ecosystem models based upon integrated environmental monitoring (Toner 1996, 116-7).

Beyond the major Program Review impacts, the New Public Management and government reinvention ethos also had impacts on Environment Canada's S&T institutions during this period. For example, attempts were made to privatize the Wastewater Technology Centre and to hive off the Meteorological Service of Canada as a special operating agency. Both of these initiatives ultimately failed and will be discussed more in the case studies. While intramural R&D continued to dominate the department's R&D expenditures, its relative proportion of spending declined throughout the decade

while the proportion going to contracts rose from 13 percent to 23 percent (Environment Canada 2000).

Nor was Environment Canada immune in this period to the broader trends towards networked programs and arms-length funding sources. For example, the department's S&T functions were either involved in or impacted by creation of the Climate Change Action Fund, the Sustainable Development Technology Fund, the Toxic Substances Research Initiative and the Canadian Foundation for Climate and Atmospheric Sciences to name just a few. Horizontal networking across the federal government also led to the memorandum of understanding among the four natural resources departments (Agriculture, Environment, Fisheries and Oceans, and Natural Resources) on S&T for sustainable development (later, these four departments were joined by Health Canada and the initiative became known as the "5NR" program).

Environment Canada in the New Century⁴³

According to its official documents, Environment Canada's mission is "to make sustainable development a reality in Canada by helping Canadians live and prosper in an environment that needs to be respected, protected and conserved" (Environment Canada 2004). In seeking to achieve this mission, the department views sound science and innovative technologies as the primary tools at its disposal.

⁴³ The information provided in this section was accurate as of the time the case studies were conducted.

Today's Environment Canada has a wide range of responsibilities which flow from the mandates of various Acts of Parliament. Its founding legislation is the *Department of the Environment Act*. Interestingly, for this heavily science-based department, the Act does not specifically reference "science" or "research." The department also administers thirteen other acts, five of them central to its S&T operations: the *Canada Water Act*, the *Canada Wildlife Act*, the *Canadian Environmental Protection Act*, the *Migratory Birds Convention Act*, and, most recently, the *Species at Risk Act*. Each of these Acts do provide the department statutory authority with respect to research, monitoring or other scientific activities. In addition, the department has responsibility for provisions of a number of Acts administered by other departments, most notably the pollution prevention provisions of the *Fisheries Act* along with the Department of Fisheries and Oceans.

To deliver on its mandate, Environment Canada employs a matrix management approach in that there are ten major organizational units (five departmental sectors headed by an Assistant Deputy Minister plus five regional operations headed by Regional Directors General) which are cross-cut by three business lines. Environment Canada's three business lines are described in terms of the following "strategic outcomes":

- protecting Canadians and their environment from domestic and global sources of pollution;
- conserving biodiversity in healthy ecosystems;

- helping Canadians adapt to their environment in ways that safeguard their health and safety, optimize economic growth and enhance environmental quality.

Of the organizational units, the three primary S&T-based services are: the Environmental Conservation Service (ECS), the Environmental Protection Service (EPS), and the Meteorological Service of Canada (MSC).

Environment Canada reports that, as a science-based department, most of its capital assets are focussed on “research and other science activities that produce a ‘public good’—providing knowledge in support of policy development, developing new methods to improve service delivery, and providing technological solutions to meet the department’s mission” (Environment Canada 2006a, 57). Environment Canada operates 15 research institutes and laboratories, 49 National Wildlife Areas, and has over 4,600 air, climate and water monitoring stations in all regions of the country “many of which are operated in partnership with provinces, Canada’s universities and international scientific agencies” (Ibid., 57).

The department’s S&T capacity is located primarily in its national and regional S&T centres and institutes. The national establishments include: the Environmental Technology Centre and the National Wildlife Research Centre in Ottawa, the National Water Research Institute and the Wastewater Technology Centre headquartered in Burlington, and the Atmospheric and Climate Science facilities at Downsview, Dorval and elsewhere. Regional S&T facilities include: the Atlantic Environmental Science Centre in Moncton, the Centre Saint Laurent in Montréal, the Prairie and Northern

Wildlife Research Centre in Saskatoon, and the Pacific Environmental Science Centre in Vancouver (Environment Canada 2004).

Environment Canada is clearly an S&T-intensive department with more than 70 percent of its budget and about two-thirds of its employees devoted to S&T activities (Ibid.). Over the decade following Program Review, Environment Canada's intramural expenditures on S&T were at a highpoint of \$464 million in 1995-96, reached a low of \$369 million in 1998-99, rose above the 1995-96 level again only in 2001-02 (\$506 million), and then rose to \$550 million in 2004-05. A similar trend is evident with respect to departmental personnel engaged in S&T activities, almost all of whom are engaged in the natural sciences: S&T staff level was at a highpoint of approximately 3,400 personnel in 1995-96, dipped to about 2,800 in 1998-99, and then recovered to its initial level of 3,400 in 2004-05. These data indicate that the Program Review cuts in the mid-1990s were being felt by the department for the better part of a decade.⁴⁴

III. CONCLUSIONS

This chapter has provided the historical and contemporary context within which government laboratories are operating generally, and also the evolving S&T situation of Environment Canada, the department within which the three case study labs function. It has also begun the process of addressing the first two research questions regarding how the institutional forms of government laboratories have been reconfigured and how this

⁴⁴ All data taken from Tremblay (2005), based on Statistics Canada data, except where otherwise noted.

impacts the labs' ability to fulfill their mandates. Evolving policy emphases from early nation-building to more specific science policies in support of a broad range of public missions (defense, health, industrial development, environmental protection, etc.) and then to broader S&T and innovation policies, as well as increasing policy emphases on efficiency, accountability, and managerialism have been contributors to the changing mandates and institutional forms of government science and of federal laboratories. Successive periods have provided particular emphases, including the early "make or buy" emphasis, the shift from science policy to S&T and innovation policy, New Public Management and a focus on fiscal discipline, and these have had diverse and complex impacts on the labs' institutional configurations.

The first of the general arguments in the dissertation also is borne out in this chapter, namely that the traditional "make or buy" and related quasi-market lens on policy analysis related to government labs does not adequately capture the increasingly formal network-based approaches regarding the labs. These include network-based approaches within the federal S&T family, including the use of senior-level integration boards, horizontal policy funds and collaborative research among government labs, but also inter-sectoral networks involving government laboratories with S&T performers in academe, industry or elsewhere. The chapter has also provided evidence in support of the second argument of the dissertation. Despite the high degree of diversity of government laboratories (as will be further demonstrated in the case study chapters), this diversity has not always been reflected in Canadian science policy. A key example from this historical

review was the “one-size-fits-all” application of the Make-or-Buy policy, despite the policy’s apparent inappropriateness to the mandates of some departments.

Overall, the chapter has also shown other related themes that emerge from the history of government science in Canada that continue to reverberate today. These include the debates about fundamental and mission-oriented research, between public and private science and the role of government with respect to the support of industrial S&T, health and safety regulation, and the institutional modes of government science.

This overview makes clear that throughout Canada’s history, the federal government has been a key player in the areas of science, technology and innovation. The review suggests that the nation-building period prior to the Second World War can largely be considered as “pre-history” while, for the period since WWII, it appears that the history of Canadian government science can usefully be divided into three broad eras. The first era, lasting from roughly the 1940s-1960s, witnessed the vast expansion of the S&T system with the federal government as the dominant player. This era can be viewed as the “hierarchy” era in the sense that the government’s S&T enterprise was organized into an increasing number of traditional science-based departments that performed S&T largely in-house. The Glassco Commission’s analysis in the early 1960s was perhaps the first indication of the coming of the second era, but it was still basically and primarily about “getting the boxes right” on the government’s organization chart, a classic concern of hierarchical systems.

During the 1970s-1990s, beginning with the Make-or-Buy policy and later with the rise of New Public Management, government science had clearly entered a new era in which their institutional designs, rationales and practices were expected to reflect market-oriented or quasi-market themes. While the earlier “efficiency in government” thrust was a precursor of New Public Management, the latter’s greater emphasis on importing or adapting private sector management techniques and orientations in public sector institutions was a significant development in this second era. Finally, with the turn of the new century, albeit with precursors in the late 1980s and 1990s, government science seems to have entered a third era which emphasizes formal policy-induced “networks” and collaborative partnerships. It is likely that this latest era has not yet reached its high-water mark.⁴⁵

It is important to be clear that while I have identified a particular institutional design emphasis with each of these concluding three eras, this is not to suggest that as government laboratories passed from one era into the next the new policy pressure and related institutional design wholly replaced the one that preceded it. That is, the emphasis on market rationales and business practices in the 1970s, 1980s and 1990s modified but did not replace what are still largely hierarchical, intramural approaches to government

⁴⁵ This characterization of the post-war historical evolution is broadly consistent with the analysis of Freeman and Perez (1988, 52) of the characteristics of firm organization and forms of cooperation and competition during recent Kondratieff waves of structural adjustment. The fourth such wave, running approximately from the 1930s/40s to the 1980s/90s, was characterized by increasing concentration, divisionalization and hierarchical control, ‘techno-structure’ in large corporations and competitive subcontracting on an ‘arms length’ basis or vertical integration, while the fifth wave, beginning in the 1980s/90s and continuing today, is characterized by networks of large and small firms based increasingly on close cooperation in technology, quality control, training, investment planning and production planning (e.g., “just-in-time” production).

science. Throughout the 1980s and early 1990s, one can find examples of the reassertion of intramural S&T. The early 1980s, for instance, witnessed a major bulge in capital expenditures for new, in-house laboratories (Gualtieri 1994). And, in the late 1980s and early 1990s, the NRC increased its support of basic research from 7 percent to 12 percent in order to protect its research base and maintain its core competency. The NRC decided that its contract research income should not exceed 40 percent of its total revenues; “otherwise, the NRC would become a service organization and not a research organization, chasing revenues instead of innovation” (Ibid., 315).

Similarly, the more recent shift to networks and arms-length funding bodies does not mean that the market-based emphases of New Public Management have completely run their course. Clearly, the Auditor General’s continuing advocacy of managerial approaches and her concerns about the new foundations (Auditor General of Canada 1999; see also Aucoin 2003), as well as the government’s continuing pressure for “commercialization” of government science (Henderson 2003b, Martin 2003, Henderson 2004) all point out that hierarchies and markets are not dead. Nor, for that matter, are networks entirely new. Rather, what this historical overview suggests is that as new policy pressures and mandates emerge, certain institutional designs gain ascendancy but are overlaid onto existing structures, functions and approaches. Government laboratories, therefore, often exhibit a mix of hierarchy, quasi-market, and formal network forms, as we will see more clearly and in greater detail in the case studies.

The history of the federal environment department also reflects the general trends and policy issues in the overall history of federal S&T, including a progression of institutional design emphases on hierarchies, quasi-markets, and networks. The intention of the final section of this chapter was to provide a snapshot of the specific departmental context within which the individual laboratories that are the subject of the case studies have been operating. I will now turn to these cases and examine them initially through the first part of the two-part analytical framework being employed in this study.

PART II: CASE STUDIES AND EMPIRICAL ANALYSIS

CHAPTER 4

CASE STUDY #1:

THE ENVIRONMENTAL TECHNOLOGY CENTRE (ETC)

The purpose of this chapter is to examine the Environmental Technology Centre (ETC) and how it has evolved as a government laboratory within Environment Canada. The case study employs the basic hierarchies, quasi-markets and networks institutional lens and also highlights some of the key problems and challenges the Centre faces, some of which flow from these institutional forms and their interactions with the lab's mandated roles and functions. This case study helps illustrate the limitations of the three discreet-category typology and provides support for the need for the second complementary part of the institutional analytical framework that will be further examined in Chapter 7.

The ETC provides, broadly speaking, specialized scientific support and undertakes R&D and RSA in support of Environment Canada's environmental protection programs. While its S&T mandate and activities are quite broad, the ETC – as one of Environment Canada's "technology centres" – is concerned primarily with technologies to monitor and control air pollution and spills of oil, chemicals and other hazardous

materials. The ETC illustrates the need for a broad conception of “government laboratory,” as an institution encompassing more than just a facility with fixed assets for the conduct of research and development. Besides traditional “bench” science, the ETC engages in “distributed” S&T through the National Air Pollution Surveillance Network, through field work to demonstrate and validate soil remediation technologies, and through on-site contamination measurements at complex spill sites of federal responsibility or national concern. As with the other laboratories examined in this study, the ETC is a complex S&T institution with diverse functions that exhibits a variety of institutional modes.

Consistent with the other case study laboratories, documentation about the ETC as an institution is not abundant nor consistently available throughout the period analyzed in this study. Nonetheless, it has been possible to trace with some confidence the ETC’s institutional evolution from about 1990 based on documentary evidence and complemented with interviews. Over this period, it is possible to identify shifts in its core institutional features and some problems associated with its evolution as hierarchy, quasi-market and network and the tensions among these.

In particular, as the chapter will illustrate, the ETC exhibited in its early history many of the hierarchy-based features traditionally associated with government laboratories, including a heavy reliance on departmental A-base funding. Through the 1990s, the ETC came to rely more and more on “soft monies” to supplement its core budgets. This shift was in part driven by the budget cuts that came as a result of the

demise of the Green Plan and of the mid-1990s Program Review, but is also associated with an increasing quasi-market reliance on IP-generated revenues and on policy-induced horizontal programs in which labs must compete with network partners for funding. The ETC also is unique among the labs studied here in its adoption of an alternative service delivery approach that privatized part of its operations. These and other institutional changes detailed later in this chapter were pursued in the interests of ensuring the ongoing viability and relevance of its operations but has put at risk, to some extent, the lab's traditional core capacities, its ability to fulfill its diverse mandates, and its ability to renew itself in the face of new challenges and opportunities.

I. ORIGINS, MANDATE AND GENERAL FEATURES

In this section, I trace the ETC's origins, mandate and mission areas, and other general descriptive features of the organization. The ETC evolved out of what was first established in 1975 as the "River Road Labs." The Centre is located at a former industrial site on a six hectare campus off River Road in Gloucester, Ontario, just south of the nation's capital. The origins of the ETC reflect those of its parent department. As the Department of Environment was forming in the early 1970s, directorates were established along environmental arenas of concern such as air, water, etc., by combining various programs and units from what are now Natural Resources Canada, Health Canada and elsewhere. The "River Road Labs" were similarly assembled by pulling together the

various R&D efforts related to air pollution from throughout the relatively new Department of Environment and from other departments.

At its birth, the Centre housed a vehicle emissions testing facility, an analytical chemical laboratory for air pollution, an engineering capacity to support the nation-wide network of air pollution monitoring stations and instrumentation, and a small program for testing small source samples of pollution for referencing purposes. These various functions reported to different chiefs at the department's headquarters, and thus, in this early period, the ETC under the "River Road Labs" moniker was actually more just a collection of co-located S&T facilities dealing broadly with air pollution.

In the early 1980s the situation was rationalized by designating an on-site director of the renamed River Road Environmental Technology Centre⁴⁶ who was brought in to manage the ETC as a traditional, hierarchy-based organization. The ETC Director reports to the Director General of the Environmental Technology Advancement Directorate of the Environmental Protection Service. Around the same time, an "emergencies science" group was shifted to the ETC from a different directorate adding a second major research emphasis to the Centre's traditional focus on air pollution.

The mission of the ETC is "to support the Departmental national and international mandate for environmental protection by:

⁴⁶ Later shortened to the Environmental Technology Centre (ETC).

- developing and transferring pollution measurement, prevention, control and remediation knowledge, and new technology in areas related to air pollution and unplanned releases of oil and hazardous materials; and
- providing relevant specialized sampling and analytical expertise and services of the highest standards” (ETC website).

In seeking to fulfill this mission, the ETC plays the following roles:

- to support the regulatory role of Environment Canada by undertaking and promoting research and development (R&D), and technology advancement and transfer in measurement and control of air pollutant emissions, and in response to unplanned releases of oil and hazardous materials;
- to support pollution assessment and assist in solving environmental problems associated with specific sources of air pollution or spill/waste sites that have international, national, or regional implications by undertaking R&D based on in-house and external expertise and resources and co-operation with stakeholders;
- to manage or support Environment Canada’s programs related to measurement and control of air pollution and releases of oil and hazardous materials by providing relevant sampling, analytical, and quality assurance expertise and services;
- to promote the better integration of economic and environmental issues and to foster a healthy and creative environmental protection industry in Canada through

information and technology transfer, and by supporting the development of national and international technology standards and policies;

- to provide advice on environmental protection technology and emerging technical issues relating to air pollution and response to spills of oil and hazardous materials to the Department and other clients including industry, provinces and territories, other R&D organizations, and the public; and
- to represent the Department and Canada in federal-provincial, national, and international environmental protection technology organizations and programs and act as full partners in the international community involved with the development and application of leading-edge technology and technical standards for environmental protection relating to air pollution and control of hazardous materials (ETC website).

This statement of mission and roles appeared as early as the 1992-94 Biennial Report and has not changed substantively since.

The ETC consists of six divisions. The characteristics and major functions of these divisions are briefly described to provide a flavour of the diversity of S&T activities at the ETC. This basic descriptive information draws heavily from the ETC's website and public literature.

Analysis and Air Quality Division

The Analysis and Air Quality Division (AAQD) was created in the mid-1990s following Program Review by reorganizing parts of the former Chemistry and Pollution Management Divisions. The AAQD consists of approximately 37 staff, primarily chemists, engineers, research scientists and technicians/technologists. Its base budget is approximately \$2.7 million and it receives an additional \$5.3 million per year as part of new money targeting ozone-related research.⁴⁷ The AAQD is responsible for coordinating the operation of the federal-provincial National Air Pollution Surveillance (NAPS) Network, as well as the two monitoring stations located in Ottawa. This network provides the air quality data that enables governments to monitor and assess the quality of ambient air in Canada and is described further under the section “ETC as Network.”

The Division also develops and evaluates new measurement technologies in support of air pollution monitoring. The AAQD’s organic and inorganic chemistry laboratories are able to measure ultra-trace levels of various compounds from a variety of environmental sources such as air sources, contaminated soils, and hazardous wastes. The Division is tightly linked to its departmental clients and develops new analytical methods to ensure the most appropriate procedures are available to support the development of environmental regulations. The Division is also involved in providing advice to, and promoting improvements in the capabilities of, analytical laboratories in the private sector, other federal departments and other governments.

⁴⁷ Part of Canada’s commitment under the Ozone Annex of the CanadaUS Air Quality Agreement signed in December 2000.

Emissions Research and Measurement Division

The Emissions Research and Measurement Division (ERMD) plays a leading national role in measuring polluting emissions originating from both mobile and stationary sources. The Division consists of approximately 27 staff, primarily engineers, scientists, and technicians, and 12 contractors. The Division's base budget is approximately \$1.5 million which is split roughly 30 percent for stationary source R&D and 70 percent for mobile source R&D. The stationary side typically brings in an additional \$30-40K per year in external funding while the mobile side receives an additional \$300-500K per year. The ERMD conducts both laboratory and field studies in support of departmental activities related to climate change, smog, toxics, and regulatory compliance and enforcement. Major emphases include:

- characterization of emissions from such sources as cars and light-duty trucks, incinerators, boilers, smelters, industrial stacks, marine vessels, aircraft, off-road vehicles, and utility engines;
- measurement of greenhouse gases and emissions from municipal landfills;
- evaluation of process control technologies;
- evaluation of remediation and waste destruction technologies;
- quality assurance/quality control;
- development of Reference Methods; and
- advice and assessment.

In particular, the ERMD conducts Related Scientific Activities such as the compliance and audit testing of new model, light-duty cars, trucks and motorcycles. Previously, this work was done under a collaborative agreement with Transport Canada which administered the regulations under the *Canadian Motor Vehicle Safety Act*. As of FY2000-01, the new-vehicle and engine emissions regulations are administered by Environment Canada under the 1999 *Canadian Environmental Protection Act (CEPA)*.

Emergencies Science and Technology Division

The Emergencies Science and Technology Division (ESTD) conducts internationally recognized R&D related to the properties, behaviour, detection, measurement, and effects of spilled hazardous materials, and on the effectiveness and environmental benefits of in-situ countermeasures. The ESTD has a staff of about 17, primarily physical and chemical scientists and technicians, and about \$26 million worth of facilities and equipment dedicated to spill studies. The Division serves as the primary centre of scientific advice on pollution emergencies to the regional offices of Environment Canada and other organizations. Major emphases include both R&D and operational aspects of:

- airborne remote sensing of spills;
- laboratory and field portable measurement techniques;
- oil properties, fate and behaviour;
- in-situ burning;

- spill treating agents;
- biological effects and toxicity; and,
- shoreline cleanup countermeasures.

The ESTD typically conducts about 40 active projects a year, most in partnership with other agencies and industry. In fact, while its base budget amounts to approximately \$1.2 million per year, the Division receives approximately an additional \$1 million annually through joint projects and cost recovery.

Historically, ESTD was predominantly concerned with oil spills. Since 1979, Environment Canada also sought to improve the response and countermeasures technology for spills of materials other than oil. ESTD develops “Priority Lists” for chemical spills to focus R&D efforts on the most frequently spilled and most harmful chemicals. Efforts have focussed on the development of analytical techniques for top priority chemicals as well as the preparation of chemical-specific response manuals (Fingas et al 2000). The Division provides training in the use of personal protection equipment and simple hazard-level measurement equipment to departmental emergencies personnel and to other responders and contingency planners. The Division also provides a “scientific response” team for on-site measurement work at major spills of federal or national concern.

Emergencies Engineering Technologies Office

The Emergencies Engineering Technologies Office (EETO), along with a contractual arrangement with Science Applications International Corporation (SAIC) Canada, has essentially replaced the ETC's in-house capacity previously organized as the Emergencies Engineering Division (EED). Prior to the change, EED undertook engineering R&D and demonstration projects on technologies for cleaning up contaminated sites, either due to oil or chemical spills or insecure hazardous waste sites. EED served as the primary centre of specialized advice on pollution emergency cleanup to the department's regional offices and other organizations. Efforts ranged from direct involvement in cleanup operations to the provision of unique equipment.

Following Program Review, the EED budget was cut by 53 percent, making it difficult to sustain the effort internally. The Centre began to seek an Alternative Service Delivery approach. As of April 1998, the Division was privatized following an extensive study and competitively bid process. As a result, the EETO is now the ETC's one-person office responsible for managing the five-year contract and providing the day-to-day technical liaison between the contractor and the department.⁴⁸ Under the arrangement, SAIC Canada at least matches the \$600,000 per year it receives from the ETC. This unique relationship is further described later under the section "ETC as Quasi-Market."

⁴⁸ At the start of fiscal year 2001-02, the EETO was integrated into the ESTD.

Special Programs Division

The Special Programs Division (SPD) provides strategic, operational, and policy support to the Director's Office. Headed by the ETC's Assistant Director, the SPD consists of only about seven individuals but is responsible for two key inputs to Environment Canada's regulatory and policy processes. The SPD ensures the availability of scientifically sound test methods and develops a base of Canadian commercial laboratories that can generate internationally accepted data on new substances. The *Methods Development and Application Section* forecasts the need for and develops new toxicological methods required for the department's regulation function. The *Good Laboratory Practice (GLP) Compliance Monitoring Unit* provides support to Environment Canada and Health Canada scientists by inspecting Canadian laboratories involved in the generation of data used to assess new substances under CEPA, and for monitoring compliance status and auditing studies on new substances at the request of regulatory authorities in other countries. The Division is also responsible for supporting the OECD's good laboratory practice activities and for in-house quality control and environmental management systems at the ETC.

Microwave-Assisted Processes Division

The Microwave-Assisted Processes (MAP) Division was formed in 1994 to accelerate the development and commercialization of various applications of

Environment Canada's patented Microwave-Assisted Processes (MAPTM).⁴⁹ This family of technologies offers environmentally-friendly processes employing microwaves for the preparation of analytical samples for subsequent biological, chemical and physical characterization and for the extraction of high value-added substances from a variety of items, including plant and animal tissues, soils, and drinking water. The Division's work emphasizes two main areas—the development of MAP-based analytical methods and of industrial-scale processes employing the MAP technology. The Division consists basically of two permanent staff, although they are often complemented by visiting scientists, often from other countries, and interns through the Youth Internship Program. This small office has a base budget of about \$300,000 which primarily covers salaries. In addition, the Division brings in approximately \$1 million through royalties from the nine licensing agreements that the Division maintains with interests in Canada, the United States, Asia, and Europe.

II. KEY INSTITUTIONAL TRENDS

While the origins, mandate and descriptive features provided above are an important starting point for understanding the ETC, they do not sufficiently convey the important pressures and dynamics of change over the period from 1990 to 2005. This section will briefly review major changes and trends in key institutional indicators such as funding, personnel, major capital, and research emphases. Not all of these overall trends

⁴⁹ MAP is a Trade-mark of Her Majesty the Queen in Right of Canada as represented by the Minister of the Environment.

are explicitly linked to policy preferences regarding institutional form, although they do provide the context within which such preferences are actualized. For example, the budget cuts associated with the mid-1990s Program Review were brought down, as was discussed in Chapter 3, as part of broader fiscal policy targeting deficit reduction and were not a part of the government's science policy per se. Nonetheless, as labs sought to deal with these cuts they faced increasing pressure to find alternative revenue streams through quasi-market or network-based approaches.

In the late 1980s, public concerns for environmental protection were raised following high-profile incidents such as the Exxon Valdez oil spill and the St-Basile-le-Grande PCB fire. In response, the Mulroney Government had earmarked additional funding for the ETC as part of the Green Plan in the early 1990s. However, this program was short-lived and was followed by the deep budget cuts of the mid-1990s Program Review.

As with most federal S&T establishments, which were particularly hard hit by Program Review, the ETC budget was cut following 1994 when its base budget had reached about \$10 million. In the post-Program Review period, the ETC experienced a 44 percent reduction in its directly appropriated funding (A-base dollars). Since then the A-base has recovered somewhat to about \$7.5 million per year. However, a key element of the ETC's operations is the additional funds it brings in from non-A-base and external sources. This portion of the ETC's operating budget has been generally higher in the

post-Program Review period. Although detailed ETC budget data was not available, the budget figures in Table 4-1 illustrate the general trends.

Table 4-1. Budget Trend at ETC

Years	Base Budget	Other Revenues	Proportion of Other to Base
1992-94	\$10 million	\$4 to 6 million	~ 50%
1994-96	\$8 million	\$3 to 5 million	~ 50%
1996-98	\$6 million	\$5 million	~ 83%
1998-00	\$6 to 7 million	\$5 to 7 million	~ 92%
2000-02	\$7.5 million	\$3 to 5 million	~ 53%

Source: ETC (1994, 1996, 1998 and 2000).

Another aspect of the funding context for the ETC was the rise over the last decade in the use of competitive horizontal (inter-departmental) program funds such as the Program on Energy Research and Development (PERD), the Toxics Substances Research Initiative (TSRI), and the Climate Change Action Fund (CCAF). Although typically managed by one or two lead departments, such programs seek to foster collaborations across government departments and with non-government researchers to focus on emerging policy priorities not adequately addressed through existing core research programs. The ETC has been successful in attracting some of this funding, although detailed figures were not available.

Personnel levels show a very different trend over the 1990s from the budget trend. With some variation, the ETC maintained a staff level of about 100 throughout the period. In the four fiscal years from 1990-91 to 1993-94 the staff level averaged about 103. In the fiscal years 1994-96 to 1998-00 the average level was 96. This represents about a 7 percent reduction from pre-Program Review staff levels.

The government staff positions can be roughly broken down as 50 percent scientific, engineering and professional, 40 percent technician/technologist, and about 10 percent administrative/support. The ETC used to make extensive use of contractors, around 50-60, who tended to be employed in the technician positions. In the 2000s, however, the ETC reduced its use of contract positions, consistent with departmental policy. At any given time, the total personnel working at the ETC also includes about ten research associates, post-doctoral fellows and students, bringing the total ETC workforce to about 160.

The vast dichotomy between trends in budgets and personnel (-44 percent versus -7 percent) through the mid-1990s Program Review period reflects a conscious decision on the part of the ETC management to protect the employees, and hence its scientific and technical staff capacity. During the period, no staff members were forced to leave involuntarily. On the downside, this approach meant that capital and operating expenditures were cut dramatically to bear the brunt of the budget reductions.

Indeed a major concern with respect to research capacity is the state of the ETC's physical assets. These include, among other things, a world-class oil laboratory, remote

sensing aircraft, emergency response field equipment and vehicles, computers, and air pollution monitoring instruments. A key concern is the aging of these capital facilities and equipment. Throughout much of its history, a significant portion of the resources for infrastructure and scientific equipment recapitalization came from opportunistic sources, such as end-of-fiscal-year slippage funds from elsewhere in the Department. As a result of the millennium Y2K concerns, some funding was made available in the late 1990s for software upgrades and to check date stamps on analyzers but, in general, capital funds have been tightly constrained. While the government has since 1997 devoted major new funding to address academic research infrastructure needs through mechanisms such as the Canada Foundation for Innovation, federal laboratories are not eligible to compete for these funds.

Another important shift relates to the nature of the S&T work performed by the ETC. Throughout the 1990s the S&T efforts at the ETC were roughly balanced between research and development (R&D), on the one hand, and related scientific activities (RSA), on the other. However, with the newer resources coming from the Ozone Annex agreement, the balance is shifting from about 50:50 to closer to 25:75. It remains to be seen how this shift toward RSA will affect the long-term value and effectiveness of the ETC S&T programs. The ETC management believes strongly that it is the applied R&D work that has been a significant factor in the successful delivery and ongoing improvement of ETC's RSA programs, and in ETC's ability to leverage external

resources. They were concerned that continuing to chase after soft monies will diminish the lab's long-term capacity to support its public goods science mandates.

III. ETC AS HIERARCHY

In this section I begin a more explicit examination of the institutional design of the ETC by exploring the extent to which it is structured and behaves along classic bureaucratic lines, as well as how it functions within a larger departmental and governmental hierarchy. As a government entity it can be expected that the ETC would exhibit many of the hierarchical characteristics of a traditional public bureaucracy. The organization chart reveals classic hierarchical lines of authority and, indeed, given the disparate activities of the various divisions, the ETC is quite hierarchical. However, it must be noted that three of the six "divisions" consist of seven or fewer people. Thus, the organization chart is a bit deceiving as to the actual internal structure of ETC which is primarily anchored around the big three divisions (i.e., AAQD, ERMD, and ESTD). The transfer of the Emergencies Engineering Division to SAIC Canada has served to flatten ETC's hierarchy and make it operate in a more quasi-market manner on the "emergencies" side of the organization. This is in line with the general trend promoted across the federal government to de-emphasize hierarchical levels (Aucoin 1997, Swimmer 1996).

Beyond the internal hierarchy, the ETC is situated within a departmental hierarchy. The ETC Director reports to the Director General of the Environmental

Technology Advancement Directorate (ETAD) who, in turn, reports to the Assistant Deputy Minister, Environmental Protection Service (EPS). Proposals for significant new initiatives or program directions are channelled through the direct line management structure for review—i.e., through the ETAD management committee, the EPS Executive Committee and the departmental Environmental Management Board (Thornton 2001). In addition, the ETC is represented on the department's S&T Management Committee, the Laboratory Coordinating Committee, and the Laboratory Managers Committee.

Most of the interaction with these higher levels of the Environment Canada hierarchy is channelled up the chain-of-command through the ETC Director or division chiefs. The ETC staff also participates in a variety of departmental planning and coordination committees or working groups focussing on particular issues. In addition, steps have been taken to improve communication across the department's science / policy interface. For example, in a "hierarchy"-based solution, managers with the Transportation Systems Branch of the Air Pollution Prevention Directorate relocated to the ETC "to strengthen further the linkages between the ETC S&T work and their policy and regulatory functions" (Thornton 2001, 6).

As discussed previously, the proponents of New Public Management (NPM) argue that NPM reforms reduce many of the common pathologies associated with hierarchy-based institutions. However, many critics have pointed out that NPM, in fact, introduces new forms of bureaucratic requirements in the interest of greater public accountability and more business-like and performance-based management approaches

(Aucoin 2008, Doern 2008, Flinders 2001). This increased bureaucracy is reflected in requirements for such things as business plans, annual reports, personnel performance appraisals, etc. The ETC produces an annual business plan with a detailed list of deliverables. The plan is integrated with all of the departmental key deliverables related to environmental protection in the Clean Environment Table Business Line Plan. The Centre also produces biennial reports that profile its activities and summarizes its contributions during the reporting period. Employees are assessed annually using the government's performance appraisal system.

The ETC documents the results of its projects in both informal (unedited) reports and formal (edited) technical reports. In addition, staff members contribute to the general scientific literature through journal articles, book chapters, conference proceedings and workshop presentations. Interestingly, the ratio of scientific publications to technical reports has increased markedly. In the early 1990s, ETC's publications were roughly balanced between, on the one hand, those of the technical report variety that were largely aimed at internal or governmental audiences and, on the other hand, publications and proceedings targeting the broader scientific community. By 2005, however, the ratio of peer-reviewed contributions to internal documents had grown to 2 to 1.

The ETC employs internal peer review, though its researchers are not subjected to much external review (other than when submitting a publication to a peer-reviewed journal). The lab occasionally is involved in public consultation which provides important input but is viewed as a weak way to assess the science. Therefore, the lab will

typically have the science reviewed first by experts, then conduct public consultations, and then publish the overall results.

A final way to examine the ETC as hierarchy centres on human resources policies and processes. In order to continue to provide its clients with cutting edge science and science advice, a government laboratory must continuously renew its human capital. The federal S&T workforce is facing a “demographic bulge” in which a large cohort of the S&T workers will soon become eligible to retire without pension penalty. While the retirements may present opportunities to redirect S&T efforts towards new and emerging research areas, the loss of institutional knowledge and expertise may be staggering.

The ETC has not escaped this pending crisis. But whereas some government S&T establishments have been granted greater independence and flexibility with respect to hiring and human resources management,⁵⁰ the ETC must comply with and operate within the core public service human resources system. This is often seen as a barrier to effective human resource management. Clearly, based on its use of the ASD contract, and the use of individual contractors, students, and programs such as the Youth Internship Program, the ETC has been creative in taking advantage of what flexibilities it has available to it. Nevertheless, continuing to attract younger staff will be critical not only because they can bring new energy, different approaches and more recent S&T knowledge, but also because of their importance in maintaining a vibrant and stimulating research environment.

⁵⁰ For example, through the “separate employer” status common in Special Operating Agencies and Schedule II and Schedule III organizations.

IV. ETC AS QUASI-MARKET

The next institutional design consideration is to examine how the ETC behaves as a quasi-market or market-like organization. In comparison with the other labs included in this study, the ETC exhibits a substantial commercial orientation and has deep links to the private sector. This is not surprising given its parent directorate's mandate to advance the environmental industry. Indeed, as described in an earlier section, the ETC's mission statement includes an explicit role "to foster a healthy and creative environmental protection industry in Canada through information and technology transfer." And its Special Programs Division has a role in supporting the development of Canada's commercial analytical laboratories.

In addition, the ETC exhibits many market-oriented or business-like practices. Perhaps the clearest example of the ETC's adoption of NPM—the pursuit of alternative service delivery through the privatization of part of its operations—is profiled at the end of this section. The fact that NPM features can show up partly under both the hierarchy and quasi-market columns is quite consistent with those critics of NPM who point out that in seeking to induce more business-like behaviour, NPM reforms can simultaneously increase bureaucratic characteristics, particularly in research establishments that historically did not have to deal with requirements for business plans, annual reports and the like (Rappert 1995, Boden et al 2004, Doern 2008). The ETC is an institution within a traditional line department of government (e.g., Schedule I of the *Financial*

Administration Act). In that sense, it is unlike more arms-length entities such as the research institutes of the National Research Council (a Schedule II entity) or the Chalk River Laboratory of Atomic Energy of Canada Ltd. (a Schedule III Crown Corporation). These and other government labs⁵¹ have in place or are experimenting with business-like boards of directors or governing councils. Rather, the ETC is ultimately governed “up” the Environment Canada hierarchy and, thus, such governing boards would be inappropriate in this context. Furthermore, unlike some other government laboratories, the ETC has not made use of an independent board of advisors, although the ETC would fall within the purview of Environment Canada’s department-wide Science and Technology Advisory Board. More focussed and program-specific advice is obtained from those with expertise in the various ETC program areas through various program-level committees. Thus, on these potential quasi-market indicators, the ETC exhibits the characteristics of hierarchy consistent with its mandate.

Another potential area of market-oriented change is in policies and practices regarding intellectual property. As noted in Chapter 3, in the early 1990s, the Government assigned management responsibilities for intellectual property to the individual science-based departments. The ETC began implementing programs involving commercial licensing of intellectual property developed in-house, consistent with its technology transfer mandate (ETC 2002). Since that time, intellectual property issues have become increasingly important to the way the ETC operates.

⁵¹ Such as the Communications Research Centre.

The chief of the Microwave Assisted Processes Division developed the initial MAPTM technology while at Agriculture Canada. In 1990, he moved to Environment Canada and later asked that the patent follow him. Since then, a number of new inventions and patents have resulted and, as has been noted, the MAPTM licensing arrangements have generated large revenues. All of these revenues are fed back into the MAP Division and a portion is awarded directly to the inventors. Moreover, the Emissions Research and Measurement Division has applied for a number of patents and has licensed a couple of technologies—the Multi-DSTM and the DOES2TM—to Canadian companies. The Emergencies Sciences and Technology Division is learning the importance of IP-generated revenues in the new funding environment. In the past the ESTD has developed new technologies but not pursued patents because it was never a concern nor viewed as central to its mandate. It will be interesting to watch whether this quasi-market policy and funding pressure alters the Division's behaviour or impacts its ability to deliver on its mandate.

Another indicator of market-oriented activity is in the realm of encouraging spin-off companies. Some federal S&T institutions such as the National Research Council have experimented with human resources policies and related IP practices to encourage and enable employees to take an idea or technology to market by leaving the NRC and forming spin-off companies (Doern and Levesque 2002). The ETC has not actively fostered such policies and, to date, no spin-off companies have been formed. However, it

should be noted that there has been discussion about whether the MAP Division might be privatized at some point.

The lab's performance is assessed under its accreditation by the Standards Council of Canada and the Canadian Association for Environmental Analytical Laboratories. Reflecting the international trend for accreditation, the ETC chemical labs have been accredited according to ISO 17025 (General Requirements for the Competence of Testing and Calibration Laboratories) and they are seeking to become ISO 9000 accredited. Here, again, is an example of the fuzzy boundaries between the hierarchy and quasi-market categories. While performance accountability has always been a concern within hierarchy-based institutions, the greater emphasis on external accreditation of lab processes is consistent with the more quasi-market NPM reforms.

Beyond these areas, the ETC certainly exhibits other business-like approaches. For example, the use of contract and term employees, business plans and performance indicators are evidence of this "business practice" ethos. The ETC occasionally does work on contract for industry but prefers to interact through joint R&D projects. The Analysis and Air Quality Division will, at times, contract in analytical work for companies although this represents only a very small share of the overall effort and the Division does not seek out such work given concerns of competing with private sector analytical laboratories.

Alternative Service Delivery at ETC

The ETC's pursuit of Alternative Service Delivery through SAIC Canada was in part a response to the general policy pressure in the 1990s to adopt New Public Management approaches. It was also viewed as a means to resolve a particular capacity concern in "emergencies S&T" following the Program Review funding cuts. To set the context, it is necessary to go back somewhat earlier and review the history of the emergencies S&T effort at the ETC.

When a mandate for "emergencies S&T" was added to the ETC portfolio in the early 1980s, the capacity was initially organized in a single division. Over time, there were concerns that the division's focus was too heavily skewed to the science side, at the expense of the engineering/technology side. Also, while the early emphasis of the division was on oil, its spill behaviour, and related response techniques, there was growing interest and needs related to chemicals, water treatment, soil remediation, and other issues concerning contaminated sites. Out of this context, a separate Emergency Engineering Division was created in the 1990-91 time frame with a more explicit mandate for technological and operational support to emergency response and contaminated sites work.

The Division found that much of this work and funding came from outside Environment Canada, including from the Canadian Coast Guard, the U.S. Minerals Management Service, and even the Canadian International Development Agency to support work overseas. The Environment Canada portion of its budget was declining

over time. Concerned about mission drift, and in order to keep control of its departmentally-mandated functions, the department began to look for alternative solutions. When the Program Review cuts came in the mid-1990s, the EED was particularly hard hit making it difficult to sustain a viable in-house effort. This provided further impetus and acceptance of the need for an ASD approach.

It was not the first time the department had considered such fundamental reform. In the early 1990s, Environment Canada looked to ASD mechanisms as a way to deliver on its mandate through novel approaches. Its first attempt centred on the Wastewater Technology Centre in Burlington, Ontario. The experiment entailed setting up the WTC as a “GOCO” or “government-owned, contractor-operated” facility. According to Environment Canada’s thinking at the time, “this arrangement would enable the Centre to bring its research and development to the marketplace while allowing its laboratory staff to share in the profits of successful technological innovations” (Wastewater Technology Centre 1990, 3). In 1991, the WTC was partially privatized on a trial basis for three years. However, by mid-decade this experiment was abandoned as unsuccessful and the WTC was pulled back within the Environmental Technology Advancement Directorate to operate in a more traditional government laboratory mode (for more details on the WTC GOCO experiment, see Brooks 2006).

Despite the problems associated with this initial experiment, ASD was again pursued by the department at the ETC. Not surprisingly, there was some reluctance at first but some believe that lessons learned from the WTC experience helped make the

ETC ASD experiment go more smoothly. Regardless, following an extensive year-long study, it was determined that an ASD approach was the way to go. A competitively bid transition process was initiated in January 1997 to privatize the operations of the ETC's Emergencies Engineering Division.

In the end only one firm, Science Applications International Corporation of Canada (SAIC Canada), bid on the contract.⁵² The parent company, traditionally positioned as a defense contractor to the U.S. government, had also managed similar programs for the U.S. Environmental Protection Agency. Its Canadian subsidiary, headquartered in Ottawa, has been operating for two decades with expertise in radiological and nuclear safety and, more recently, emergency preparation and planning.

As of April 1, 1998, the Emergencies Engineering Division became a privatized organization known as the *Environmental Technologies Program of the Emergency and Safety Services Division of SAIC Canada*. Under the arrangement, the ETC provides \$600,000 annually for R&D work and feasibility studies (see more below). SAIC was required to match the Department's annual investment by year three of the initial contract but did so in year one.

SAIC Canada undertakes research studies and technology evaluation services as requested, specified, and approved by Environment Canada through an ongoing series of work orders. These work orders are managed through the one-person Emergencies Engineering Technologies Office of the ETC. An Advisory Committee composed of

⁵² As an aside, this is consistent with the experience in the U.K. where, when the government sought to privatize public laboratories, it often faced a striking lack of private sector buyers (Boden et al 2004).

stakeholders helps to identify priority needs and shape the research agenda. However, SAIC is also free to make separate arrangements with external clients for the provision of similar technical services and studies (ETC 2000). For example, it contracts separately with the Chemical, Biological, and Radio-Nuclear Research and Technology Initiative (CRTI) run by Defence R&D Canada. Indeed, most of its non-ETC funding comes from other government sources although some also derives from private sources.

Interestingly, the relationship between SAIC Canada and the ETC is described as “arms-length” while at the same time SAIC is viewed as “part of the family.” This is understandable since, in addition to being co-located on the ETC’s campus (sharing, for example, the same cafeteria), the SAIC unit consists of a large number of former ETC employees. Collaborative research and co-authorship of research articles occurs across the blurry public/private boundary. Unlike in the WTC case where public employees went on a leave without pay status and had two years in which to make a final transition decision, here the employees had a single chance to “jump ship” to the private employer. This decision was made easier by the fact that SAIC Canada offered similar salaries, pension and other benefits. Initially, eight of ten EED personnel joined SAIC Canada. The unit has since expanded to sixteen people.

Under the terms of the initial ASD contract, SAIC Canada retained any new intellectual property it developed, although the ETC reserved the right to royalty-free use of the IP for R&D purposes. Over time, however, there was some concern about the appropriateness of this relationship and the potential for conflict of interest. For example,

in the Sydney Tar Ponds cleanup effort (a very “hot,” politically sensitive issue), SAIC Canada could have been in the position of competing for cleanup contracts championing particular technologies while at the same time providing “independent” advice and assessments to Environment Canada of emergencies technologies and techniques. It was felt that SAIC had to do one or the other. The company has subsequently decided to forgo IP licensing itself, leaving the technology transfer and development function to others, and focus on its role in providing advice and feasibility studies and thereby avoid such conflict of interest situations. This decision was also in keeping with the company’s traditional culture as a consulting firm—i.e., it was not primarily interested in the commercialization of technologies. The contract has been rewritten to reflect this shift in focus.

The original five-year contract allowed for an extension and following a review was renewed for an additional five years. Both sides are pleased with the arrangement, describing it as a “win/win” situation. The contractual arrangement ensures a greater stability in the funding for this work. On the other hand, there is at least the hypothetical concern of a dilution of that capacity given that a privatized entity might, over time, pursue other interests resulting in a diminished capacity to address the concerns of the government. This concern has been raised in the UK following that government’s more extensive privatization of public sector research establishments (Boden et al 2004). The reciprocal concern often raised in this context is the potential for a loss of receptor capacity within the government agency to know what questions should be put to the

private performer and what to do with the results obtained. These concerns are not seen as a problem in this case as SAIC Canada has reached a 40:60 equilibrium in its funding structure (ETC funding to non-ETC funding), and the ETC retains significant in-house capacity within the ESTD to both guide and interpret the SAIC Canada's effort.

V. ETC AS NETWORK

As discussed previously, informally networked forms of organization are common among scientific and professional groups, and government laboratories were network-based historically long before formal networks and partnerships were officially encouraged through policy and management practice and requirements. The study as a whole is focussed more on formal networks but in the ETC, both informal and formal networks are involved and it is important to understand exactly what mix of network characteristics are exhibited by government laboratories.

Internally, the ETC includes informal networking based on discipline or project activity as officials at similar levels across the formal hierarchy interact with, learn from and develop trust in one another. But the more common notion of networks in the current era centres on what kinds of partnerships, alliances and other relationships of trust and exchange are fostered with key external stakeholders and S&T institutions such as in other government departments, provincial governments, universities, industry, and non-governmental organizations.

ETC scientists are closely networked informally with the broader environmental S&T community. An element of this broad-based networking is the participation of ETC staff at domestic and international conferences and workshops, “which brings staff into contact with old and potential new colleagues with interests and objectives that are often complementary to those of the ETC” (Thornton 2001, 9). ETC’s formal network relationships involve primarily other government departments, provincial governments, and industry. Other networking is evident with scientists in academe and internationally, although to a lesser degree. Interactions with non-governmental organizations are even less common. This section will examine some of the types of networking, both formal and informal, employed at the ETC. One formal network, the National Air Pollution Surveillance (NAPS) Network, is profiled at the end of this section.

Networking with Regional Offices, Provincial Governments and Other Federal Departments

The ETC is involved in a variety of networks involving other parts of Environment Canada, other government departments, and provincial, territorial and municipal governments. Examples include:

- In its role of coordinating the National Air Pollution Surveillance (NAPS) Network, the ETC regularly convenes the NAPS Management Committee that includes the participation of all of the NAPS Network partners, the department’s Air Pollution Prevention Directorate, and the Meteorological Service of Canada.

The collaborative, inter-jurisdictional nature of the NAPS program contributes to a uniform national database used for tracking Canada-wide Standards. (See more on the NAPS Network at the end of this section.)

- For the environmental emergencies science effort, the ETC does extensive work with the department's regional offices and even has one staff member located at a sub-office in Edmonton. Annual planning and coordination meetings are convened with input solicited from the regional offices, as well as operational and R&D organizations in Canada and overseas.
- Under the Canadian Council of Ministers of the Environment, ETC staff co-chair the federal-provincial Development Committee on the Canada-wide Standard for Petroleum Hydrocarbons-in-soil.
- ETC staff participate, and often play a lead role, in the activities of the federal-provincial Inter-governmental Eco Toxicity Group, which facilitates the development and implementation of ecological toxicity testing by governments in Canada.
- The Emissions Research and Measurement Division has cooperated with the City of Calgary to assess and quantify emissions of greenhouse gases from Calgary's three active landfills.

Networking with the Private Sector

Linkages between the ETC and industrial firms are extensive. The Centre has key industrial sectors (e.g., automotive, petrochemical, pharmaceutical, cosmetics products manufacturers, agri-food processors) as major clients and partners. To the extent that these client relations are commercialized (e.g., fee-for-service or contractual transactions) they are more appropriately addressed as indicators of quasi-market approaches.

However, one way in which the ETC is closely tied to its industrial partners is through joint research projects. These more collaborative relationships are more properly discussed as indicators of network-based approaches within the analytical framework employed in this study because they represent non-commercial interactions. For example, the Emissions Research and Measurement Division collaborates with industry, particularly the automotive and petrochemical sectors, on research and development of new technologies that help reduce pollution. Such projects have involved the ETC in the evaluation of:

- alternative and reformulated fuels for light-duty passenger cars and trucks;
- alternative fuels and after-market exhaust emissions control equipment for on-road, heavy-duty vehicles;
- electric and hybrid vehicles, both light- and heavy-duty; and
- new sampling and analysis instrumentation for stationary source emissions testing.

When developing a new analytical methodology the laboratory will often have it reviewed more informally by those who will put it in practice both within the department and the private sector.

The ETC also engages in industrial demonstration projects. For example, the MAP Division is undertaking a demonstration project in collaboration with CanAmera Foods and BC Research to test the use of the Microwave-Assisted Process in extracting cooking oil from canola. It is hoped that the project will eventually lead to limiting or eliminating the use of hexane, a contributor to greenhouse gases, in the canola oil production industry. Given MAP's potential for much more energy-efficient industrial processes, a number of companies in countries such as South Korea, China, Colombia, Malaysia, Pakistan and India are interested in the outcome of the project.

Networking with Universities

For the most part, universities are not major collaborators with ETC and are certainly not a key source of funds. In fact, in the last decade they have often been viewed as competitors for federal research funding. This perspective was enhanced by the government's creation of new foundations and funds for which universities were eligible to compete but federal laboratories were not. The ETC as an institution participates in few formal networks involving universities and does not exhibit particularly close ties with the academic sector. However, the ETC is involved in some bi-lateral arrangements such as collaborations with Carleton University on emissions

from turbines and on environmental genomics. The ETC also participates in Auto 21, a Network of Centres of Excellence involving a number of universities.

In addition, many ETC scientists maintain personal, informal networks with academic researchers. The MAP Division conducts joint projects with researchers at McGill University and the University of Moncton. Many ETC scientists serve as adjunct faculty at various Canadian universities (including McGill, Carleton, and Ottawa) and occasionally an academic researcher will spend time at the ETC. At any given time the ETC hosts about 10 graduate students or post-doctoral fellows who are supervised by ETC scientists and are able to make use of its facilities. Students usually “bring their own money,” typically through an NSERC grant or other forms of support. Increasing networks with universities is seen as desirable by ETC management.

International Networking

Beyond the normal, informal networking that occurs naturally with the global S&T community, the ETC is engaged in some more formalized international activities. Canada has a strong international reputation in some areas of environmental leadership, and Environment Canada has in place many bi- or multi-lateral agreements involving China, India, Pakistan, and a number of countries in Latin America. Through these programs, the ETC is involved in a wide range of activities such as conducting joint research projects, technology transfer, training, and institutional capacity building. A number of Memoranda of Understanding are in place with the United States, specifically

the Environmental Protection Agency, the Department of the Interior Minerals Management Service, and the U.S. Coast Guard, that facilitate the development and delivery of joint projects with the U.S. government.

The Analysis and Air Quality Division encourages international visits and collaborates with foreign scientists in developing reference materials. The Division has worked with scientists in the United States, United Kingdom, India, Hong Kong and Latin America. While there has not been a formal evaluation of the NAPS program recently, the Division anticipates bringing in international experts for this purpose. As mentioned, the Special Projects Division is responsible for supporting the good laboratory practice activities of the Organization for Economic Cooperation and Development. The MAP Division is involved in a CIDA-funded project to work with McGill University in the training of scientists at the Chinese Research Academy of Environmental Sciences and China's Nankai University. MAP also has a pilot plant operating in Beijing. The Emergencies Science and Technology Division works with international committees to collaboratively set research agendas and is involved in a joint project with 25 parties to conduct research on the effects of oil on shorelines. The ETC is often the lead partner in these international networks.

The National Air Pollution Surveillance (NAPS) Network

The National Air Pollution Surveillance (NAPS) Network is a quintessential example of an ETC-centred formal network. Since the late 1960s, scientists and the public became increasingly concerned about the negative impacts of air pollution including its contribution to urban smog and the acid corrosion of infrastructure. Subsequently, governments began to measure the ambient levels of air pollution and to put in place controls to reduce certain gases, chemical compounds, and particulate matter in the air. The NAPS Network was created in 1969 as a joint program of the federal and provincial governments to monitor and assess the quality of the ambient air in Canada's urban centres. Consistent with the ETC's regulatory support mandate, the network provides the air pollution data that allows governments to assess whether National Air Quality Objectives are being met. The Network consists of some 600 air-monitoring instruments at 230 largely-automated sampling stations located in over 100 urban centres in Canada. Since 1980 the NAPS database has also included ozone observations from Canadian and U.S. rural monitoring locations to enable analysis of regional ozone episodes.

From its beginnings the NAPS Network was instrumental in contributing to the government's efforts to reduce air pollution. By the mid-1990s, however, the data showed a levelling off of the downward trends in air pollution and showed that ozone levels were not recovering. It was determined that the overall increases in transportation had overtaken the gains brought on from introducing controls and emissions-reducing

technologies. The U.S. and Canadian governments recommitted their nations to fighting air pollution and in February 2001, the Environment Minister announced extra funding over four years for the NAPS Program as part of the Clean Air Strategy. This funding targeted the new equipment needs for the monitoring stations and was viewed as urgently needed for the revitalization of the aging network.

The coordination and operation of the NAPS network are the responsibility of the ETC's Analysis and Air Quality Division in collaboration with the co-operating agencies from the provincial, territorial, and regional/municipal governments. Indeed the inter-jurisdictional and cooperative nature of the NAPS program reflect some of the strengths of a network-based organization. Some of the research and development and technical support services related to NAPS are conducted with the participation of, or in collaboration with, other Environment Canada departmental units and regional offices, other government departments (particularly Health Canada and Agriculture and Agri-Food Canada), non-government organizations, academe, the private sector, and foreign and international organizations including the U.S. Environmental Protection Agency, the U.S. National Institute for Standards and Technology, and the World Health Organization.

Table 4-2. Overview of ETC as Hierarchy, Quasi-Market, and Network

Hierarchy	Quasi-Market	Network
<ul style="list-style-type: none"> - accreted structure of 6 units with multiple, distinct mandates - 1 unit shed via ASD approach - regulatory and emergencies roles, but also industry support - vertical reporting to ADM EPS - review largely internal - communications traditionally weighted toward internal technical reports - no unit dedicated to science / policy interface - major Program Review cuts to A-base, less in staff (no involuntary departures) - A-base only two-thirds of total budget - increasing bureaucracy with increased use of policy funds - public service HR policies seen as barrier - modest capital holdings but some unique facilities; opportunistic capital reinvestment but a growing concern 	<ul style="list-style-type: none"> - greater commercial orientation; explicit industrial support mandate - privatized emergencies engineering operation - revenue targets not central but earns large external revenues - no board of directors/advisors - moderate levels of ETC-owned IP and revenues - no spin-off companies - very focussed on key industrial and other clients in its literature - produces 3-year business plans and biennial reports - use of term appointments and on-site contractors - lab certification and quality assessment processes 	<ul style="list-style-type: none"> - academic links not central but growing - some staff serve as adjuncts - some graduate students on-site - increasing emphasis on scientific journal publications - external peer review not institutionalized - links to business are extensive through joint research, and demonstration projects - virtually no links with NGOs - wide variety of links with regional offices, other federal departments and provincial governments - international networks growing through OECD, CIDA-funded work; many MOUs in place particularly with U.S. agencies

The previous sections have described the ETC's institutional characteristics as hierarchy, quasi-market and network. These are summarized in Table 4-2. This case study has shown how these institutional categories are fuzzy, as many of the indicators could be discussed under more than one category. Often, a decreasing indicator in one type could just as well be discussed as a rising indicator of another type. For example, the shedding of a division at the ETC is an indicator of decreasing hierarchy, while doing this through privatization is an indicator of increasing quasi-market approaches. Similarly, budget cuts to the lab's A-base funding is listed under hierarchy but the related reliance on external revenues is also a quasi-market indicator. Other indicators, such as the ETC's extensive relationship with business can be viewed as both increasing network-based and quasi-market approaches. Such findings provide support for the need to

complement the basic hierarchies, quasi-markets, and networks tyopology, with its discreet categories, with an approach that allows greater degrees of freedom across these categories.

VI. KEY PROBLEMS AND CHALLENGES

In this section, I summarize some of the problems and challenges facing the ETC. Many of the problems and challenges are related to the institutional design types, the tensions among them, or tensions between them and the lab's mandates.

Among the most important problems and challenges facing the ETC is the need for additional and more stable funding. In particular, some of the cited program areas that require additional funding include the analysis of toxics, fixed sources emission testing, and on-site response to emergencies (including terrorism-related emergencies), i.e., areas that support the ETC's regulatory and environmental protection roles. The ETC has clearly had much success in attracting "soft monies" through collaborative agreements. While this approach has a number of benefits, Table 4-1 indicates the instability in this funding. This funding uncertainty creates a number of management challenges related to maintaining core capacities in both human and capital terms. There is a concern that the ETC has been operating in a "hand-to-mouth" mode and that more stable funding would be of great benefit to realigning capacity to meet emerging needs. The need for reinvestment in the physical assets of the laboratory is considered urgent. For example, with the influx of the Ozone Annex money, the AAQD will spend fully half of this new

money on upgrading capital equipment with the other half going to support operations.

Thus a key problem in the overall shift to more quasi-market and network-based forms of institutional design and away from the traditional A-base form of funding associated with hierarchy is that it has had negative implications for the lab's funding stability and hence the maintenance of core capacities, particularly in its public goods science roles.

There were concerns that the science/policy relationship could be improved.

Employees are involved at multiple levels of the department's policy-making function but they must continue to make the linkages to key policy concerns or risk missing out on opportunities (particularly for additional money through the new horizontal program-based sources of funding). It was suggested that a formal statement from the policy "client" of Environment Canada indicating their need for ETC data and demonstrating the effectiveness of regulations informed by ETC data would be useful.

Another key problem and challenge, this one attributed to the persistence of hierarchy-induced bureaucracy, is ensuring the ongoing renewal of the lab's workforce. The ETC competes with industry in the recruitment and retention of high calibre laboratory scientists, technologists and technicians. As is the case across the public service, new hires are often brought in on short term assignments or as contractors. While this is an understandable reaction and work-around in the public service staffing environment, such an approach makes it difficult to ensure the long-term integrity of the workforce and the attractiveness of government laboratories as employers.

In recent years there has been pressure, given the enthusiasm for the New Public Management reforms, for government laboratories to adopt more market-oriented approaches in their operations. As has been shown, the ETC has been in the forefront of pursuing such approaches. While its experiment with Alternative Service Delivery is viewed as a success, a key question here is to what extent the ETC could or should be expected to do more in this area. In considering the answer, it should be recognized that pursuing such practices further may alter the organizational culture to the extent of weakening the ETC's ability to conduct long-term public good research, regulatory science, and related scientific activities, and to ensure its S&T feeds into departmental regulatory and policy missions. The use of ASD inherently leads to reduced control over the scientific product as the role of the government scientists shifts to being contract managers as opposed to active researchers. Over time, this can reduce the Centre's ability to attract and retain the best and brightest researchers and to remain an intelligent consumer of the S&T advice or other products generated by the alternative service provider.

Finally, the ETC has had modest success in the commercialization of intellectual property, bringing in an estimated \$2 million to date (ETC 2002). However, since technology transfer is not the primary mandate of the Centre, such activity has been undertaken on an ad hoc basis with very limited dedicated resources. According to an ETC planning document, "Sustained pursuit of such intellectual property revenues requires significant managerial investments in marketing and business development

activities” (Ibid., 4). If government policy signals that the ETC should move more aggressively in this direction, it can be expected that such an approach will not only present a steep learning curve for ETC managers and staff, but might very well raise serious concerns about the organizational culture and ongoing S&T effectiveness of the institution.

VII. CONCLUSIONS

In common with the other case studies, the chapter has employed a basic hierarchies, quasi-markets, networks typology as an initial organizing and analytical framework to understand the ETC and how it has changed as an institution. The use of this first part of the overall analytical framework was based partly on a view that federal S&T policy towards government laboratories will not fully succeed if government laboratories such as the ETC are not understood as institutions and if the institutional diversity across labs is not better understood and reflected in such policies.

Indeed, one of the concluding observations about the use of an explicit institutional analysis is that there is also great institutional diversity *within* a lab such as the ETC, with its multiple mandate areas and varying emphases on R&D, RSA and other functions. Another observation that emerges as a result of thinking more concretely about institutional variety and evolution is that it is not always readily apparent where the boundaries of the ETC as an organization lie and where the boundaries between the public and private sectors now reside. To a certain degree, the hierarchies, quasi-markets

and networks framework forces us out of some of our comfortable but possibly too simplistic interpretations about what goes on inside the various government laboratory “black boxes.”

In terms of a hierarchical organization, the ETC does exhibit many of the characteristics common to a public institution. It consists of six distinct divisions organized along classic hierarchical lines with only occasional links across them. This is probably vestigial of the ETC’s creation and early evolution as an amalgamation of various activities. Communications and relationships with the parent department are largely vertical through the chain-of-command. In addition, there are important kinds of procedural bureaucracy that emerge from the new array of networks, partnerships, performance-based approaches, and rules accompanying new interdepartmental funds.

The chapter has shown that in terms of a quasi-market orientation or business-like operations there are quite a few examples to speak of at the ETC. The ETC managers know their departmental clients and collaborators and maintain contacts on a day-to-day basis. The Centre has made extensive use of both on-site and off-site contractors although the use of on-site contractors is diminishing. As described earlier, its Emergencies Science and Technology Division occasionally employs cost recovery approaches to service delivery. Through joint projects, the ETC receives substantial funding from external sources, including industry and other (including foreign) government departments. Intellectual property activity is large and increasing. No spin-off companies have been created from the ETC although SAIC created a Canadian

subsidiary in part to compete for the ASD contract and it appears likely that the MAP division will spin off to a private entity at some point.

The ETC is clearly a highly networked organization, both regarding the many informal networks examined in the chapter and also regarding the formal National Air Pollution Surveillance (NAPS) Network profiled above. The lab networks particularly with partner organizations in other federal, provincial and municipal governments to deliver core services. The extent and nature of these government networks provides initial support for my consideration in Chapter 7 of the usefulness of splitting the network type. The lab also has extensive relationships with the private sector which are categorized here as indicators of the network form, given their highly collaborative nature (e.g., an example of “collaborate” vs. “buy”). Networking with academic institutions remains largely informal but is becoming increasingly important. Networks involving non-governmental organizations are virtually non-existent.

This chapter has examined how the Environmental Technology Centre has changed at an institutional level. It has not sought to evaluate the substantive S&T activities, contributions and performance of the ETC’s research groups. The analysis has also illustrated in related ways how the ETC has had to respond and adapt to changing policies at the federal and departmental level and to changes in the underlying dynamics of its mission in environmental science and technology.

The ETC has had to deal with problems and challenges related to changes in budgetary support due to the demise of the Green Plan, the Program Review budget cuts

of the mid-1990s and continued constraints on its A-base funding. It has also had to respond to the mixed blessing of the growth of competitive, interdepartmental program funds, and the increasing quasi-market and network-based imperatives to find alternative revenue streams to supplement core funding. Similarly, the ETC has steered through changes in public service delivery policies and expectations related to cost recovery, leveraged funding, networking, partnerships, and alternative service delivery.

The ETC has faced problems and challenges in departmental policies and emphases (e.g., reducing contractual employment, increasing intellectual property attention) and changes to environmental research priorities and approaches (e.g., ozone depletion; air pollution; sustainable development; climate change; oil, chemical and other hazardous materials spills or intentional releases related to terrorism; accreditation and good laboratory practices). It has also had to contend with changes in federal S&T policy in which the roles and organizational health of laboratories were not first order concerns but where such changes had, perhaps unintended but often adverse, effects on the laboratories and their ability to fulfill their mandates (e.g., the lingering impacts of the Make-or-Buy policy, the gradual shift from *science policy* to *innovation policy*, with the greater emphasis on commercialization of government S&T). The ETC has clearly faced these problems and pressures and sought to carry out good work in the context of its broad mandate, constrained resources, and an aging workforce and infrastructure. The ETC seems to have fared quite well and is looking ahead to new growth areas that will surely present both new challenges and opportunities.

CHAPTER 5
CASE STUDY #2:
THE ATMOSPHERIC AND CLIMATE SCIENCE DIRECTORATE (ACSD)

The purpose of this chapter is to examine the Atmospheric and Climate Science Directorate (ACSD) of the Meteorological Service of Canada (MSC) and how it has evolved as a federal S&T laboratory within Environment Canada. The chapter again employs the initial basic hierarchies, quasi-markets, and networks analytical framework to better understand the ACSD and also highlights some of the key problems and challenges it faces, especially those that flow from these institutional forms, their interactions, and their impacts on the ACSD's ability to fulfill its mandates. The case study will provide further support for the need to refine the network category as developed in the complementary second part of the two-part institutional analytical framework in Chapter 7.

The Meteorological Service has set as its long-term vision to be the recognized authority and source of science and information on weather, climate, water, atmospheric chemistry, and air quality. In achieving this vision the MSC faces major problems and challenges related to limited resources and broadening mandates related to shifting from

traditional atmospheric models to providing a wholly integrated environmental prediction system encompassing atmospheric, oceanic and hydrologic models. The MSC has developed a strategy for R&D reinvestment that emphasizes severe weather, new observation strategies, environmental prediction, and science integration and communications. In implementing this strategy, the MSC places greater emphasis on research networks and partnerships with universities and other collaborators than it did in the past.

The Atmospheric and Climate Science Directorate is the focal point within the Meteorological Service for atmospheric and climate research and development and related scientific activities. As a directorate managed by a Director General with staff distributed across multiple “lab” sites, the ACSD is a somewhat different breed than the ETC studied in the last chapter. In addition, the ACSD is closely connected with the operations side of the Meteorological Service in the provision of weather forecasts and other science-based services. As with the other labs examined, the ACSD is a complex S&T institution carrying out diverse activities that extend beyond traditional research and related scientific activities.

Even what is included under “research” must be further examined in the ACSD context, because in addition to the traditional scientific activities of making observations, conducting experiments and developing and testing theories, the ACSD engages in pioneering work in *modelling*. Modelling is a relatively newer form of scientific activity quite distinct from traditional “bench” or “field” science. Researchers interested in

understanding the dynamics of the earth's climate over vast spatial and temporal scales are not able to "stop the world" in order to run controlled experiments. Fortunately, the vast increase in computing power in recent decades has enabled the use of supercomputers for modelling or simulating experiments that could not be conducted in a laboratory. Indeed, the use of modelling has become so great that it is now considered a third major approach to scientific discovery, along with theory and experiment (U.S. DOE 2003). The ACSD is at the forefront of the use of modelling to advance our understanding of the atmosphere and climate change.

While it is difficult to know precisely what the institutional characteristics of the ACSD were in its early history, due to a lack of documentary evidence, it is quite possible to trace the broad trends of this evolution over the period from about 1990 to 2005. As will be discussed in this chapter, the ACSD has not exhibited much in the way of quasi-market characteristics. Rather, the chief trend has been in the direction of increasing network-based forms and this has created both benefits and problems. On the positive side, networks involving a wide range of partners enables the ACSD to access expertise across the natural and social sciences to deliver a more integrated science effort than could be achieved in isolation. On the other hand, as the chapter reveals, the push to operate in a more formally networked mode has led to concerns about management and research capacity to support these collaborative partnerships and the resulting increased procedural bureaucracy which negatively impacts the conduct of S&T.

I. ORIGINS, MANDATE, AND GENERAL FEATURES

As commemorated in 1968 with a 5-cent stamp marking their 200th anniversary, Canada's first long-term, fixed-point weather observations began at Fort Prince of Wales near Fort Churchill on September 10, 1768. William Wales and Joseph Dymond, who were there to observe the transit of Venus on behalf of the Royal Society, made daily measurements by barometer and thermometer for nearly a year (Spurgeon 1968). Thomas (1991, 85), however, claims that in fact "climate records from Québec City from 1742 to 1756 are the earliest known observed meteorological data" in Canada. What is clear is that institutionalized meteorology did not take hold in Canada until the 19th century.

The Meteorological Service of Canada (MSC) has evolved out of what was first established in 1871 as Canada's national weather service, centred at the Toronto Observatory. The service was created "to provide warnings to mariners on the Great Lakes and the St. Lawrence River" (MSC 2001, v). The system slowly expanded across the prairies through the late 19th century and into the north in the early 20th century. As commercial aviation grew so too did the demand for weather information and, in 1936, the service came under the management of the Department of Transport (Thomas 1991). The World War II era saw a great expansion of the Service as hundreds of meteorologists and technicians were hired to support the British commonwealth Air Training Program. In the post-war decades, "extensive programs of meteorological research were commenced and applied meteorological services undertaken for agriculture, forestry, construction and building research, water resources and industry" (Ibid., 268).

Then in 1971 the meteorological and hydrological functions of the weather service were transferred to the newly created Department of the Environment. In addition to the traditional responsibilities in weather forecasting and climatology, the new Atmospheric and Environmental Service became responsible for research into air quality, air pollution and the atmospheric environment in general. By the mid-1990s the AES was again named the Meteorological Service of Canada and there was consideration given to separating the MSC as a special operating agency. This did not come to pass but in 1999 the MSC was designated a “departmental service organization” within Environment Canada (MSC 2001).

Within the MSC, the Atmospheric and Climate Science Directorate (ACSD) is the focal point for atmospheric and climate research and development and related scientific activities. Although the ACSD does not seem to have a formal “mission statement” per se, according to its website the ACSD:

...conducts research in climate, meteorology, air quality, and environmental impacts and adaptation. It produces science assessments on pressing environmental issues (such as climate change, acid rain, and the depletion of the ozone layer, etc.) for Canadians and government policy makers. Important components of this research are atmospheric and meteorological monitoring networks, process research studies (including field experiments), and the development of supercomputer models for environmental and weather prediction. (MSC 2002e)

The Directorate’s products are “used to forecast atmospheric changes and help Canadians adapt to them, and to prevent or mitigate atmospheric catastrophes” (Ibid.).

Even more than the other two labs studied, the ACSD is a dispersed entity located at multiple sites. The bulk of the Directorate’s S&T activities are located at two sites: 1)

the Thompson Laboratory at the MSC headquarters in Downsview, Ontario, just north of Toronto, and 2) the Canadian Meteorological Centre in Dorval, Québec, just west of Montréal (which also houses the operations side of the MSC). In addition, since 1993, the Directorate's climate modelling group has been located at the University of Victoria in order to better access the modelling expertise located there. Other sites include research stations and observatories in various, often remote, locations throughout Canada. Some of these facilities represent nodes of international atmospheric monitoring networks. Among these sites are:

- the Bratt's Lake Station, near Regina, Saskatchewan;
- the King Weather Radar Research Station, near King City, Ontario;
- the Centre for Atmospheric Experiments (CARE), in Egbert, Ontario;
- the Alert Global Atmospheric Watch Observatory, on the northeastern tip of Ellesmere Island, Nunavut;
- the Eureka Arctic Stratospheric Ozone Observatory, in Nunavut; and
- the Dry Deposition Research Centre at the Canadian Forces Station Camp Borden, Ontario.

In addition, as will be discussed further below, much of the Directorate's work is done in collaboration with academic research centres at universities across Canada.

The ACSD consists of the Director General's office and the following five units:

- the Meteorological Research Branch;
- the Air Quality Research Branch;

- the Climate Research Branch;
- the Adaptation and Impacts Research Group; and
- the Science Assessment and Integration Branch.

The basic characteristics and major functions of these units are briefly described below, drawing on the ACSD's website and public literature. While it is not possible here to describe each unit in full, what follows provides a flavour of the diversity of the S&T activities within the ACSD. For more details on the activities and accomplishments of each unit refer to MSC (2002b).

Director General's Office

Consisting of the Director General and nine staff members, the Office provides strategic planning and research policy development, and manages the ACSD's financial and human resources functions. It manages the Visiting Fellowship Program, the MSC Scholarship Program, the Industrial Research Chairs Program, and youth employment programs. The office represents the ACSD on MSC and departmental management committees and on collaborative initiatives with external agencies.

Meteorological Research Branch

The Meteorological Research Branch (MRB) represents the Service's traditional core scientific effort in that it conducts the R&D that is needed to improve operational weather and environmental predictions and severe weather warnings in Canada. With 85

staff members, the Branch is organized into three divisions that focus on, respectively, cloud physics, data assimilation and satellite meteorology, and numerical predictions research.

The *Cloud Physics Research Division* studies fundamental atmospheric processes including the basic physics and chemistry of clouds, freezing processes related to aircraft icing, and fog/water processes. In addition to improving weather predictions and climate models, this research seeks to improve aircraft safety by determining safe operating conditions and safe aircraft design elements. The Division operates the Doppler radar research facility near King City, Ontario.

The *Data Assimilation and Satellite Meteorology Division* focuses on the use of remote sensing technologies such as satellites and Doppler radars to monitor meteorological conditions and severe weather events. Canada does not operate its own weather satellites but rather relies on those operated by the United States and, increasingly, by agencies in Europe and Japan. These systems can provide measurements with greater frequency and over larger areas than traditional ground-based observers and weather balloons. Reflecting the increasing importance of remote sensing, the Division staff grew from one in 1988 to about 25 in 2002. Additional research is concerned with developing advanced techniques for assimilating the data gathered through these remote sensing technologies with the data gathered through traditional in-situ observations. The Division also conducts R&D on remote sensing of sea ice in support of the Canadian Ice Service.

The *Numerical Prediction Research Division* advances numerical and statistical techniques to further improve the highly sophisticated weather prediction models run on the MSC's supercomputer to generate weather forecast information. Chief among these numerical models is the multi-scale Global Environmental Model used for short and mid-term operational weather forecasting. An international peer review of this model held it up as "a world leader," representing "the leading edge of the science" (MSC 2002d). Among the Division's priorities is to further advance the atmospheric models by coupling them with oceanic and hydrology models in order to better predict flooding, ice cover, and climate change as well as developing integrated atmospheric and chemical models to better model air quality. The Division has also made significant progress in simulations of wind energy which are of interest to the nascent wind energy industry.

Air Quality Research Branch

Consisting of 133 staff members, the Air Quality Research Branch (AQRB) is the largest in the Directorate. The AQRB was formed in 1971 with an initial emphasis on acid rain. Its R&D emphases have since evolved to address a broad range of air quality issues including smog, acid deposition, hazardous air pollutants, stratospheric ozone and greenhouse gases. However, rather than organizing its sub-units around these specific air quality issues, the Branch maintains four pools of expertise relevant to the R&D components common to all such issues—systematic measurements, field studies, data analysis, and numerical modelling. The Branch's divisions are organized largely around

these components and the required expertise is combined as necessary, on a project basis, to investigate various air quality issues.

The *Measurements and Analysis Research Division* develops methods for routine monitoring of air quality. Through various observing networks it conducts systematic measurements of the long-term trends and variability of trace gases in the atmosphere, and analyses the potential impact of human activities on the atmosphere. In addition, the Division develops leading-edge data analysis techniques.

The *Processes Research Division* leads the Branch in the design and implementation of intensive field studies. Through these studies and the development of advanced measurement methods, the Division seeks to better understand the underlying physical, biological and chemical processes that determine the chemistry of the atmosphere. In short, the Division's scientists study "how chemicals enter, move through, and exit the atmosphere" (MSC 2002b, 40)

The *Modelling and Integration Research Division* carries out modelling research on the transport, transformation and removal of pollutants by the atmosphere. It develops air quality models that are used to support policy development in evaluating potential emissions scenarios. It also ensures that models are transferred to MSC Operations for service delivery through the production of air quality forecasts and advisories.

The *Experimental Studies Division* is the Branch focal point for the study of ozone depletion and the photochemical balance of the stratosphere. It conducts both ground-based and space-based measurements of radiation and maintains key international

radiation measurement standards. In 1992, Canada became the first country to implement an Ultraviolet (UV) Index program that provides Canadians an indication of the daily sunburning power. This index has been adopted by the World Meteorological Organization and World Health Organization and is now operating in many countries.

Climate Research Branch

The 63 members of the Climate Research Branch (CRB) conduct both field and airborne experiments as well as modelling R&D in support of advancing climate and climate change science. The Branch consists of three divisions directed at understanding the climate system—through modelling, investigating fundamental processes, and assessing the current state of climate—in support of policy development and decision-making on issues of climate change.

The *Climate Modelling and Analysis Division* was formed in 1993 when its predecessor organization in the former Canadian Climate Centre was relocated to the campus of the University of Victoria. This was done to better access the West Coast expertise in ocean and sea-ice modelling. The Division's mandate is to develop and use climate models that combine atmospheric, oceanic, land surface and sea-ice models in order to improve understanding of present, past and future climates. The Division makes more than 2800 years of climate model output available to researchers via its Web site. In addition, the Division works with the Meteorological Research Branch and the Canadian Meteorological Centre to improve seasonal forecasting.

The *Climate Processes and Earth Observation Division* recognizes that the interactions between the atmosphere and its underlying land surfaces need to be more realistically included in climate models. To this end, the Division conducts a combination of field and model studies to improve understanding of energy, water and carbon cycles, with an emphasis on cold climate processes. Particular attention is placed on the role of the cryosphere consisting of the world's ice masses and snow deposits.

The *Climate Monitoring and Data Interpretation Division* monitors and analyses the Canadian and global climate through the acquisition, adjustment and analysis of observed data. This data is collected from a network of observation stations which are increasingly being automated. In addition, the Division reconstructs climate indicators from proxy data such as through the analysis of tree rings or borehole data. The resulting datasets document climate trends and variations and are used by ACSD and external scientists to better understand and attribute these changes to global warming, ocean circulation changes, or other causes.

Adaptation and Impacts Research Group

Established in 1994, the Adaptation and Impacts Research Group (AIRG) conducts research on the impacts of climate, air quality, and weather on human health and safety, economic prosperity and environmental quality. The Group works with universities and stakeholders to develop research capacity, tools and methodologies in support of atmospheric change impacts research and new approaches for the evaluation of

adaptation options and strategies. In short, the Group attempts to address the questions “So what?” and “What should we do about it?” and provide that information to decision-makers and the public in support of reducing vulnerabilities and seizing opportunities. To this end, the Group often publishes both technical and “plain language” documents. It also has co-hosted the first international symposium on communicating climate change to explore effective communication and outreach strategies and the role they play in responding to climate change.

The Group’s research consists of a mix of the physical and social sciences. Rather than build up and maintain an in-house capacity in the social, behavioural and policy sciences, it was decided that the Group’s work would be conducted largely through regional, national and international partnerships and collaborations. Through formal arrangements with the Universities of British Columbia, Waterloo, and Toronto, the Group’s 11 staff members, all federal employees, are actually co-located in academic institutes and faculties. They report to the Branch Director, the only AIRG employee at the Downsview office. The Group is funded through A-base funds at approximately \$1.1 million and receives another \$1 million in soft money from sources such as the Climate Change Action Fund, the Canadian International Development Agency and United Nations agencies. Part of the research team also receives a small amount of industry funding.

Science Assessment and Integration Branch

The Science Assessment and Integration Branch (SAIB) is a small unit that provides a rather unique bridge across the science / policy interface. The 13 staff members view themselves as “advisors” who facilitate communication between, on the one hand, the “researchers” of the ACSD (and the broader atmospheric scientific community) and, on the other, the “policy” staff within Environment Canada (and the broader policy community in federal/provincial venues, in the North American context, and internationally). The Branch is totally funded through A-base money from the Weather and Environmental Prediction business line.

The Branch performs three primary functions: 1) science assessments, 2) science advice, and 3) communications/knowledge management. Under the first activity, the Branch engages in formal, peer-reviewed assessments of the state of the science in areas such as smog, ground-level ozone, and climate change. These assessments do not generate primary research knowledge but rather seek to synthesize the results of existing research studies, identify the current knowledge gaps, and package the information in a way that will be useful for policy makers. The actual assessment *process*, which is considered to be as important as the *content* in establishing the credibility of the assessment, differs with each issue; it ranges from in-house advisors pulling together the results from published reports for a rapid turn-around assessment, to bringing together multi-disciplinary teams of researchers from multiple sectors for more medium-term assessments, to managing Canada’s participation in major, long-term international

assessments such as those coordinated through the Intergovernmental Panel on Climate Change.

The second function includes the more ongoing and ad hoc provision of science advice to the department's policy sector and other stakeholders. Activities range from preparing briefing notes for senior officials to participating in the department's consultation processes on new legislation. The Branch often serves as an entry point for those seeking advice by assisting them in identifying the most appropriate experts within the research branches.

The third, "communication" function involves a lot of "teaching" of the science behind a policy issue, whether for the Minister, departmental policy advisors, or the public. Indeed, the Branch has an explicit focus on public outreach. A Branch science advisor has been identified as the spokesperson for each issue (e.g., acid rain, smog, climate change) and the Branch provides multi-lingual products and services (e.g., Web sites, CD-ROMs, teaching aids) to facilitate information sharing.

II. KEY INSTITUTIONAL TRENDS

While the origins, mandate and descriptive features provided above are an important starting point for understanding the ACSD, they do not sufficiently convey the key pressures and dynamics of institutional variety and evolution historically. This section briefly reviews major changes and trends in key institutional indicators such as

formal organizational structure and culture, research emphases, funding, personnel, and infrastructure.

One of the most basic changes during the case study period which affected many federal S&T institutions was the government's general shift in policy preference toward having basic research conducted in the university community rather than internally. Commenting on this shift, an international peer review panel viewed it as having a positive impact on the ACSD by expanding its science base. But the panel also cautioned that the transfer does not negate the need to maintain a strong internal capacity in order for the ACSD to remain a "smart buyer" of science from academe (MSC 2002d, 3). The policy shift is reflected organizationally in ACSD by the transfer of the Climate Modelling and Analysis Division and the Adaptation and Impacts Research Group to university locations as well as the general increase in networking and collaborative activity with universities discussed further below.

Another basic change to the organizational structure was the transfer into the ACSD of the Science Assessment and Integration Branch. Prior to 1999 the SAIB was located within the policy arm of the MSC. In January 1999 it was moved to be co-located with the ACSD researchers in order to ensure stronger linkages between the SAIB and the working scientists.

These structural changes have led to another important shift relating to the nature of the S&T work performed by the ACSD. Throughout the 1990s the ACSD's primary focus was on conducting, funding and facilitating R&D in the natural sciences. In the

latter part of the case study period, with the transfer of both the science assessment and the impacts and adaptation analysis efforts into the Directorate, the ACSD's portfolio includes more social sciences research and related scientific activities (RSA). To some degree this changes the traditional organizational culture of the Directorate and introduces different challenges with respect to human resources management and performance measurement.

The evolution of the Directorate's research emphases also reflects shifting government priorities, new opportunities or simply the advancement of scientific understanding. One of the most obvious changes during the 1990s was the increased importance placed on the issue of climate change. With the declaration on climate change at the 1992 Rio Summit followed by the Kyoto Protocol in 1997, as well as a series of record warm years and severe weather events, the issue of climate change received increasing attention by policy makers and the public at large. This interest is reflected in part by the establishment in 1998 of the Climate Change Action Fund to help Canada meet its commitments under Kyoto to reduce greenhouse gas emissions. The ACSD has benefited from some of this targeted funding.

In addition, the advancement of technology has led to important increases in computing power that has enabled the steady advancement of modelling capabilities. Whereas earlier models tended to focus on a single physical or chemical process, researchers are now able to couple models of atmosphere, hydrology, sea-ice, wind, waves, etc., in order to obtain more realistic and reliable predictions. Similarly, advances

in remote sensing technology have led to new opportunities. For example, prior to the 1990s some satellite data had been provided to the regional forecast offices but only as an additional support for traditional forecasting. In the years since, remote sensing data has been increasingly integrated into the ACSD's numerical prediction models and the standard products of the Canadian Meteorological Centre.

As with many federal S&T establishments, the Program Review of the mid-1990s negatively impacted the ACSD budget. Its total budget dropped from almost \$47 million in 1994-95 to a low of \$35 million in 1998-99, rising again to about \$40 million in 2003. A key element of the ACSD's overall budget is the additional funds it brings in to supplement its A-base funds. This non-A-base portion of the ACSD's budget has been generally increasing in the post-Program Review period, growing from a low of 12 percent in 1995-96 to 22 percent in 2002-03. There is some concern about the potential for "mission drift" away from the Directorate's core research mission to activities that are more immediately responsive to these non-A-base funding objectives. However, as a counterpoint it should be noted that, due to the Green Plan, non-A-base funding represented 41 percent of the total budget prior to Program Review.

In addition, it should be noted that for the ACSD most of this non-A-base funding was derived from other federal government sources, not external sources. Thus, it can be assumed that the associated funding priorities are reasonably consistent with federal government priorities. A key change in the federal S&T funding context over the period

was the increase in the use of horizontal (inter-departmental) or targeted program funds.⁵³ These include the Program on Energy Research and Development (PERD), the Great Lakes Action Plan, Science Horizons, the Ozone Annex, the Climate Change Action Fund (CCAF), and Action Plan 2000. Again, while the ACSD has been successful in obtaining resources from these various funds, there is some concern that the increased management costs associated with operating in this mode impinges negatively on the conduct of R&D.

In terms of personnel the ACSD actually grew through the case study period. Unfortunately, staff data was unavailable from ACSD for years prior to FY1996-97 so it was not possible to analyze the effects of the 1994-95 Program Review on staff levels using a single consistent data set. Data from another source shows a decrease from 319 employees in FY1994-95 to 274 employees in FY1996-97.⁵⁴ ACSD personnel confirmed that there were some involuntary departures during that down-sizing period. According to ACSD data, in 1996-97 the full time equivalent total was 279 and grew to 316 (as of October 18, 2002), or approximately back to its pre-Program Review level. This 13 percent increase is almost completely accounted for by an increase of scientific staff, particularly in the physical sciences and chemistry categories, while the levels of technical support staff and administrative staff remained basically flat. This staffing

⁵³ To the extent that such funding is used as an indicator of the “network” form, these findings suggest the need to split the network category to better capture the differences between federal networks and inter-sectoral networks, as will be discussed in Chapter 7.

⁵⁴ Data provided by Philip Enros on personnel levels in CARD, the Climate and Atmospheric Research Directorate, ACSD’s predecessor organization.

pattern has led to a distribution of labour as follows: 66 percent in the “scientific” category including (from greatest to fewest) research scientists, physical scientists, meteorologists, chemists, research managers, and mathematicians; 17 percent in the “technical” category including (from greatest to fewest) engineering technicians, electronic scientific support, and engineers; and 17 percent in the “administrative support” category including (from greatest to fewest) computer scientists, administrative staff, and financial officers.

Also of note and consistent with the general trend across the public service is the steady increase in the number of short-term employees relative to permanent employees, from just 8 term employees or 3 percent of the total in 1996-97 to 66 term employees or 21 percent of the total in 2003. This shift towards term appointments was consistent across each of the three broad occupational categories listed above. Consistent with policy pressure to avoid the misuse of professional service contracts, the ACSD does not make extensive use of on-site contractors. It will, at any given time, host a number of students (about 14 in 2003), post-doctoral fellows (about 21 in 2003), and visiting researchers.

A common concern for federal S&T institutions throughout the period related to maintaining research infrastructures. The rapid pace of S&T advancements brings positive benefits but also leads to obsolescence of R&D facilities and equipment. As noted in previous chapters, while the government has devoted major new funding to address Canadian research infrastructure needs through mechanisms such as the Canada

Foundation for Innovation, federal laboratories are not eligible to compete directly for these funds. The Directorate benefited from capital investments earlier in the 1990s, probably related to the Green Plan. But maintaining the quality of research assets requires ongoing investment and there is some concern at ACSD about the need for additional capital investments. Many of the Directorate's research assets represent unique capabilities whose loss would be difficult if not impossible to compensate for. Despite the recognized importance of the high-latitude Eureka observatory—measurements from this site have been credited with characterizing the 1997 Arctic ozone depletion event—the station was “mothballed” in June 2002 due to funding shortages. According to an ACSD document, “options for alternative funding and management are being explored” (MSC 2002b, 49).

III. ACSD AS HIERARCHY

The organization chart shows classic lines of authority and a hierarchical structure consisting of five branches, with 11 divisions under the big three research branches. However, it must be noted that below the division level the structure is quite flat. And two of the branches consist of 13 or fewer people and are essentially flat. Thus, the organization chart is a bit deceiving as to the actual degree of structural hierarchy in ACSD. Also, the transfer of the Adaptation and Impacts Research Group to academe makes it operate in a more horizontal manner. The general trend towards more integrated

modelling of weather, climate and air quality requires more horizontal operations and is in line with the attempt to de-emphasize hierarchical levels.

Beyond the internal hierarchy, the ACSD is situated within a departmental hierarchy. The Director General reports to the Assistant Deputy Minister in charge of the MSC who, in turn, reports to the Deputy Minister of Environment Canada. Most of the interaction with these higher levels of the Environment Canada hierarchy is channelled up the chain-of-command through the Directors and Director General. However, the researchers do participate in a wide range of departmental planning and coordination committees or working groups focussing on particular issues. Furthermore, the addition of the Science Assessment and Integration Branch has provided a focal point within the Directorate for improving communications across the science / policy interface. This move is viewed positively by both the SAIB and the other branches; if anything, now the challenge for the SAIB science advisors is maintaining strong interactions with the policy side of the house, given the geographical separation between Downsview and Environment Canada headquarters and the regional offices.

As discussed previously, even while NPM reforms were introduced in the federal government in an attempt to reduce certain pathologies common to hierarchies, they at the same time introduced new forms of bureaucratic processes and requirements in the interest of greater public accountability and more business-like and performance-based management approaches (Rappert 1995, Boden et al 2004, Doern 2008). This is reflected in requirements for such things as business plans, annual reports, personnel performance

appraisals, etc. In this sense, it is appropriate to discuss NPM impacts under the hierarchy category as these increased reporting requirements are traditionally associated with the bureaucratic “red tape” of hierarchy-based organizations.

Consistent with the more client-focussed approach of NPM, the ACSD aligns its S&T activities to support the key results and outcomes identified for each of the department’s core business lines. The ACSD’s budget and research agendas are closely tied to two of these, namely, Weather and Environmental Predictions (WEP) and Clean Environment (CE). According to ACSD documents, the WEP business line provides 75 percent of all salary and operating resources while the CE business line provides approximately 19 percent of total funding. The remaining 7 percent comes from other federal government departments and programs (5 percent) and from external sources (2 percent), including some licensing revenues.

The ACSD has produced a multi-year retrospective “annual report” summarizing the activities and accomplishments of the Directorate during the 1996-2002 period. This document contains significant technical content and is intended primarily for government S&T managers and key scientific collaborators. The Directorate also prepared a shorter, more glossy companion document that celebrates the ACSD’s accomplishments through stories of the impacts of atmospheric and climate science. It is intended for a broader audience including potential partners and the interested public. In addition, the results of ACSD research are published through a variety of channels including government

publications, technical reports, Fact Sheets, Web sites and through peer reviewed journals, conference proceedings and presentations.

Employees are assessed annually using the government's performance appraisal system. A key element of the appraisal, as with most scientific institutions, is research productivity as demonstrated through the quality and quantity of scholarly publications. Over the period 1999-2001, scientists in the big three research divisions published 512 articles in 108 peer-reviewed journals, the Adaptation and Impacts Group published 52 peer-reviewed publications, and the Science Assessment and Integration Branch published 14 peer-reviewed publications and prepared 11 major assessments over the 1996-2001 period. The importance placed on publication citations is illustrated by this passage from the annual report: "The importance of this discovery can be gauged by the remarkable 282 times that their paper, published in *Nature*, has been cited since its appearance in 1988" (MSC 2002b, 43).

It is important to note here how this last indicator highlights that the three categories of the hierarchies, quasi-markets, and networks framework are not watertight but rather spillover in some ways. The government's standard performance appraisal system is a classic characteristic of hierarchies but its approach, in the S&T context, to assessing scientific productivity through publications in the broader academic literature is also an indicator of the importance of engagement with the academic sector, an indicator of networking discussed later. The nature and extent of these cross-category spillovers highlights the need to use but also critique the initial hierarchy, quasi-market and network

typology employed but also to develop a complementary but extended and more multi-dimensional typology that is the second part of the analytical framework discussed and applied in Chapter 7.

A final way to examine the ACSD as hierarchy centres on human resources policies and processes. In order to continue to provide its clients with cutting edge science and science advice, a government laboratory must continually renew the knowledge embodied in its human capital. The federal S&T workforce is facing a “demographic bulge” in which a large cohort of S&T workers will soon become eligible to retire without pension penalty. While the retirements may present opportunities to redirect S&T efforts towards new and emerging research areas, the loss of institutional knowledge and expertise may present a challenge in the short term.

The ACSD is not immune to this demographic problem and human resources management is viewed to be the chief challenge in coming years. The ACSD has been able to attract graduate students and post-doctoral fellows, many of whom stay on as employees. It also hosts visiting scientists as well as scientists seconded from other government departments. Nevertheless, continuing to attract younger staff is viewed as critical not only to replace retiring researchers but also because of their importance in maintaining a vibrant and stimulating research environment. But whereas some government S&T establishments have been granted greater independence and flexibility with respect to hiring, the ACSD must comply with and operate within the core public

service human resources system which is often seen as a barrier to effective human resource management.

IV. ACSD AS QUASI-MARKET

The next institutional design consideration is to examine how the ACSD behaves as a quasi-market or market-like organization. In short, the ACSD exhibits very little commercial orientation and has limited links to the private sector. This is not surprising given its predominantly public goods science mandate. The ACSD does exhibit some business-like practices which will be explored in this section.

The ACSD is an institution within a traditional line department of government. Other more arms-length government labs⁵⁵ have in place or are experimenting with business-like boards of directors or governing councils. The ACSD is ultimately governed through the MSC and Environment Canada hierarchy and, thus, such governing boards would be inappropriate in this context. In addition, ACSD has not made use of an independent board of advisors, although it would fall within the purview of the MSC's service-wide Advisory Board.

Created in 2001, the Advisory Board consists of senior executives from various stakeholder and client groups. The Board provides advice from a client perspective to the Assistant Deputy Minister on MSC's programs and priorities, reviews technical reports, and promotes cooperative efforts involving MSC and the private sector, other government

⁵⁵ Such as the research institutes of the National Research Council (a Schedule II organization) or the Chalk River Laboratory of Atomic Energy of Canada Limited (a Crown corporation).

departments, universities, and provincial governments. Although the Board's composition primarily reflects key clients (including "clients" within Environment Canada), a scientific perspective is provided by some members with a research background including the Special Science Advisor to the Deputy Minister. More focussed and S&T-specific advice is obtained by ACSD from external advisors via network-based activities such as the formal International Peer Review as well as more informally through ACSD's participation in various international programs and committees.

The discussion of clients above raises another way in which the ACSD acts in a more business-like way in that it has a clear view of who its clients are. Chief among these are MSC's Regions and the Canadian Meteorological Centre which draw heavily on ACSD R&D to provide services to the public, and to aviation (e.g., NAV CANADA) and defence clients (e.g., Department of National Defence, the Canadian Coast Guard). Many of the Directorate's clients are identified throughout this chapter. The MSC has conducted surveys of these and other clients to assess their satisfaction with the ACSD. Results from these surveys were provided as background to the peer review panel (MSC, 2002d). Thus, a client-orientation and client-based performance metrics have been adopted by the ACSD.

Another area of market-like change in federal S&T is in policies and practices regarding intellectual property. Management responsibilities for intellectual property were assigned to science-based departments in the early 1990s. The ACSD has not been

extensively active in the commercial licensing of intellectual property although that is the source of some additional revenues. The Air Quality Branch has developed the Research Data Management and Quality Control Software System or RDMQ™. This system provides a “formal objective system for quality controlling and managing environmental datasets” (MSC 2002b, 40). It has been licensed to the consulting industry, the World Meteorological Organization, the U.S. Environmental Protection Agency, and the department’s Environmental Protection Service. The Air Quality Branch was also responsible for developing the Brewer instrument for measuring column ozone and ultraviolet radiation which was subsequently licensed to the private sector for production. This instrument has become the standard for ground-based measurements and is used in 41 countries around the globe. Finally, the Cloud Physics Division of the Meteorology Research Branch is supporting Version 5 of the Forecast Production Assistant software that is being used commercially by Weathernews International and the U.S.-based Surface Systems Incorporated (MSC, 2002b).

Another area of market-oriented activity is in the realm of encouraging spin-off companies. As noted in earlier chapters, some federal S&T institutions such as the National Research Council have experimented with human resources policies and related IP practices which enable, indeed encourage, employees to commercialize an idea/technology by leaving government and forming spin-off companies. Reflecting its public goods science mandate and lack of commercial technology development, the

ACSD has not fostered such policies and, to date, no spin-off companies have been formed.

Beyond these areas, the ACSD exhibits other business-like approaches. For example, the more explicit use of term appointments, business plans and performance indicators are evidence of this “business practice” ethos. Overall, however, the degree of market orientation should not be overstated.

V. ACSD AS NETWORK

Internally, as has been discussed, the ACSD informally networks based on discipline or project activity as researchers across the branches and divisions collaborate with one another. For example, the Meteorology Branch collaborates with the Climate Branch on producing seasonal forecasts and it collaborates with the Air Quality Branch on developing air quality forecast models. Another indicator of internal ACSD networking are the 11 cross-branch journal publications (i.e., co-authors from two or more branches) published between 1999 and 2001. In terms of networking across the Meteorological Service there are many examples such as how the ACSD’s numerical weather prediction modelling and data assimilation activities are performed in close partnership with the operational Canadian Meteorological Centre to ensure the smooth transfer of knowledge and technology into operations.

The more interesting aspect of its network characteristics are the partnerships and other collaborative relationships with key external stakeholders and S&T institutions such

as in the broader Environment Canada matrix, other government departments, provincial and municipal governments, universities, industry, and non-governmental organizations (NGOs). ACSD scientists are closely networked with the broader atmospheric and climate science community, both domestically and internationally. ACSD networks primarily involve other parts of Environment Canada including the Regions, other federal departments, and universities. Interactions and networking with the private sector and NGOs are less common. This section will highlight some of the types of networking, both formal and informal, employed at the ACSD.

Networking within Environment Canada and the Regional Offices

The ACSD collaborates with other parts of Environment Canada and its Regions. Collaboration occurs among the department's three services—the MSC, the Environmental Protection Service, and the Environmental Conservation Service—on priority setting, policy development, international negotiations, method development and use of facilities and expertise (MSC 2002b). ACSD also collaborates with the Environment Canada Regional Offices on priority setting, program development, research projects, measurement programs, publications, and service delivery. Examples include:

- The Air Quality Research Branch cooperates with departmental regional staff in the operation of approximately 40 monitoring stations in locations ranging from the Pacific to the Atlantic, and from the Great Lakes to the high Arctic.

- The Meteorological Research Branch collaborates with departmental regional science units and the departmental regional weather centres on a continuing basis to improve the science underlying Canada's operational weather prediction and warning programs.
- The Atlantic Environmental Prediction Research Initiative involves the ACSD with collaborators at Dalhousie University and in industry to develop an environmental prediction capability in the Atlantic Region.

Networking with Other Federal Departments and Other Governments

The ACSD works collaboratively with a number of other federal government departments and, to a lesser extent, provincial and municipal governments. Examples include:

- Collaboration with the NRC's Institute for Aerospace Research to operate the Environmental Research Aircraft Facility (ERAF). The ERAF has expanded the measurement capabilities of the Convair-580 and Twin Otter aircraft that are provided by NRC to support ACSD's research needs. In addition, an informal arrangement with the Canadian Forest Service has been used to develop a small, inexpensive Cessna platform for certain requirements.
- The Aircraft Icing Research Alliance, of which MSC, NRC, NASA and Transport Canada are members, was formed after several aircraft disasters in which icing was the primary cause. Funding sources included Boeing, the National Search

and Rescue Secretariat, NASA, the Federal Aviation Administration, and Transport Canada.

- In partnership with the Geodetic Survey Division of Natural Resources Canada, research is underway to evaluate the usefulness of water vapour information that is retrieved from ground-based Global Positioning System receivers.
- Collaboration also occurs with the Canadian Council of Ministers of the Environment and with provincial and municipal governments on the development and delivery of air quality indexes, forecasts, and advisories, Canada-wide Standards, monitoring and data exchange, and priorities and logistics for field studies (e.g., Pacific 2001, Toronto Niagara Region Study).

Networking with Universities

The ACSD exhibits particularly close ties with the university sector through personal, informal networks with academic researchers as well as more formalized relationships. The high degree of publications in the peer-reviewed academic literature has already been noted. In addition, many ACSD researchers serve as adjunct professors and graduate student supervisors with a view to building capacity in atmospheric and climate sciences and in environmental impacts and adaptations research both in Canada and internationally. At any given time the ACSD hosts a number of graduate students and post-doctoral fellows who work with ACSD scientists and make use of its facilities. The MSC provides annually up to five graduate supplements to NSERC scholarships to

encourage graduate research in areas of interest to the ACSD and to increase contacts with and training of potential candidates for future employment at the MSC.

The ACSD has established extensive bi-lateral arrangements with certain universities and has been instrumental in establishing broad-based partnerships involving the academic sector. The motivation for this networking activity was not (at least primarily) as a way to obtain additional funding but as a way to promote research collaboration in order to build capacity and access expertise.

One formal network involving the ACSD with academe is the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS). The CFCAS was established by the government in its 2000 Budget with a one-time \$60 million grant to be disbursed over six years. The Foundation supports research networks and projects centred around universities following consultations with MSC and other government agencies on their strategic scientific needs. ACSD researchers are active participants in many of the funded networks.

International Networking

Because of the transboundary nature of the subject, atmospheric and climate research is of global interest and concern. Canada has a strong international reputation in atmospheric and climate science and the ACSD works closely with its counterpart organizations around the world. This collaboration works through both bi-lateral or regional agreements and networks such as the Canada-U.S. Air Quality Agreement, the

tri-lateral North American Research Strategy on Tropospheric Ozone, and the Commission for Environmental Cooperation, as well as multi-lateral, international bodies and programs such as the World Meteorological Organization, the United Nations Economic Commission for Europe, and the Intergovernmental Panel on Climate Change. Many of the Directorate's scientists serve as Canada's representatives to these various international bodies. The partners benefit from collaboration on the development of research strategies, coordination of intensive field studies, monitoring protocols, data quality management and data exchange standards, and environmental assessments.

Another example of international collaboration is the use of experts from the U.S. and the U.K. on a peer review panel in 2002 (MSC 2002d). The panel was invited to review all aspects of MSC R&D with particular emphasis on excellence, relevance and impact of the science and to provide recommendations to senior management. This practice not only provides an independent, expert assessment but allows for informative exchanges between the panel members, ACSD scientists, as well as external collaborators, clients and peers.

Networking with Non-government Organizations (NGOs)

In general, the ACSD does not have extensive collaboration with NGOs. The Adaptation and Impacts Research Group is perhaps the most closely connected to this community. In its research on human health and safety impacts the AIRG has collaborated with NGOs such as Pollution Probe and the Institute for Catastrophic Loss

Reduction. In the area of natural ecosystem and water resources issues it has collaborated with the Soil and Water Conservation Society, Ducks Unlimited and the Great Lakes Coastal Wetlands Monitoring Consortium.

Networking with the Private Sector

Linkages between the ACSD and private sector partners are even less common. This is not due, as with some laboratories, to an explicit concern about interacting with a regulated industry; rather, it is a reflection that the products of ACSD R&D and RSA are of limited commercial interest and that there are not many private sector stakeholders in atmospheric and climate science research. Unlike some of the other Environment Canada laboratories, such as the Environmental Technology Centre, which have key industrial sectors (e.g., automotive, petrochemical) as major clients and partners, the ACSD's major clients and partners are primarily within the public sector and academe, and the general public.

There are, however, some exceptions. For example, ACSD works with The Weather Network, a private broadcaster that provides value-added weather products. ACSD also enjoys some co-funding of research by the energy sector. In particular, the Meteorology Branch's growing expertise in the area of wind modelling has resulted in partnerships with engineering consulting firms and power-providers interested in the field of wind energy prospecting.

Table 5-1. Overview of ACSD as Hierarchy, Quasi-Market and Network

Hierarchy	Quasi-Market	Network
<ul style="list-style-type: none"> - large structure of 5 units with complementary mandates - 1 unit added in last decade - 1 division operates remotely - meteorological operations support and policy advice roles - vertical reporting to ADM MSC - departmentally-oriented communications through assessment reports - unit dedicated to science / policy interface - major Program Review cuts in A-base and staff (some involuntary departures) - A-base is 78% of budget - increasing bureaucracy with increased use of policy funds - public service HR policies seen as barrier - modest capital holdings; some Green Plan capital reinvestment but loss of Eureka station 	<ul style="list-style-type: none"> - limited commercial orientation - some links to weather services and wind energy industries - limited non-federal revenues - no board of directors/advisors - increased use of term appointments - very limited use of contracting - modest IP activity and revenues - no spin-off companies - increasing client-focus - no public business plans or annual reports; has produced a retrospective performance report - lab certification and quality assessment processes 	<ul style="list-style-type: none"> - one division located at University of Victoria - pervasive links to academe - many staff serve as adjuncts - graduate students on-site - academic-oriented communications in scientific journals - external peer review exists but is not institutionalized - few industry/business links - limited links with NGOs - significant links with regional offices, provincial governments and other federal departments - extensive international collaborations and participation in intergovernmental activities; strong ties with U.S. and U.K.

As with the ETC case study, this examination of the ACSD suggests a need for a richer institutional typology for the analysis of government laboratories. In particular, the ACSD suggests that there would be value in splitting the network category into intra-sectoral and inter-sectoral types to better highlight the differences in network form. This will be discussed further in Chapter 7.

VI. KEY PROBLEMS AND CHALLENGES

Having described in the previous sections the ACSD's institutional characteristics as hierarchy, quasi-market and network as summarized in Table 5-1, I now discuss some of the problems and challenges facing the ACSD. Many of these problems are related to the institutional design types or the tensions among them and the ACSD's mandate. In

considering the problems and challenges being faced by the ACSD there clearly exist two types: 1) scientific and 2) policy/institutional. An example of the first category is the challenge for the ACSD to align weather, climate and air quality models to allow for an integrated environmental prediction system. As discussed earlier, this has led to new research in the area of coupling a variety of numerical prediction models.

Organizationally, this evolution to increasingly more integrated models will likely require greater internal networking across the Directorate as well as with a variety of external collaborators in order to draw on the necessary expertise wherever it resides.

The ACSD is also clearly experiencing many of the policy/institutional problems and challenges common to many federal laboratories. Some of these flow from the above noted trend toward decreasing A-base budgets and increasing reliance on “soft monies.” While this approach has a number of benefits, the greater uncertainty of the funding creates a number of management problems and challenges related to maintaining core capacities in both human and capital terms.

Indeed, among the most important problems facing the ACSD are challenges related to human resources. The key problem is the ongoing renewal of the workforce. Given the large number of retirements expected in coming years it is critical to renew the scientific staff in a way that maintains scientific excellence. The greater use of short-term employees, while beneficial in many ways, can make it difficult to ensure the long-term integrity of the research capacity given the potential for employee turnover. The need for

capital investment in the physical assets of the Directorate is not yet considered urgent but it, too, remains a management concern.

Although the ACSD's dependence on soft money is not as great as the other two labs studied, the International Peer Review Panel was concerned that the increasing reliance on soft money may diffuse the focus of the R&D program away from the Environment Canada mandate (MSC 2002d). Related to this concern, the push to operate in a more formally networked mode has led to a concern that science management is being spread too thin across the many projects. Researchers believe that too often the organizational requirements—i.e., the need for supporting administrative staff and junior researchers—are not fully taken into account when entering new collaborative arrangements. They feel this results in scientists becoming increasingly involved in procedural paper work. This general increase in bureaucratic process (e.g., seeking out and managing partnerships, attending program meetings, performance reporting and evaluations) is viewed as impinging negatively on the conduct of S&T.

VII. CONCLUSIONS

This chapter has explored the Atmospheric and Climate Science Directorate. It has employed the initial basic hierarchies, quasi-markets, and networks part of the analytical framework. The approach helps us understand not only the ACSD as an individual laboratory but also helps elucidate the diversity of government laboratories that

science policy must contend with to be fully effective. The problems and challenges for the ACSD associated with the institutional designs were also examined.

Use of the hierarchies, quasi-markets and networks typology invites us to examine what goes on inside the various government lab “black boxes” and their relationships with other actors. As stressed from the outset, and as highlighted by the ACSD, a “lab” must be seen as an institutional melange of fixed laboratory assets, S&T specialists at distributed sites engaged in research and development and related scientific activities, policy-centred funding mechanisms, and complex brokerage activity involving public servants and collaborators and partners throughout Canada and the world.

The chapter has shown that, in terms of hierarchy, the ACSD exhibits many of the characteristics common to a government institution. It consists of five fairly distinct sub-units organized along classic hierarchical lines. Communications and relationships with the parent department are largely vertical through the chain-of-command. Investments in human and physical capital are constrained by public service rules and procedures. And, in one of the many examples of cross-category impacts, additional procedural bureaucracy is associated with the new array of network-oriented partnerships, performance-based approaches, and interdepartmental funds.

In terms of network-based design characteristics, the ACSD is a highly networked organization, both informally and formally. In particular, the ACSD collaborates, often from a lead position, with partner organizations in other parts of Environment Canada, in other federal government departments, the academic sector, and with foreign national and

international agencies. Networking with academic institutions is becoming increasingly important and formalized. Networks involving firms, provincial research organizations, and non-governmental organizations are less central to ACSD's operations. This is a reflection of where the research is being conducted with which the ACSD must connect. Thus, the type of scientific activities performed by ACSD heavily influences the types of networks in which it participates.

The ACSD does not exhibit much of a market orientation or many business-like operations. The ACSD makes little use of on-site or off-site contractors and does not typically employ cost recovery approaches to service delivery. Although the ACSD relies increasingly on funding from external sources, the bulk of this comes from public funds. While there has been some licensing of products, intellectual property activity for revenue generation has not been a central concern. No spin-off companies have been created from the ACSD.

This case study has not sought to assess the ACSD's actual S&T activities and contributions but has attempted to show how the Directorate has had to respond and adapt to changing institutional forms and policies at the federal level, as well as in the evolution of atmospheric and climate science in particular and the conduct of government S&T more generally. The ACSD has had to grapple with: changes in budgetary support (e.g., the rapid rise and fall of the Green Plan, Program Review cuts, and the changing mix of A-base, interdepartmental program, and external funding); changes in public service management and delivery policies and expectations (e.g., matrix management, cost

recovery, leveraged funding, networking, partnerships, alternative service delivery); changes in research priorities (e.g., acid rain, smog, ozone, aircraft icing, climate change) and approaches (e.g., coupled models, remote sensing, international assessments); and changes in S&T policy in which the labs may not have always been primary concerns but where such changes had often adverse effects on the laboratories (e.g., the shift of basic research support to the university sector, the shift from *science policy* to *innovation policy* with greater emphasis on the economic development roles of government S&T).

The ACSD has changed and continues to evolve as federal laboratory. It has had to cope with added functions, unsteady budgets, an aging workforce and infrastructure, changing research priorities and shifting government policies and expectations. In response it has evolved as an institution, adopting different organizational characteristics, while continuing to provide unique and high quality outputs that advance atmospheric and climate science and support meteorological forecasting and environmental policy.

CHAPTER 6

CASE STUDY #3:

THE NATIONAL WATER RESEARCH INSTITUTE (NWRI)

Canada is home to nearly ten percent of the world's renewable freshwater but this country is not immune from water-related public policy issues. According to the Canadian Water Network (n.d.), health problems related to water pollution cost Canadians \$300 million annually; Canada's water infrastructure is aging and water main breaks in North America cost over \$1 billion per year; and of course, Canada has experienced tragic crises tied to contaminated water in Walkerton, Ontario and in North Battleford, Saskatchewan. In this context, a key role of the federal government is to ensure that freshwater policy is informed by sound science.

The purpose of this chapter is to examine the National Water Research Institute (NWRI) and how it has evolved as a government laboratory within Environment Canada. The case study employs the first part of the two-part analytical framework, i.e., the basic three-category hierarchies, quasi-markets and networks institutional framework, and also highlights some of the key problems and challenges the Institute has faced and continues to face, especially those issues that flow from institutional modes and tensions between

them and the lab's mandated roles. Building on the findings in this chapter, the complementary second part of the analytical framework, the institutional design space typology, will be further developed in Chapter 7.

Of the three case labs, the NWRI is perhaps the one which most exemplifies a traditional government laboratory. Born in response to a clear public policy problem—pollution in the Great Lakes—the laboratory has been primarily devoted to a mission of advancing knowledge and providing scientific evidence through basic and applied research to address the policy and regulatory needs of its parent department. Although the NWRI has changed and continues to change as an S&T institution it represents a classic public mission-oriented government laboratory. Policy pressures to be more market-like or formally networked seem to have had less impact on the NWRI than the other labs studied. It has little or no quasi-market orientation and few business-like practices outside of one of its testing labs. The Institute's networking is heavily oriented to government-based networks, again suggesting the need to adapt the analytical framework in a way that further delineates intra-governmental networks from cross-sectoral networks. This observation will be pursued further in Chapter 7.

I. ORIGINS, MANDATE AND GENERAL FEATURES

According to its website, the NWRI is Canada's largest freshwater research facility. It consists of over 300 staff with expertise in a variety of environmental science fields. The Institute's scientific, technical and professional staff includes aquatic

ecologists, hydrologists, toxicologists, physical geographers, modellers, limnologists, environmental chemists, research technicians and “experts in linking water science to environmental policy” (NWRI website).

The NWRI consists of two main centres. The main facility is at the Canada Centre for Inland Waters (CCIW) located just inside Hamilton Harbour in Burlington, Ontario. The other major facility is the National Hydrology Research Centre (NHRC) in Saskatoon, Saskatchewan, which opened on October 3, 1986. The Saskatoon centre houses the National Hydrology Research Institute and other research units of Environment Canada including regional labs of the Water Quality Branch and an office of the Meteorological Service. In the mid-1990s, it was absorbed into the NWRI organizational structure. The case study focuses primarily on the main NWRI centre at the CCIW in Burlington.

The NWRI also has staff located at the Environment Canada headquarters in Gatineau, Québec, in Fredericton, New Brunswick, and in Victoria, British Columbia. The NWRI’s distributed regional presence is also highlighted on its website which notes that the Institute maintains “research sites across Canada from remote locations in the vast Mackenzie Delta in the Northwest Territories to the waterfront in the City of Toronto; from farmland in Saskatchewan and Ontario to isolated sub-Arctic lakes; from National Parks to sewage treatment plants” (NWRI website).

The NWRI can trace its roots to the establishment in 1967 of the Inland Waters Branch of the Department of Energy, Mines and Resources. Its creation was prompted by

“the need for coordinating all inland water survey and research work within one branch” (CCIW 2008, 2). In August of that year, the Great Lakes Division of the embryonic Inland Waters Branch, consisting of about fifty scientific and technical staff, moved from its temporary accommodations in Ottawa to occupy a 25,000 square foot complex of trailer offices and laboratories at the newly created CCIW in Burlington (Department of Energy, Mines and Resources, 1967).

Interest in creating the CCIW came in response to growing concerns about “pollution of the waters of the Great Lakes and of other lakes, rivers and streams in the areas of population and industrial development throughout the country” (CCIW 2008, 1). The original submission to the Treasury Board discusses the rationale for the creation of the CCIW and is worth quoting at length:

The growing public demand for effective action [on water pollution] by all levels of government is a matter of common knowledge. Appropriate response to this demand can be met by the Federal Government through establishing an interdisciplinary centre for applied and basic scientific and engineering research, integrated with and guided by related planning, economic, social and legal studies. Because of the major national and international implications of the Great Lakes problem, leadership and initiative by the Federal Government is a proper and desirable role that it can assume. (Ibid., 1)

Thus, from the beginning the CCIW had a multifaceted role in basic and applied research focussed on “the Great Lakes problem,” given its “national and international implications.”

The CCIW’s location on the shores of Lake Ontario was ideally suited for its early research emphasis on the Great Lakes and the pollution effects of the region’s population and industrial pressures. Interestingly, it was also noted at the time that the location put

the CCIW within an hour drive of nine universities (Environment Canada 1975). In these early days, the CCIW conducted research primarily in support of pollution abatement and other water management projects. The research was supported by two major research vessels, the 147-foot C.S.S. *Limnos* christened in April 1968 and a charter vessel the M/V *Theron* (CCIW 1968). Although permanent accommodations would not be constructed until the early 1970s, the new CCIW held official opening ceremonies on May 31, 1968 with over 4,000 visitors attending the Open House (Ibid.).

Over the next couple years, the CCIW became the home for the water research activities of the Department of Energy, Mines and Resources, the Fisheries Research Board/Department of Fisheries and Forests, and the Department of National Health and Welfare. During the key transition year of 1970, these activities were consolidated as responsibility for the CCIW shifted from the Minister of Energy, Mines and Resources, to the Minister of Fisheries and Forests, and finally to the Minister Designate of the newly created Department of Environment. The following excerpt from the 1970 Annual Report demonstrates the emphasis on efficiency and coordination through centralized hierarchies that was predominant at the time:

...all components of the Canada Centre for Inland Waters will form part of the new department. There is no doubt that a Centre administered entirely by a single department will offer a greater degree of efficiency in the use of administrative and support services and a higher level of coordination in program planning than could be expected from the multi-departmental form of organization with which CCIW started... (CCIW 1970, 3)

The early 1970s brought a great deal of construction activity to the CCIW. The primary buildings, including the Main Lab Building and the Water Quality Pilot Plant (now the Wastewater Technology Centre) were constructed in the 1970-72 period. The Hydraulics Lab was occupied in 1972, and 1973 brought the establishment of a Centre for Spill Technology and the addition of two more research vessels (CCIW 1971, 1972 and 1973).

In addition to these organizational and physical foundations, the early 1970s saw the laying of the CCIW's legislative mandate and related foundations. The *Canada Water Act* was proclaimed in September 1970 and provided for the federal role in managing Canada's water resources. In addition, the 1972 *Canada-United States Great Lakes Water Quality Agreement*, signed by Prime Minister Trudeau and President Nixon, led to work for the CCIW in support of various International Joint Commission boards, committees, and reference groups. In the mid-1970s, CCIW was formally designated as the World Health Organization (WHO) International Collaboration Centre for Surface and Ground Water Quality and it became the lead institute for the North American contribution to the OECD program on lake eutrophication (CCIW 1974). By the late 1970s, the largest division housed at the CCIW became known as the National Water Research Institute (NWRI) and this name has remained to this day.

The NWRI's campus at the CCIW is owned and managed by Environment Canada. In addition to serving as the headquarters of the NWRI, the CCIW is home to other Environment Canada programs including the Ecosystem Monitoring and

Assessment Network Coordinating Office, the department's Ontario Region offices, and the Wastewater Technology Centre which specialises in the treatment of municipal and industrial wastewater. The Department of Fisheries and Oceans is also present on the CCIW campus with its Bayfield Institute, a national centre of expertise in aquatic biology, freshwater fisheries and navigational charting. The Bayfield Institute comprises the Great Lakes Laboratory for Fisheries and Aquatic Sciences and the headquarters of the Canadian Hydrographic Service in the department's Central and Arctic Region, responsible for the Arctic Ocean and major navigable inland waters in Ontario, Manitoba, Saskatchewan, Alberta, the Northwest Territories and Nunavut. As highlighted on the website, this federal campus provides Environment Canada and Department of Fisheries and Oceans with shared facilities for environmental research and development, as well as monitoring, resource management and navigational charting.

Today, the Institute presents its mission as follows:

NWRI conducts a comprehensive program of ecosystem-based research and development in the aquatic sciences, generating and disseminating scientific knowledge needed to resolve environmental issues of regional, national or international significance to Canada, and to sustain our natural resources and freshwater ecosystems. (NWRI website)

The Institute is clearly situated in the realm of advancing knowledge in the aquatic sciences for public purposes.

The NWRI consists of the Director General's office and the following six S&T units: three core research branches focussed respectively on aquatic ecosystems impacts, management and protection, a national environmental testing laboratory, a water quality

monitoring branch and a research support branch. In addition, the NWRI is the home of the United Nations (UN) program office for water quality. A Science Liaison Branch and a Corporate Services unit round out the organization chart. Basic descriptions of these units are provided below, drawing heavily from the NWRI's public literature.

Aquatic Ecosystem Impacts Research Branch

The Aquatic Ecosystem Impacts Research Branch conducts research to understand and predict the impacts of environmental stressors on the hydrology and ecology of aquatic ecosystems, emphasizing stresses related to climate and atmospheric change, land use, human activities, and cumulative environmental effects on aquatic biodiversity. A unique feature of the program is the integration of hydrological, chemical, ecological and modelling approaches within national and international research projects designed to support Environment Canada's goals for sustainability of water resources and aquatic ecosystems. The Impacts Research Branch consists of approximately 67 staff members, of which 43 are in the scientific and professional categories and 24 are technicians or other technical support staff. The Branch is organized into four divisions focussed on climate impacts, human impacts, land use impacts, and cumulative impacts, with capacity highly distributed in Victoria, Burlington, Saskatoon, and Fredericton, respectively.

Aquatic Ecosystem Management Research Branch

The Aquatic Ecosystem Management Research Branch conducts research to manage and assess surface and groundwater systems degraded by human activities. Key research activities include assessing aquatic ecosystem health in large ecosystems, developing indicators of ecosystem state and recovery, determining impacts of urban point and non-point sources of pollution on receiving environments, controlling urban water pollution, and generating remediation tools and technologies for contaminated groundwater and sediments. The Management Research Branch consists of approximately 51 staff members, of which 33 are in the scientific and professional categories, including one emeritus scientist, and 18 who provide technical support. The Branch is organized into four divisions focussed respectively on groundwater, lake management, urban water management, and sediment remediation.

Aquatic Ecosystem Protection Research Branch

The Aquatic Ecosystem Protection Research Branch conducts research to protect aquatic ecosystems from the deleterious effects of toxic chemicals by developing knowledge and understanding of priority pollutants to support informed environmental decision making and sustainable management practices. Projects focus on determining the persistence, fate and exposure of toxic chemicals in aquatic environments; evaluating effects of priority substances on aquatic organisms; developing indicators and bioassays to detect, identify, and measure contaminant effects in aquatic ecosystems; and assessing

the distribution and biological effects of atmospherically transported persistent organic pollutants and metals in aquatic ecosystems and food chains. The Protection Research Branch consists of approximately 50-60 staff, roughly balanced between scientific/professional staff and technical support staff. The Branch is organized into four divisions that focus respectively on atmospheric contaminants, ecosystem health, priority substances effects, and priority substances exposure.

National Laboratory for Environmental Testing (NLET)

The National Laboratory for Environmental Testing (NLET) offers a broad range of standardized and customized analytical services to support Environment Canada monitoring and research programs. NLET was begun in 1980 as an independent unit but was incorporated into the NWRI in 1994. Perhaps due to its independent origins, the NLET retains a mission statement distinct from the NWRI's:

The NLET mission is to support the laboratory science needs of Environment Canada research and monitoring programs and to delivery quality management products and services, through responsive, cost-effective laboratory services that meet international standards of quality. (NWRI website)

Headed by a director, it consists of approximately 13 specialists in organics analysis, inorganics analysis and information and quality management.

NLET is formally accredited to International Organization for Standardization (ISO) Guide 25 equivalency by the Standards Council of Canada. In addition to the analytical services provided in its Organics Laboratory and Inorganics Laboratory, NLET conducts and reports on inter-laboratory proficiency testing and performance evaluation

studies. As an integral part of the accreditation process for environmental laboratories, success in these studies demonstrates proficiency of the labs to perform at the required level of ISO standards. NLET also produces and markets a variety of certified reference materials, including natural and fortified water and sediment for both organic and inorganic constituents, and provides expert quality assurance advice to numerous laboratories within and outside Environment Canada.

Water Quality Monitoring Branch

The Water Quality Monitoring Branch promotes monitoring as the foundation for understanding aquatic ecosystem health. The Branch's goal is "to detect, monitor, and describe ecosystem change and environmental quality, and increase awareness and understanding of how human activities affect the Canadian environment" (NWRI website). Working with Environment Canada offices and external partners across the country, the Branch strives "to bring regional perspectives together into a cohesive, national picture of Canadian water quality" (NWRI website). The Branch's Environmental Effects Monitoring (EEM) Office focuses on the impacts of effluents in aquatic ecosystems, works with stakeholders to develop scientific technical guidance and regulatory requirements for conducting environmental effects monitoring programs, and provides information needed to assess the adequacy of pollution prevention measures and control technologies. The Monitoring Branch consists of 6 scientific professionals.

GEMS/Water Program Office

The United Nations Environment Program (UNEP) operates the Global Environment Monitoring System (GEMS) for Freshwater Quality Program, a multi-faceted water program addressing freshwater quality issues throughout the world. Canada participates in this global program through managing the small UNEP GEMS/Water Program Office housed at NWRI. NWRI maintains the GEMS/Water database composed of over 1.7 million water quality data points from a total of 865 stations (rivers, lakes, reservoirs and groundwater) distributed throughout 76 countries. Promoting sustainable freshwater quality, GEMS/Water is actively involved in global and regional assessments, capacity building in developing countries, operating an effective and global quality assurance/quality control program, and providing expertise to governments and international agencies in water quality management. NWRI provides scientific expertise and five staff members to support ongoing and developing GEMS/Water operations worldwide.

Research Support Branch

The Research Support Branch provides scientific research support in the areas of information management and information technology, engineering R&D, field instrumentation and calibration services, and expert technical/logistical support for ship-based and shore-based field studies. As a centralized support organization, the Research Support Branch seeks to ensure that the most effective technologies and human resources

capabilities are available to support present and future water research and monitoring projects. While it primarily supports the research programs of the NWRI, the Branch's facilities and services are available to other units of Environment Canada, other government departments and to other external clients, both national and international, including in the private sector on a cost recovery basis. The Branch consists of approximately 20 engineers, technologists, machinists, computer specialists and other technical support personnel.

Science Liaison Branch

The Science Liaison Branch consists of approximately 10 science policy advisors, science communicators and liaison officers. It seeks to raise the profile of the NWRI by communicating the Institute's research on current and emerging water quality and quantity issues in Canada to federal government departments, provincial and territorial governments, legislators and regulators, universities, and the private sector. The Branch's goal is to ensure that new scientific knowledge generated by NWRI's Canada-wide research programs is widely accessible and can be translated effectively into sound environmental policy and decision-making. Communications products include electronic newsletters, fact sheets, brochures, periodic scientific assessments and websites.

As one example of its work, between 2002 and 2005 the Science Liaison Branch organized at the request of the Canadian Council of Ministers of the Environment a series of national Science-Policy Workshops on high-priority water quality issues. The goal of

these workshops was to strengthen linkages between researchers and decision makers. Specifically, they provided “a forum for leading scientists to present the latest research to policy makers, to help identify research priorities, and to explore ways of sustaining dialogue between these two groups” (NWRI website). The workshops covered themes such as the effects of agricultural activities on water quality, groundwater quality, water reuse and recycling, wastewater treatment for small communities, and water quality monitoring.

Corporate Services

The Corporate Services unit is responsible for a range of standard corporate services including financial planning and management; health, safety and security; strategic human resources planning; intellectual property and commercialization; and leases and agreements. In addition, Corporate Services provides facilities management including the Environmental Management System (EMS) and recapitalization projects, and is the landlord for the CCIW in Burlington and the NHRC in Saskatoon.

II. KEY INSTITUTIONAL TRENDS

While the history, mandate and descriptive features provided above are an important starting point for understanding the NWRI, they do not sufficiently convey the important institutional and policy pressures and dynamics of change that the organization has experienced. This section briefly reviews changes and trends in key institutional

indicators such as formal organizational structure and culture, research emphases, funding, personnel, and infrastructure.

In 1990, a departmental document identified the NWRI's roles as:

- to advise senior management on priority issues;
 - to provide leadership on rapidly developing or emerging science programs;
 - to represent Environment Canada in national and international water science organizations;
 - to provide functional guidance to operate water programs; and
 - to provide expert spokespersons for public discussions of water science issues
- (Environment Canada, 1990).

The document indicated that the NWRI pursued these roles through a multi-disciplinary program of basic research, applied research and experimental development. The reference to “a multi-disciplinary program” is consistent with the general shift away from discipline-based structures in government laboratories in this period. An earlier annual report had noted that a division had been reorganized along “problem” rather than disciplinary lines, and since 1986 the NWRI's entire research program has been organized by projects conducted by multi-disciplinary teams (CCIW 1972, Environment Canada 1990).

The most fundamental changes to the organization over the period 1990 to 2005 came as a result of the major structural reorganizations. The NWRI absorbed two existing units of Environment Canada—the National Laboratory for Environmental

Testing and the National Hydrology Research Centre—and relocated some of its capacity to the University of Victoria and the University of New Brunswick. Thus, the organization has grown both larger overall but more disbursed as well, with concomitant impacts on organizational management and culture.

The addition of the National Hydrology Research Centre expanded the NWRI's research emphases, adding water *quantity* issues to the CCIW's traditional emphasis on water *quality*. It also added capacity in cold climate science, northern contaminants, and groundwater research and enabled the NWRI to better deliver on regional issues and to strengthen linkages with academe. Rather than contributing to a lack of organizational cohesiveness the restructuring was viewed as a positive development that provided more legitimacy to the NWRI's "national" focus. The addition of the new units has also meant that the NWRI's portfolio of S&T activities expanded from its traditional basic and applied research focus to include Related Scientific Activities such as testing and monitoring functions.

In the early 2000s, the science communications and liaison function was elevated to Branch status, signalling the importance the NWRI places on such activities. This is consistent with the Institute's unusually high degree of attention to the policy and public interface that has been evident from its very beginning. For example, a Public Relations and Information Services unit was established at the CCIW in 1969 and a Speakers' Bureau Service was added in 1971. According to an early report, the NWRI offered public tours of its campus, supported a Lecture Series, and sponsored exhibits at the

Ontario Science Centre (CCIW 1971). Also, from the bulleted list above, one of NWRI's roles has been "to provide expert spokespersons for public discussions of water science issues."

Another institutional feature of interest from the early period of the NWRI was the attention given to social sciences research. The excerpt from the Treasury Board submission quoted earlier indicates that from its conception, NWRI's research was to be "integrated with and guided by related planning, economic, social and legal studies." In the early years, a Socio-Economic Unit consisting of five members was created, recognizing that effective water resource management benefits from insights not only from the natural sciences but also from economics, sociology, geography and political science. The unit was to provide:

- quantitative analyses in support of policy formulation;
- assessments of the economic impact of proposed water management policies;
- cost/benefit analyses;
- assessments of the attitudes and perceptions of public officials and the general public;
- analysis of legislation and institutional arrangements; and,
- assessments of the impact and diffusion of research in support of water resources management (CCIW 1973).

References to this unit were dropped from the annual reports after 1974 and it is not clear from the historical record what became of it, although the Science Liaison Branch has assumed some of its responsibilities.

Another shift that is evident is the greater focus on Environment Canada as the primary client for the work of the Institute, consistent with the client-focussed emphasis of New Public Management. This can be illustrated by comparing a previous mission statement of the NLET with the more recent one. In 2001, the NLET presented its mission as the following: “The NLET Mission is to support the laboratory science needs *of our clients* by providing responsive, cost-effective analytical and laboratory services that meet international standards of quality” (NWRI 2001, my emphasis). Comparing it with the 2007 statement which begins, “The NLET mission is to support the laboratory science needs *of Environment Canada research and monitoring programs ...*” (NWRI 2007, my emphasis) makes more explicit that the department is the “first client.” Today, the NWRI as a whole positions itself very much within the policy and regulatory needs of the federal government:

Freshwater is a priority area and applied and relevant freshwater science ultimately helps ensure clean, safe and secure water for people and ecosystems. A key federal role is to provide scientific knowledge upon which decisions and sound policies and regulations can be based. (Brannen et al 2005, 9)

Senior managers confirmed that given the NWRI’s extensive networking and partnering with a wide range of actors there is a risk and problem of mission dilution. Increased emphasis has been placed on ensuring that the NWRI’s portfolio of activities continue to directly serve environmental policy needs.

Analysis of the NWRI's overall funding and personnel trends is made difficult by the fact that no public information about these organizational indicators was available. Senior managers at NWRI reported that the Program Review of the mid-1990s had negative impacts on budgets and staff levels. The interviews also revealed that the NWRI's budget consists mostly of A-base funding but that the non-A-base portion is increasing, primarily through policy and program funds. Most of the non-A-base funding was from other governmental sources, not external sources. Increasingly, these horizontal programs are structuring the priorities for the A-base funded research. These findings provide further impetus for the reconsideration of the network category as discussed in Chapter 7.

As for personnel, again no aggregate data was available for analysis. The following information was gleaned from the interviews. The NWRI staff structure is top heavy as the personnel are aging and not being offset by junior staff. There was very little hiring over the past decade and workforce renewal and transition planning emerged as chief concerns. In terms of employment status, it seems that most of the staff are permanent public service employees. The NWRI has made use of Environment Canada's Science Horizons program and does attract a large number of graduate students to its facilities each year. In the 1990s, the NWRI apparently made greater use of on-site contract personnel but this practice was curtailed following some lawsuits and some occupational health and safety concerns.

Consistent with the other labs studied, the NWRI has concerns related to maintaining the quality and currency of its research infrastructure. The NWRI maintains significant capital holdings not only at its centres but also in terms of its field research and monitoring equipment. Some of this capital represents unique or difficult to replace assets such as the research vessels and the hydraulics laboratory. Maintaining these assets requires ongoing investment. In the latter part of the case study period, the capital funding that had come available was targeted to the needs of the buildings first and research equipment second.

III. NWRI AS HIERARCHY

As a government entity, the NWRI clearly exhibits many of the hierarchical characteristics of a traditional public organization. The organization chart reveals a formal structure of nine branches and sub-divisions and related superior-subordinate relationships. As discussed, the organizational structure has grown over the last two decades with the addition of the NLET and the NHRC capacity. Interestingly however, while the NLET was basically added as an additional “box,” the capacity of the NHRC has been distributed throughout the organization and the country.

Beyond the internal hierarchy, the NWRI is situated within a departmental hierarchy. The Director General of the NWRI reports to the Assistant Deputy Minister, Environmental Conservation Service (ECS) who, in turn, reports to the Deputy Minister of the department. Accountability and communications typically flow through the chain-

of-command to these higher levels of the department. However, researchers and research managers also increasingly participate on various departmental and interdepartmental committees and working groups.

The NWRI is very much influenced by the mandates of Environment Canada. The *Department of the Environment Act* specifically includes enforcement of the rules of the Canada-U.S. International Joint Commission and the NWRI's research supports the IJC processes. As indicated in its literature, the results of NWRI research also contribute to the knowledge and evidence requirements of the *Toxic Substances Management Policy*, the *Canadian Environmental Protection Act*, the *Fisheries Act*, and the *Pest Control Products Act*. As we have seen, the NWRI places great importance on these science advice and regulatory support functions and has a unit dedicated to communicating its results across the science / policy interface.

In addition, information generated by NWRI research plays a role in developing national programs and international agreements to reduce emissions. As examples, "NWRI research findings have figured prominently in major national assessment reports of aquatic effects of acid rain in 1985, 1990, 1997 and 2004" and "NWRI research helped prompt national and international recognition of the need for global action on Persistent Organic Pollutants (POPs) (Brannen et al 2005)." The work on POPs led to the shaping of the Stockholm Convention to reduce these hazardous chemicals (Ibid.).

Despite these hierarchical features, there are also obvious examples of how the lab has **not** adopted some of the more bureaucratic features of the New Public Management

reforms. For example, the lab no longer produces public annual reports. This is in contrast to its early history when it did issue annual reports. Nor does it produce public business plans. It does require annual performance reporting but of note is the fact that most of the researchers, those in the “research scientist” or RES occupational category, are evaluated using traditional scientific measures of performance. These include, for example, publications and conference presentations but not contributions to policy advice or service in networks. One of the interviewees characterized the earlier history of the NWRI as a “university without students” and it still maintains a bit of that aura.

Indeed, the strong orientation of the NWRI towards the scientific community is immediately evident. One indicator of this is its emphasis on scientific publications as a key product of the lab. This emphasis was apparent from the beginning as stated in the NWRI’s first annual report: “The early vigour of the Centre’s research program is amply attested to by the extensive list of papers published and/or presented by staff members in 1968” (CCIW 1968). Today, one can access the NWRI’s lists of publications from the home page of its website which states that “NWRI scientific and technical staff publish their research in national and international scientific journals, technical publications, and in various report series” (NWRI website). Analysis of the publications lists indicates that in 2004 NWRI researchers authored 199 scientific publications in journals, books or conference proceedings and 10 technical notes or other government reports. These numbers were down from 1997 when NWRI researchers authored 271 scientific papers and 6 technical reports. These findings indicate a traditional research establishment

operating more in the informal network mode common to the academic scientific community, not the more hierarchy-based form expected in a government bureau.

There are other indications of the NWRI's close association with the broader scientific community. The *Water Quality Research Journal of Canada* receives support from the NWRI. NWRI scientists lead and serve on learned societies and national committees, sit on the editorial boards of top science journals, and have received prestigious national and international grants, awards and fellowships.

The final comment on the NWRI as hierarchy relates to human resources policies and processes. The NWRI is facing the same demographic pressures as other government institutions and is clearly concerned about workforce renewal. However, as an organization without separate hiring authority, the NWRI must comply with and operate within the core public service human resources systems. This is seen as a problem regarding effective human resources management.

IV. NWRI AS QUASI-MARKET

The next institutional design area to consider is how the NWRI behaves as a quasi-market or market-like organization. With its heavy "science for policy" emphasis, the NWRI exhibits very little commercial orientation and has limited interactions with the private sector. However, the NWRI and, in particular, the National Laboratory for Environmental Testing (NLET) do exhibit some business-like practices and these are examined in this section.

One of the emphases of the New Public Management has been for government organizations to adopt a more explicit focus on its clients to better understand and respond to their needs. As discussed, the existence and activities of the Science Liaison Branch is a clear indication that the NWRI pays close attention to its key clients in the policy-making arena. As a testing service provider, the NLET also exhibits a client-centred orientation. One example is its refinement of the methodology for acidic herbicides to improve sensitivity and selectivity at the request of the department's Prairie and Northern Region (NWRI 2001). The NLET produces a semiannual newsletter, *The NLETTER*, to provide updates to its clients on its activities and has developed and employs an electronic client survey to "allow clients to communicate their concerns" (Ibid., 4).

Another market-oriented reform that flows from NPM is the increased attention to accreditation. The NLET's laboratory operations are accredited by the Standards Council of Canada through the Canadian Association for Environmental Analytical Laboratories to the ISO 17025 standard which defines general requirements for the competence of testing and calibration laboratories. In addition, as a major collaborator with CAEAL in the provision of proficiency testing samples, NLET is also accredited by SCC to ISO Guide 58 equivalency (NWRI 2001).

The NLET makes significant use of cost recovery. Its two main functions, laboratory services and quality assurance, comprise approximately 80 percent and 20 percent of its activities, respectively. On the lab services side, approximately 20 percent

of this activity is cost recovered, primarily from other parts of Environment Canada. On the quality assurance side, cost recovery accounts for virtually all of this activity.

Certified Reference Materials are an essential quality assurance tool for assessing the accuracy and reliability of laboratory measurement processes. These are useful in applications such as multi-agency data comparability studies, evaluation of new methodologies, inter- and intra-laboratory quality control, analytical contract selection, and environmental research, monitoring and surveillance. The NLET produces CRMs using the ISO 30 standards for distribution to analytical laboratories, nationally and internationally, on a cost recovery basis.

The Research Support Branch supports the environmental technologies industry by supporting hydraulic laboratory studies for private sector companies seeking to develop new products or methodologies. Examples include support to companies involved in the development of water disinfectant technologies and to engineering consulting firms requiring physical hydraulic modelling of flow structures. These services are provided on a cost recovery basis.

The NWRI does not make extensive use of contracting out. Interestingly, this is in contrast with its early days when it let research and engineering contracts to university and industry specialists to undertake portions of the Centre's research program. The 1968 Annual Report highlights contracts to the Great Lakes Institute of the University of Toronto, the University of Waterloo, and a geo-engineering firm in Ottawa (CCIW 1968). An appendix listing let contracts existed in the Centre's annual reports from 1969 but was

dropped after 1973. More recently, the NLET tendered a contract to obtain analytical services from the Centre Saint Laurent in Montréal after it was determined that background levels of polychlorinated biphenyls in the air at the CCIW were adversely affecting data quality (NRWI 2001).

As a line unit of a federal department, the NWRI does not have an external governing board. It has, however, made use of an advisory board in the past. Interestingly, the Association of Universities and Colleges of Canada (AUCC), through the National Advisory Committee on Water Resources Research, was instrumental in the creation of the CCIW and in relaying the needs of the university community for space and facilities at the Centre. In the 1960s a broad-based Advisory Committee to the CCIW was created under the chairmanship of a Professor E. G. Pleva of the University of Western Ontario. The Advisory Committee was to consist of seven university members, six private sector members, and six federal or provincial government members but in fact had three, four, and seven members respectively from these communities.

The Advisory Committee's role was "to advise CCIW management on research priorities and programs, including the most effective allocation of space and facilities at the Centre for the university community" (CCIW 1969, 2). The AUCC had hoped that this Committee would become a permanent advisory committee to the Centre (DEMR 1967). However, references to the Advisory Committee in the Centre's annual reports were dropped after 1972. The NWRI does not make use of an independent board of advisors, although the NLET has a steering committee of departmental executives that

meets annually. In addition, the Institute's activities are within the purview of Environment Canada's departmental S&T advisory board.

Another area of business-oriented change in federal S&T is in policies and practices regarding intellectual property. Management responsibilities for intellectual property were assigned to science-based departments in the early 1990s. Since that time, some government laboratories have aggressively exploited their intellectual property through commercial licensing, creating significant revenues. The NWRI has not been very active in this area. The intellectual property of the Institute consists primarily of the scientific knowledge that it publishes in the open scientific literature. There have been some licensing agreements of sediment remediation techniques for the treatment of contaminated sites.

One final area of market-oriented activity to be examined is in the creation of spin-off companies. Some federal S&T institutions such as the National Research Council have experimented with their human resources and intellectual property policies and practices to enable, indeed encourage, employees to commercialize an idea or technology by leaving NRC and forming spin-off companies. The NWRI has not pursued such activity and, to date, no spin-off companies have been formed.

In summary, the NWRI has adopted some business-like practices including a more explicit client focus, an emphasis on accreditation, and the use of cost recovery for certain services. Overall, however, the degree of market orientation and business-like practices

at the NWRI is minimal. Much more evident is its network-based nature which is explored in the next section.

V. NWRI AS NETWORK

The NWRI is characterized by many informal network arrangements but also some more formal policy-induced networks, as discussed below.

Internally, the NWRI engages in networking across its hierarchy along disciplinary or multi-disciplinary project activity lines. One example of broader internal networking is the NLET's piloting of the Japanese Quality Circle concept. Under this approach, a group of ten employees representing different levels and units within the organization meet on a regular basis to discuss ways to improve operations at the Burlington location (NWRI 2007).

Again, as with the other case labs, the more interesting aspect of the NWRI's network characteristics are the partnerships and other collaborative relationships that it has with key external stakeholders and S&T institutions within Environment Canada, other federal departments, provincial and municipal governments, universities, industry, non-governmental organizations, and international actors. As has been discussed, the NWRI has historically been oriented towards and is closely linked with the broader academic scientific community. But more than the other labs studied, the NWRI's collaborative relationships are heavily geared towards government organizations, at all

levels of government both domestic and international. Interactions with the private sector and NGOs are much less common.

Networking within Government: Departmental, Federal, Provincial and Municipal

With the possible exception of its partnering with academic institutions, the NWRI's most extensive networking occurs within government, including networking within its parent department, with other federal departments and agencies, with provincial governments and with municipal governments. Its role in these networks varies from lead partner to peripheral contributor.

At the departmental level, the NWRI often collaborates with the Canadian Wildlife Service (CWS) and the Meteorological Service of Canada (MSC), as well as with the department's various regional offices. For example, the NWRI has partnered with MSC researchers in a study of mercury in runoff water from forest fire areas and in high arctic snows. And it has partnered with the CWS and the Canadian Cooperative Wildlife Health Centre, an organization encompassing Canada's veterinary colleges, on assays for detecting wildlife pathogens.

More significant, at least as indicated by its public documentation, is NWRI's networking with the broader federal S&T family, including Agriculture and Agri-Food Canada, Department of Fisheries and Oceans, Health Canada, Parks Canada, and Natural Resources Canada (particularly the Canadian Forest Service and the Geological Survey of Canada), but also Canadian Heritage, Indian and Northern Affairs Canada, the National

Research Council (particularly the Biotechnology Research Institute and the Canadian Hydraulics Centre), and the Canadian Space Agency. As part of the federal government's horizontal Northern Contaminants Program, NWRI collaborated with the Department of Fisheries and Oceans, Health Canada, and other parts of Environment Canada, as well as the Universities of Guelph and Trent, to conduct multi-year studies on the presence and impact of brominated flame retardants in the Canadian Arctic. NWRI and Health Canada have collaborated on a survey of 20 southern Ontario drinking water facilities investigating the presence of acidic pharmaceuticals in the water supply. And NWRI led a collaboration of four other federal departments to produce a national science assessment in 2001 of the environmental impact of nutrients derived from human activity, such as nitrogen and phosphorous. Building on these foundations, the NWRI is leading an initiative to bring federal departments together in a Federal Water Research Network to enhance collaborative research.

The NWRI also exhibits links to provincial government agencies, particularly in Ontario but also in Alberta, British Columbia, New Brunswick, and Saskatchewan. This is due in part to its participation in activities of the Canadian Council of Ministers of the Environment (CCME). The CCME is the forum for facilitating federal, provincial and territorial collaboration on national environmental priorities. The NWRI has supported a federal-provincial water quality monitoring network in British Columbia. Closer to home, the NWRI was part of a broad-based collaboration that included the Ontario Ministries of Environment and Natural Resources in the Turkey Lakes Watershed Study

to assess regional aquatic effects of acid rain. In the area of watershed management, the NWRI has partnered with the Niagara Peninsula Conservation Authority which coordinates the implementation of the Niagara River Remedial Action Plan through a partnership agreement with the Ontario Ministry of the Environment and Environment Canada. And in another example of a multi-level partnership, NWRI collaborated with Indian and Northern Affairs Canada, Environment Canada's Prairie and Northern Region, the Alberta Environmental Protection Agency, and Simon Fraser University to study the impacts of climate on changing hydrology and ecology of western and northern rivers and deltas.

At the municipal government level, the NWRI has worked directly with at least 11 Canadian municipalities and with the Metropolitan Water District of Southern California. In 1999, NWRI joined seven major municipalities, the Ontario provincial government (specifically the Ontario Clean Water Agency and the Ontario Ministry of the Environment), and two university partners to form the Ontario Water Works Research Consortium. This cooperative group, a unique model in Canada, was established to address water taste and odour problems in Lake Ontario and the St. Lawrence River. In another project, the NWRI and the Wastewater Technology Centre partnered with the cities of Toronto, Niagara Falls, Welland, and Windsor, the Ontario Ministry of the Environment, and Queen's University to study stormwater management and advanced treatment of combined sewer overflows.

Networking with Academe

Networking with academic institutions is extensive at the NWRI. Partnerships have involved research relationships with some 22 Canadian universities. Among these, the following universities stand out as frequent partners: Calgary, Guelph, McMaster, Saskatchewan, Toronto, and Waterloo. The nature of this networking ranges from collaboration on individual research projects, such as a recent Trent University/NWRI study of pharmaceuticals in the sewage treatment plant effluents of fourteen Canadian cities, to more formalized arrangements such as the partnership with the University of Victoria to create the Water and Climate Impacts Research Centre. Other examples include:

- The Ecosystem Health division of the Aquatic Ecosystems Protection Research Branch has collaborated with the Canadian Network of Toxicology Centres, a formal network of university-based toxicology research centres funded by Environment Canada, to study the impacts of pulp mill effluents and develop sublethal indicators of endocrine impairment.
- The NWRI is a key participant in the Canadian Water Network, a federally-funded Network of Centres of Excellence. The extensive Network counts 55 universities, 32 industries, and over 100 government departments and agencies as partners. NWRI staff have sat on the Network's scientific committees and one manager sat on the governing board in 2005.

- The Canadian Rivers Institute (CRI) was founded in 2000 at the University of New Brunswick to build a network of researchers from across universities, governments, and industry with interests in river science. In 2001 the CRI developed cooperative research agreements with the NWRI and the department's Atlantic Region. In 2002, the NWRI expanded its agreement and relocated four staff members, including the Chief, of the Cumulative Impacts on Aquatic Biodiversity division of the Impacts Research Branch to the CRI.

In addition to these domestic network arrangements, NWRI frequently collaborates on research projects with foreign academic institutions, particularly in the United States. Some of these institutions, such as Miami University (Ohio), Wayne State University (Ohio), Northwestern University (Illinois), and the State University of New York are located in bordering Great Lakes states. But the NWRI has also partnered with Louisiana State University, Texas A&M University, and the University of North Carolina. International academic partners have also included the universities of Amsterdam, Exeter, Lund (Sweden), Wales, the United Nations University and the Technical Universities of Berlin, Hamburg, and Munich.

Many NWRI scientists hold adjunct professorships at Canadian universities and have mentored hundreds of graduate students. These activities are viewed by senior managers as essential not only for the NWRI to deliver on its mandates but also to maintain access to new highly qualified personnel.

Networking with Non-Government Organizations

Network links involving non-governmental organizations (NGOs) are not extensive at NWRI but some exist. Examples include:

- The NWRI has partnered with Ducks Unlimited Canada and university researchers on wetlands research in prairie agro-ecosystems.
- The St. Lawrence River Institute of Environmental Sciences, a non-governmental research centre located in Cornwall, Ontario, was involved in the research project on taste and odour compounds in Lake Ontario and the upper St. Lawrence River that were affecting the quality of drinking water.
- As discussed, the NLET works closely with the CAEAL in its accreditation processes.

In general, however, it is clear that the NWRI does not engage in much networking with NGOs.

Networking with Business and Industry

Given its largely public science and environmental conservation mandates, it is perhaps not surprising that the NWRI is not heavily involved in research collaborations with the private sector. In fact, one interview began with the interviewee directing my attention out his office window to the steel plants (Stelco and Defasco) situated across Hamilton Harbour and referring to them with tongue-in-cheek as “the enemy.”

Nonetheless, the NWRI does engage in some collaborations with the private sector. Companies that it has partnered with in recent years include Novacor, Suncor, and Synrude, Geosyntec Consultants, Komex International Ltd., Redlog Environmental Ltd., China Harbour Inc., and Weyerhaeuser Canada. Most of the networking with private sector actors is in the context of broader partnerships on research projects. An example is the project with the Canadian Rivers Institute, Weyerhaeuser Canada and the City of Grande Prairie, Alberta, to investigate the impacts of multiple and complex effluent discharges on the biota of the Wapiti River.

The NWRI has also partnered on occasion with industrial associations.

Researchers in the Aquatic Ecosystem Protection Research Branch partnered with the Lambton Industrial Society to study the estrogenic potencies of effluents from petroleum refineries and petrochemical industries. The Society (now the Sarnia-Lambton Environmental Association) is a non-profit association of fourteen industries in the Sarnia-Lambton region that partner to assess and promote environmental control measures, particularly with respect to the St. Clair River.

In another example, the Protection Branch partnered with the Silicones Environmental, Health and Safety Council of North America, a not-for-profit trade association comprised of silicone chemical producers, to research the occurrence of volatile methylsiloxanes in sewage and sludge. And after an informal relationship with the pulp and paper industry over the last two decades, the Branch now has a more formal relationship with PAPRICAN (now part of FPInnovations) to develop analytical methods.

In addition, as discussed in the previous section, the NWRI can and does provide analytical and research support services to the private sector on a cost recovery basis.

North American/International Networking

International networking is also quite evident at the NWRI and is of two types. The first form of international networking is the lab's collaborative relationships with foreign research bodies. The second form of international networking relates to the more formal and strategic level of bi-lateral and multi-lateral treaty obligations and relationships to address complex transboundary issues.

Not surprisingly, given the transboundary nature of much of its research, the NWRI is heavily involved in collaborations with U.S. federal government agencies, including the U.S. Army, the Environmental Protection Agency, the U.S. Geological Survey, the National Institute of Standards and Technology, and the National Oceanic and Atmospheric Administration. It has also worked with U.S. state government departments of natural resources of border states including Michigan and Wisconsin.

One major collaborative program with the U.S. is the bi-national Integrated Atmospheric Deposition Network (IADN). The IADN is a joint monitoring and research program created as a result of Annex 15 of the *Great Lakes Water Quality Agreement*. The goals of Annex 15 are "to identify airborne toxic chemicals, their sources and fate and to define the spatial and temporal trends of atmospheric deposition to the Great Lakes and its basin" (NWRI 2002, 1).

Another example of collaboration with the U.S. is the Souris River Bilateral Water Quality Monitoring Group. The Group was established in 1989 under the *Canada-US Agreement for Water Supply and Flood Control* in the Souris River Basin. The Agreement was developed to encourage cooperation amongst the Group on issues of common interest and enabled the exchange of funds, reporting procedures, compensation, and dispute resolution measures. The Monitoring Group prepares annual reports on the water quality of the Souris River and provides recommendations to governments regarding the monitoring program and the development of water quality objectives at the two boundary crossings of the Souris River. The NWRI's National Laboratory for Environmental Testing contributes to the program by producing quality assured inorganic and organic data used for water quality assessment and early identification of unusual water quality conditions (NWRI 2005).

In another example of Canada/U.S. collaboration, university and NWRI researchers and several partners including the Department of Fisheries and Oceans, the U.S. Environmental Protection Agency, and the U.S. National Oceanic and Atmospheric Administration continue to investigate the impacts of alien invasive species such as zebra mussels on Great Lakes' ecosystems. The U.S. Fish and Wildlife Service has estimated the potential economic impact of the zebra mussel invasion to be \$5 billion over ten years (Brannen et al 2005). The NLET has collaborated with the National Water Quality Laboratory of the U.S. Geological Survey for many years and this relationship is viewed as "mutually beneficial" (NWRI 2005).

Further afield, the NWRI has had research collaborations with European institutes, particularly in Germany—the ESWE Institute for Water Research, the GKSS Institute, the Institute for Freshwater and Inland Fisheries in Berlin, and the Max Planck Institute in Jena, Germany—but also with the Norwegian Institute for Water Research, the Swedish Marine Fisheries Service, and the Swiss Federal Institute of Technology. In the developing world, the NWRI has collaborated with the Kawanda Agriculture Research Institute of Uganda, and with the National Institute of Hydrology and National Geophysical Research Institute of India in a project studying the application of environmental models to coastal watersheds. Beyond purely research collaboration, the NLET engages in technical collaboration and cross-training with similar institutes in other countries including Argentina, Australia, Brazil, China, India, Korea, New Zealand and Pakistan. For example, it recently provided training to a delegation from the Central Pollution Control Board of India.

The NWRI is also very active in the United Nations and related international organizations. NWRI research led to the development of the International Maritime Organization proposal to ban the application of organotin antifouling paints. NWRI contributes to the UN Economic Commission for Europe’s Task Force on Persistent Organic Pollutants (POPs) and it played an essential role in shaping the UN POPs Convention (the Stockholm Convention) in 2001 which seeks to reduce or eliminate emissions of these hazardous chemicals.

As indicated, NWRI manages the UNEP GEMS Water Program Office on behalf of Canada. This unit partners with the UNEP Division of Early Warning and Assessment in Nairobi, Kenya, the World Meteorological Organization, the World Health Organization, the Global Program of Action for the Protection of the Marine Environment from Land-based Activities centred in The Hague, and many other international programs. In addition, NWRI contributes its expertise and leadership to various international activities such as the Arctic Monitoring and Assessment Program, the Intergovernmental Panel on Climate Change, the UNESCO International Hydrology Program, the UNESCO Intergovernmental Oceanographic Commission, the NATO Science for Peace Program, NATO Advanced Workshops, and the OECD Expert Group on Endocrine Disruptors.

Table 6-1. Overview of NWRI as Hierarchy, Quasi-Market and Network

Hierarchy	Quasi-Market	Network
<ul style="list-style-type: none"> - large structure of 9 units with complementary mandates - 2 units accreted in last decade - 2 divisions operate remotely - policy, management, and regulatory roles - vertical reporting to ADM ECS - departmentally-oriented communications in technical reports and policy audience products - unit dedicated to science/policy interface - Program Review cuts reported - A-base reported to be overwhelming share of budget - more procedural bureaucracy/reporting with increased use of policy funds - workforce renewal seen as major challenge - significant/unique capital assets (vessels, hydraulics lab); some capital reinvestment but a growing concern 	<ul style="list-style-type: none"> - very limited commercial orientation - limited links to private sector through joint research projects - extensive use of cost recovery but limited non-governmental revenues - no board of directors/advisors - very limited use of contracting - less use of on-site contractors - modest IP activity and revenues - no spin-off companies - increasing client-focus - no pubic business plans or annual reports; - extensive lab certification and quality assessment processes 	<ul style="list-style-type: none"> - pervasive links to academe - many staff serve as adjuncts - graduate students on-site - external peer review not institutionalized - academic-oriented communications in scientific journals - 1 division at UVic, 1 at UNB - some industry/business links - limited links with NGOs - pervasive links with regional offices, other federal departments, provincial governments and municipal governments - extensive foreign collaboration & participation in inter-governmental activities; strong ties with U.S. on Great Lakes work; home to UN GEMS Water Program office

VI. KEY PROBLEMS AND CHALLENGES

The previous sections have described the NWRI's institutional characteristics as hierarchy, quasi-market and network and these have been summarized in Table 6-1. Here I summarize some of the key problems and challenges facing the Institute. Many of these are related to the institutional types examined above and the tensions among them.

The most critical problems and challenges facing the NWRI, as expressed by those interviewed, are related to keeping the organization robust and current with the state of the art. This seems to have two dimensions. The first dimension relates to renewal of the Institute's aging workforce. This problem was couched variously as the need for more junior researchers and technicians, the need for transition planning, the lack of

hiring over the case study period, etc. Regardless of how it was characterized, the issue was raised in each of the interviews.

The NWRI competes to some extent with the academic sector and with other government laboratories for critical talent. One interviewee admitted that programs such as the Networks of Centres of Excellence and the Canada Research Chairs “hurt us” as the NWRI lost one researcher to the Canadian Water Network. In addition, the NWRI finds it difficult to find hydrologists given competition from the United States. The NWRI is experimenting with alternative approaches to accessing capacity including co-location of staff at universities. While this was not done solely with workforce renewal considerations in mind, the approach does increase interactions with graduate students that may generate more interest in careers at the lab.

The second dimension deals with the related challenge of maintaining the organization’s ability to deal effectively with newly emerging issues and evolving technologies. The NWRI must respond to the existing issues of concern to Environment Canada but also seeks to be pro-active in identifying new challenges. This helps maintain the interest level and productivity of the scientists but also creates ongoing pressures as new mandates get added but are rarely eliminated.

In terms of evolving technologies, nanotechnology was highlighted as an area where the NWRI envisions future work. Challenges will come both in terms of the new analytical approaches that nanotechnologies will enable and require but also the potential for new environmental problems and adverse impacts that they may generate. A key

challenge for the NWRI is being able to keep abreast of ongoing developments in a fast-moving area where it does not have much or any capacity. This dimension seems to highlight Doern's observation that responsive "science on demand" may be crowding out the more anticipatory "patient science" at Environment Canada (Doern 2000). The NWRI's extensive networking is viewed as an effective means to address lack of capacity.

Another problem is renewal of the NWRI capital infrastructure, a problem it has in common with many government laboratories. There was some indication among interviewees that the government's choice to invest heavily in university research infrastructure since 1997, while probably necessary and appropriate, has meant an eroding capital base for the government's science infrastructure. There has been some opportunistic capital reinvestment but this remains a challenge area for the NWRI.

VII. CONCLUSIONS

Employing the basic hierarchies, networks and quasi-markets typology as an organizing and analytical concept, this chapter has sought to understand the NWRI and how it has changed as a government laboratory. Federal S&T policy towards government laboratories will not fully succeed if government laboratories such as the NWRI are not understood as institutions and if the institutional diversity across labs is not better understood and reflected in such policies. The hierarchies, networks, and quasi-markets

framework helps us better understand what goes on inside the various government laboratory “black boxes.”

The chapter has shown that the NWRI does exhibit many of the hierarchical characteristics common to a public institution. It consists of 9 divisions organized along classic hierarchical lines that correspond to different but complementary aspects of its mandate. Communications and relationships with the parent department are largely vertical through the chain-of-command, although researchers are increasingly participating on departmental committees. In addition, the NWRI has a dedicated unit for communicating its results across the science / policy interface and to stakeholders. The NWRI continues to rely heavily on its A-base for funding and looks primarily to government for resolving its human resource and capital infrastructure challenges.

Given its public goods science mission, there is very little market orientation at NWRI. In terms of business-like practices, these are also relatively minimal at the NWRI, although the National Laboratory for Environmental Testing does exhibit a strong client orientation, delivers services on a cost recovery basis, and makes use of an advisory board. The NWRI does not make much use of on-site or off-site contractors. It occasionally employs cost recovery approaches to service delivery. Intellectual property activity is largely based on scientific publications and is not revenue generating. No spin-off companies have been created from the NWRI.

The NWRI is extensively networked, mainly on an informal basis but also through formal policy-induced networks such as those funded through Canada’s Networks of

Centres of Excellence. It networks particularly with partner organizations in other federal, provincial and municipal government departments, with academe, and with international organizations. The NWRI often serves in a lead position within these networks and serves as the Program Office for the UN GEMS Water Program. Networks involving businesses and non-governmental organizations are much less common.

This chapter has also examined how the National Water Research Institute has changed as a federal S&T institution. I have not sought to evaluate the Institute's substantive S&T activities, contributions and performance. But I have explored the institutional nature of the NWRI and how it has responded to changing policies at the federal and departmental level and to changes in the underlying dynamics of its mission in water science and environmental research.

As with the other case labs, the NWRI has had to deal with the problem of an aging workforce and infrastructure, and uncertain budgets. Its lack of alternative revenue streams makes it highly reliant on its direct funding although it has also made use of various interdepartmental program funds to supplement core funding. The NWRI has been very active in adopting networking and partnership approaches to deliver its mandate.

The NWRI has dealt with changes in departmental policies and emphases (e.g., reducing contractual employment) and changes brought about through restructuring and the accretion of the NHRC and the NLET. These changes expanded its historical focus on basic and applied research in water quality and pollution in the Great Lakes to a more

national and even global mandate including research, monitoring, testing, accreditation, and science policy. It has also had to contend with potentially adverse changes in federal S&T policy in which the roles and organizational health of government laboratories were not key concerns. In particular, the gradual shift from *science policy* to *innovation policy*, with a greater emphasis on commercialization and economic development roles of government S&T, has not been to the advantage of the NWRI that largely lacks an economic support role.

From local cleanup of Hamilton Harbour to global monitoring of water quality, the NWRI has become a world leading centre for freshwater research. As Brannen et al (2005, 9) conclude:

NWRI has made major contributions to restoration of the Great Lakes, reductions in acid rain, regulation of toxic substances, creation of international atmospheric conventions, and has helped shape environmental management of Canadian freshwater resources, from the smallest stream to the largest watershed in Canada.

Although the NWRI has changed and continues to change as an S&T institution it represents a classic mission-oriented government laboratory dedicated to supplying public goods science.

CHAPTER 7

CASE ANALYSIS AND THE UTILITY OF A COMPLEMENTARY INSTITUTIONAL DESIGN SPACE TYPOLOGY

This chapter analyses the three case study laboratories overall using first the basic hierarchies, quasi-markets and networks typology that guided the previous three case study chapters. This includes a summary concluding view of the utility and limitations of this first part of my two-part analytical framework, based not only on some of the quandaries initially previewed and anticipated in the Chapter 2 discussion of the conceptual issues inherent in this framework but also the empirical evidence of the case studies. The broader Canadian history of science, science policy, and Environment Canada science and policy from Chapter 3 also enters this summary analysis.

Based on this summary, the chapter then provides more detail on the development and application of the second part of the study's analytical framework, the institutional design space typology. As previewed in Chapter 2, this institutional design space framework is presented as a needed and useful complementary analytical extension to draw out conceptually, descriptively and to some extent normatively the more complex ranges and types of institutional design, particularly regarding types of networks. In addition, by shifting from a discreet-category world to a multi-dimensional space, the

design space approach not only allows the analyst to better capture the complex institutional reality as evidenced in the case labs but it also enables the analyst to better consider the relationship between the multiple mandates and the mix of institutional forms that exist in government laboratories.

In light of the above, the chapter presents the study's findings and contributions in response to the three key research questions, posed in the Introduction, namely:

1. How have the institutional designs of government laboratories been reconfigured during the period 1990-2005?
2. What are the laboratories' mandates and how do these reconfigurations affect the labs' abilities to fulfill their mandates? and
3. How might Canadian science policy analysis better take account of the importance, diversity and complexity of government laboratories?

The first section responds to questions 1 and 2 by summarizing and analyzing the initial results of the case studies comparison. The second and third sections attempt to tackle question 3 by further developing the complementary institutional design space typology and then suggesting how it could be applied in the Canadian context.

I. ANALYSIS OF CASE STUDY RESULTS: HIERARCHIES, QUASI-MARKETS AND NETWORKS

In this section I analyse the results of the case studies across the three laboratories. This analysis provides a partial response to the research questions by discussing the mandates and institutional mix of Canada's federal laboratories and their evolution. Table 7-1 provides a summary profile of the three case study labs using the hierarchies, quasi-markets, and networks framework.

Mandates

With respect to the case laboratories in this study, the mandates and functions are to a large degree focussed on S&T in support of public policy, regulation and the provision of public goods and services, roles which are derived vertically from the legislated mandates of the parent department. This is perhaps not surprising given the choice of Environment Canada as the parent department for all three case labs. Nonetheless, some variation across the three labs is evident.

Of the three case labs, the Environmental Technology Centre has the most explicit element of market-orientation in its mandate given its explicit mandate to support industry. Even at ETC, however, this element is set within a broader context of supporting the environmental protection mandates of Environment Canada. This dual-nature created tensions that were quite evident at the lab.

The mandates of the National Water Research Institute and the Meteorological Service of Canada lab are more exclusively public-oriented as they concentrate on supporting key regulatory roles and public services such as weather forecasting. Nonetheless, in both cases the labs are increasingly responding to horizontal, whole-of-government policy challenges around water, climate change and sustainable development and engaging in multi-departmental and broader network-based approaches to delivery of their mandates.

Table 7-1. Summary of Labs as Hierarchies, Quasi-Markets and Networks

	Environmental Technology Centre	Atmospheric and Climate Sciences Directorate	National Water Research Institute
Hierarchy	<ul style="list-style-type: none"> - accreted structure of 6 units with multiple, distinct mandates - 1 unit shed via ASD approach - regulatory and emergencies roles, but also industry support - vertical reporting to ADM EPS - review largely internal - EC-oriented communications and technical reports - no unit dedicated to science / policy interface - major Program Review cuts to A-base, less in staff (no involuntary departures) - A-base only 67% of total budget - increasing bureaucracy with increased use of policy funds - public HR policies seen as barrier - modest capital holdings, unique facilities; opportunistic capital reinvestment but growing concern 	<ul style="list-style-type: none"> - large structure of 5 units with complementary mandates - 1 unit added in last decade - 1 division operates remotely - meteorological operations support and policy advice roles - vertical reporting to ADM MSC - EC-oriented communications and assessment reports - unit dedicated to science / policy interface - major Program Review cuts to A-base and staff (some involuntary departures) - A-base is 78% of total budget - increasing bureaucracy with increased use of policy funds - public HR policies seen as barrier - modest capital holdings; some Green Plan capital reinvestment but loss of Eureka station 	<ul style="list-style-type: none"> - large structure of 9 units with complementary mandates - 2 units accreted in last decade - 2 divisions operate remotely - policy, management, and regulatory roles - vertical reporting to ADM ECS - EC-oriented communications, technical reports and policy products - unit dedicated to science / policy interface - Program Review cuts reported - A-base reported to be overwhelming share of budget - increasing bureaucracy with increased use of policy funds - workforce renewal seen as major challenge - significant capital including unique assets; some capital reinvestment but a growing concern
Quasi-Market	<ul style="list-style-type: none"> - greater commercial orientation; explicit industrial support mandate - privatized emergencies engineering operation - revenue targets not central but earns large external revenues - no board of directors/advisors - extensive use of on-site contractors and increased use of term appointments - moderate IP activity and revenues - no spin-off companies - focussed on clients - produces 3-year business plans and biennial reports - extensive lab certification and quality assessment processes 	<ul style="list-style-type: none"> - limited commercial orientation - some links to weather services and wind energy industries - limited non-federal revenues - no board of directors/advisors - very limited use of contracting - increased use of term appointments - modest IP activity and revenues - no spin-off companies - increasing client-focus - no public business plans or annual reports; has produced a retrospective performance report - lab certification and quality assessment processes 	<ul style="list-style-type: none"> - very limited commercial orientation - limited links to private sector through joint research projects - extensive use of cost recovery but limited non-governmental revenues - no board of directors/advisors - very limited use of contracting or on-site contractors - modest IP activity and revenues - no spin-off companies - increasing client-focus - no public business plans or annual reports; - extensive lab certification and quality assessment processes
Network	<ul style="list-style-type: none"> - academic links not central but growing, including journal publications - some staff serve as adjuncts - some graduate students on-site - external peer review not institutionalized - extensive links to business through joint research and demonstration projects - virtually no links with NGOs - wide variety of links with regional offices, other federal departments and provincial governments - international networks growing through OECD, CIDA-funded work; many MOUs in place particularly with U.S. agencies 	<ul style="list-style-type: none"> - pervasive links to academe - one division located at University of Victoria - many staff serve as adjuncts - graduate students on-site - journal publications important - external peer review, but not institutionalized - few industry/business links - limited links with NGOs - significant links with regional offices, provincial governments and other federal departments - extensive international collaborations and participation in intergovernmental activities; strong ties with U.S. and U.K. 	<ul style="list-style-type: none"> - pervasive links to academe - 1 division at UVic, 1 at UNB - many staff serve as adjuncts - graduate students on-site - journal publications important - external peer review not institutionalized - some industry/business links - limited links with NGOs - pervasive links with regional offices, other federal departments, provincial and municipal governments - extensive foreign collaboration & inter-governmental activities; strong ties with U.S. on Great Lakes work; home to UN GEMS Water Program

Labs as Hierarchies

The first aspect of the institutional designs of the three laboratories examined was the extent to which they are structured and operate along classic bureaucratic hierarchical lines, as well as how they function within the hierarchies of their parent department and the broader federal government. As government establishments it is not surprising to find that the laboratories exhibit characteristics of hierarchy to a high degree.

As departmental units all of the labs continue to have their primary accountability channelled vertically through the departmental chain-of-command, consistent with traditional hierarchies and unlike the more arms-length arrangements of some other federal S&T institutions. The labs are all managed within Environment Canada's structure of four business lines which align the department's operations to the federal government's priorities and initiatives. As indicated in Chapter 3, the four business lines are 1) Nature, 2) Clean Environment, 3) Weather and Environmental Predictions, and 4) Management, Administration and Policy. The labs must also be responsive to various government-wide policies, international treaties, and, in some cases, federal/provincial jurisdictional considerations.

Reporting on progress against the goals of the departmental business lines is achieved primarily through internal communications. The ACSD and NWRI as organizations do not produce annual reports that are publicly available. For many years, the ETC produced biennial reports that are publicly available but seems to have discontinued the series. On the other hand, the NWRI is notable in the degree to which it

produces communications products for public and policy maker consumption, and the ACSD has produced a retrospective report of accomplishments.

The laboratories are situated within the Environment Canada hierarchy and most of the interaction with the department flows through the labs' senior management. This facilitates accountability but may interfere with more horizontal approaches to communications across the department. Both NWRI and the ACSD have dedicated units to facilitating the communication of the labs' science for policy stakeholders.

As with any traditional government bureau, it can be expected that a high proportion of the laboratories' funding would derive from its annual direct taxpayer-paid appropriation (A-base). As we have seen, however, there is considerable variation in the sources of funding across the labs and all have seen declines in the proportion of their budgets coming from A-base. Of the three, the NWRI seems to be most reliant on its direct appropriations although the lack of official budget data from this lab makes this observation tentative. This is in sharp contrast to the situation faced by the ETC where less than two-thirds of its total budget comes from A-base funding. Since the mid-1990s, the ETC and to a lesser extent the ACSD and NWRI have become more dependent on non-A-based funding. However, a key difference here is that the ACSD's and NWRI's external funding is primarily from other federal government sources, including interdepartmental policy or program funds, while ETC attracts significant revenues from sources external to government.

As the conceptual discussion in Chapter 2 suggested, this reality is not well-captured by the basic three-category framework in that there are boundary issues empirically in institutional characteristics such as source of funding that may be partly hierarchy-based and, in this instance, partly quasi-market- or network-based. Indeed, as also noted earlier, all three labs are relying to a greater extent than in the past on funding from horizontal policy funds; some of these horizontal funding initiatives were intended to foster or require formal network formation internally among government labs and with outside funders/performers as well.

As part of the broader Government of Canada hierarchy, the labs were all subject to the Program Review of the mid-1990s. The subsequent cuts to budgets and personnel had major impacts on all of the labs although, interestingly, as the case studies show, the labs made different tradeoffs between cuts to staff and operating budgets. The ACSD experienced cuts of approximately 35 percent in its budget and some downsizing in staff, including some involuntary departures. At the ETC, the budget took a greater hit of 44 percent cuts to the A-base while staff declined by only 7 percent and there were no involuntary departures. No aggregate data from the NWRI was available.

Another aspect of the labs as hierarchies within the broader public service centres on human resources policies and processes. In order to continue to provide its clients with cutting edge science and science advice, a hierarchical organization must continually renew the knowledge embodied in its human capital. All of the labs studied face the problem of an aging workforce and view the renewal of human resources as a major

concern. But whereas some government laboratories have been granted greater independence and flexibility with respect to recruitment and retention practices (a quasi-market or network indicator), the three case labs must comply with and operate within the public service human resources system (a hierarchy indicator). This is often seen as a barrier to effective human resources management.

For example, research indicates that it takes an average of 230 days to complete a new permanent hire competition in the public service (Council of Science and Technology Advisors 2002). In a competitive labour market in which knowledge workers are in high demand, such bureaucratic hurdles – often even more than the lack of salary dollars – can make it very difficult for government laboratories to attract the best and brightest researchers. In such an environment, the labs have all made use, to varying degrees, of what flexibilities they do have available to them, including the use of short-term appointments and students. The ETC also makes extensive use of on-site contractors. But, as we have seen, there are also very real constraints on the extent to which these alternative or complementary devices can be used.

While the above discussion relates some problematical features of the labs as hierarchies, it is also important to note that, normatively, hierarchy is also associated with the positive value of accountable, democratically-elected government. Thus, some of the same measures discussed above bear witness to the value and staying power of hierarchy in the institutional makeup of the labs.

Labs as Quasi-Markets

The second institutional design consideration relates to how the labs have evolved to become more quasi-market or market-like. My amended framework did not use the simple notion of markets as in some of the literature reviewed in Chapter 1 because it is evident that Canadian government labs are generally government owned and operated. Two related aspects of market-like behaviour were explored. First, the case studies examined the extent to which the labs exhibit a partial or explicit commercial orientation in their mandates, funding, and products. Second, the cases examined the extent of the labs' use of business-like practices such as boards of directors/advisors, the use of cost recovery, contracting, and other business practices, greater attention to intellectual property regimes and revenues, and the creation of spin-off companies.

The labs vary in their degree of quasi-market orientation and in the extent of their links with the private sector. The ETC, as a "technology centre," has an explicit mandate to support its relevant industries and the lab exhibits deep links with industrial clients. On the other hand, consistent with their public goods and regulatory science mandates, the ACSD and the NWRI have virtually no market orientation and links with the private sector are minimal.

In the past, as Chapter 3 has shown, government labs have been charged with the criticism that they operated as "universities without students." Whether or not this was a fair characterization, government labs have had to change their cultures and discipline-based forms of organization to become more clearly client-focussed, cross-sectoral or

horizontal, and project-based. Not surprisingly, there appears to be some correlation between the degree of quasi-market orientation in its mandate and the extent a lab employs business-like practices.

The ETC brings in about a third of its overall budget from external sources and employs many business-like practices. The lab is experimenting with an alternative service delivery approach by privatizing its emergencies engineering unit. Under the arrangement, the contractor undertakes research studies and provides technical services through work orders and at least matches the \$600,000 per year it receives from the ETC.

None of the labs employ corporate-style boards of directors such as those that exist at some other government laboratories. Nor do they have lab-level external advisory boards to provide strategic advice on the lab's overall priorities and operations. The three labs employ various mechanisms including ad hoc peer review panels, participation on working groups, and client surveys to obtain external feedback and advice on their programs. Also, all of the labs fall under the potential purview of Environment Canada's external S&T advisory board, although none of them have been reviewed by the board. These examples show, as expected, that some kinds of evidence of quasi-market behaviour and activities (e.g., seeking client input and feedback through peer review panels and participation in working groups) could also be cast as forms of networking.

Increased attention to policies and practices regarding intellectual property (IP) are another area of quasi-market institutional reconfiguration and change. Responsibility for IP management was decentralized to science-based departments in the early 1990s and IP

issues and revenues are becoming increasingly important. Though propelled by a central policy desire to see greater use of IP as a revenue source and an indicator of commercial relevance and innovation, the decision to decentralize IP management has provided a more discretionary tool in the hands of each lab, further increasing the observed diversity of the government labs.

The ETC has had considerable success in the commercialization of IP, bringing in an estimated \$2 million in revenues to date. The ACSD and the NWRI have not been very active in the commercial licensing of intellectual property although it is the source of some additional revenues.

Another potential market-like behaviour is the entrepreneurial creation of spin-off companies. As noted in previous chapters, some federal S&T institutions such as the National Research Council are experimenting with human resources and intellectual property policies to encourage and enable employees to form spin-off firms in order to commercialize an idea or technology. The evidence from the three case studies is clear. None of the labs studied have created any spin-off firms, although the MAP Division at the ETC has been considered for spin-off.

Other quasi-market institutional features include the use of cost recovery, fee for service and contracting approaches. The NWRI, through its NLET and Research Support Branches, makes extensive use of cost recovery. The labs varied in their use of contracting for human resources. For example, approximately a third of the total ETC workforce are contract employees. The NWRI used to make use of on-site contractors

but has made a deliberate move away from this practice following some liability concerns. The ACSD does not make much use of contract personnel.

A final indicator of a more business-like ethos at all three labs is the move toward lab certification by mixed public-private certification authorities. The analytical laboratories seek ISO accreditation through the Standards Council of Canada and the Canadian Association for Environmental Analytical Laboratories. The ETC and the NWRI have additional responsibilities of promoting good laboratory practices and quality assurance monitoring.

As discussed and anticipated in the Chapter 2 account of both the framework and the methodology, some of the above quasi-market features exhibit boundary problems with related features of the New Public Management and hence with hierarchy and network features. Nonetheless, there is reasonable evidence of the presence of quasi-market features among the labs, albeit to varying degrees.

Labs as Networks

Emerging from the network thinking of recent years is the belief that the benefits of the national science and innovation system emerge “not only from more R&D but from strong partnerships, networks and linkages” that facilitate information flows, knowledge transfer, research collaboration and the training and mobility of highly qualified personnel (de la Mothe 2000, 34). It is accepted that, in many cases, public science is best advanced not through the federal intramural laboratories or university laboratories working in

isolation but through linkages among them and with other research performers (although, as discussed in Chapter 1, more research is needed within the “systems” stream to understand the nature and impacts of the linkages among the system components, including government laboratories).

Similarly, the older conception of “technology transfer”—which often seemed to suggest that government laboratories had technologies sitting on their shelves just waiting to be commercialized—is giving way to much more pro-active and interactive public-private partnerships to foster knowledge mobilization and commercialization (Ham and Mowery 1997 and 1995). The nature and extent of these partnerships, and the policies that foster them, need to be better understood.

As stressed in earlier chapters, the notion of labs as networks refers to both formal networks as induced or required by policy and policy makers and as informal networks more inherent in the nature of science but also a key element of most complex organizations. Whether cast as networks or under the rubric of partnerships, linkages and the like, the labs have been under pressure over the last two decades to engage in more horizontal relationships and collaboration. Internally, the labs engage in informal networking based on discipline, cross-discipline or horizontal project-based research or RSA activity as personnel in different parts of the organization interact with one another for mutual benefit. More formal internal networking also occurs, as the case studies have shown, where labs operate with formal multi-disciplinary teams that vary over more

extended periods of time depending on the needs of a project, or as advances in science and technology both enable and require greater coordination of expertise across the lab.

But the more important notion of networks in the current era centres on what kinds of formal networks, partnerships and other related horizontal relationships are fostered with key external stakeholders and S&T actors in the broader Environment Canada matrix, other government departments, provincial and municipal governments, universities, business and industry, non-governmental organizations, local communities, as well as internationally. While all the labs studied have extensive informal networks with their respective parts of the broader scientific community, what is evident is the use of more formal network arrangements. The account in Chapter 3 of science policy history shows that this is partly policy induced but it also can arise from policies and decisions within a lab and across several labs. The labs participate in these networks, and in fact often serve as the lead coordinator and catalyst, in order to access expertise, leverage additional funding, and, increasingly, to deliver core programs.

Networking with Academe

As Canada's science and innovation system has matured research capacity has become more distributed and universities, in particular, are increasingly important players. But they are seen by some in the federal S&T community as competitors for federal funding. As the Introduction and Chapter 3 have shown, institutions of higher education enjoyed steady increases in federal funding for academic research from 1997 to

2005, while funding for federal intramural R&D remained relatively flat. Typically, government laboratories are not directly eligible to compete for the academic funding. At the same time, while the universities are rarely a source of funding for the labs, they remain an important source of expertise and the most important source of highly qualified personnel.

In general, relationships between the three labs and the academic sector are important but the degree of networking with universities varies considerably across the three labs. At the ETC, networks involving universities have not been central to their operations but are growing in importance. One example is the recently created Environmental Technology and Training Institute. On the other hand, academic linkages are pervasive and increasing at the ACSD and the NWRI. The NWRI has staff located at the University of Victoria and the University of New Brunswick, while the ACSD has staff located at the University of Victoria. Both are heavily engaged in formal networks involving universities.

All of the labs have scientific staff serving as adjunct professors at a variety of Canadian, and in some cases foreign, universities. These relationships are beneficial in a couple ways. First, they facilitate intellectual and interpersonal connections with academic researchers and graduate students. Second, adjuncts are often eligible to compete for granting council and other third-party funding. All of the labs host graduate students, post-doctoral fellows and visiting scientists. There is varied emphasis across

the labs on publishing scientific results in the academic literature, reflecting the labs' differing mandates and audiences for their knowledge products.

Networking with Business, Industry and Non-Governmental Organizations

The nature and extent of linkages between the labs and the private sector vary considerably. The ETC has key industrial sectors (e.g., automotive, petrochemical, agri-food processors) as major clients and partners and it engages in joint research and industrial demonstration projects. This is not the case with the ACSD which has only limited links with certain weather-related services firms and a nascent relationship with Canada's wind energy sector. Given its public science mandate and the lack of commercial interests in most of its research, the NWRI engages in much less networking with the private sector although some research projects have included private sector collaborators. Linkages between the three labs and NGOs are minimal.

Networking with the Regions, Other Federal Departments, and Other Domestic Governments

Operating in a large country of regions, government labs are under pressure to have segments of S&T activity located throughout Canada's regions. While this goal is understandably politically attractive and often makes sense from a scientific point of view as well, it presents challenges to lab managers who must maintain a critical mass of S&T capacity in a given location to ensure the viability of the work. Geographically, all three

labs are headquartered in Ontario although they each have facilities and operations in other provinces as well. The ACSD and the NWRI are both highly dispersed organizations. All three labs work extensively with personnel in the department's regional offices.

All of the labs have exhibited growth in the degree of networking with other federal departments and agencies, particularly the other large science-based departments of Agriculture and Agri-Food Canada, Fisheries and Oceans Canada, Health Canada, the National Research Council, and Natural Resources Canada, but also Parks Canada, Indian and Northern Affairs Canada, the Canadian Space Agency, Transport Canada and others. Much of the interactions with other government departments is a result of the increasing use of interdepartmental program-based funding mechanisms that induce greater collaboration. It is also a reflection of the horizontal nature of the policy challenges facing government as well as the recognition that no laboratory can “know it all” or “do it all” (de la Mothe 2000, 34). The pervasiveness of networking within the federal S&T community that is evident across all three case labs, even in the absence of networking in one or more of the other sectors, suggests the potential usefulness in extending the analytical framework by further differentiating the basic “network” category into intra-sectoral and inter-sectoral networks. This idea will be further pursued in section II of this chapter as part of the further development of the second part of the two-part analytical framework.

Finally, the labs network with provincial, territorial and municipal governments. The NWRI in particular stands out among the case labs as being heavily involved in research collaboration with these other levels of government. The ETC and ACSD also exhibit such linkages but to a lesser extent. Across the three labs, collaboration occurs through the Canadian Council of Ministers of the Environment and through various other federal-provincial agreements and committees working on a range of activities. These include setting Canada-wide environmental standards, monitoring water quality, and developing air quality indices to name just a few.

International Networking

The involvement of the labs in international networking is also prevalent and is of two types. The first form of international networking is the informal collaboration that occurs naturally within the global scientific community. This networking results in the coordination of research priorities, joint projects and publications in international journals and reports, presentations at international conferences and workshops, participation on foreign and international peer review panels, cross-training, and the occasional foreign visiting scientist working in one of the labs or a Canadian researcher working for a time abroad.

The second form of international networking occurs at a more formal or strategic level due to treaty obligations, increasing trade relations, or simply the complexity of transboundary issues. A number of bilateral agreements and Memoranda of

Understanding are in place that foster linkages between the labs and various foreign governments, research institutes, and international organizations. Much of the work of the NWRI is within the context of the International Joint Commission and concerns related to the Great Lakes. The ETC is increasingly engaged in international networks and, in 2005, was involved in a CIDA-funded project to provide training and institutional capacity building in China. Similarly, many of the ACSD scientists serve as Canada's representatives to various international bodies such as the World Meteorological Organization and the Intergovernmental Panel on Climate Change.

The inherent transboundary nature of air and water pollution and of atmospheric and climate science necessitates international networking. Some other, usually larger, federal labs have established international offices to better foster and manage these links. The case labs have not.

Overall, it is clear that the case study labs are more formally networked and that some of this flows from explicit policy requirements and inducements to network. But the case studies also show that it is empirically difficult at times to differentiate formal from underlying informal networks that are inherent in the conduct of science and in the relations among scientists in the lab workplace and outside it. The analysis also shows that there is a need to better capture the different kinds of networks which is part of why the second part of my analytical framework is needed. It provides analytical room for a differentiation of network types and serves as a useful complement to the basic hierarchy, quasi-market, and network typology.

Problems and the Need to Go Beyond “Make or Buy”

This section has thus far examined the institutional designs of the case labs by summarizing their characteristics and evolution as hierarchies, quasi-markets, and networks. Overall, in relation to the first research question posed, the labs have been reconfigured so as to force, induce or give greater room for quasi-market and network-based modes of organization. In the first instance, the quasi-market push was embodied in the mid-1970s fairly simplistic “make or buy” policy discussed in the Introduction and Chapter 3. The case studies, however, further bear out the first main argument advanced in this analysis, namely that the traditional “make or buy” and related quasi-market analytical lens on the labs does not adequately capture their increasingly formal network-based approaches. Indeed, the cases show how a “make, buy or collaborate” set of choices is needed to understand these labs. Moreover, as summarized above and as revealed in the lab case studies, network-based approaches exhibit both formal and informal network attributes. The study’s primary emphasis is on formal networks as a federal policy preference in recent years but the case studies also reveal, not unexpectedly, that informal networks permeate the labs and have done so even before there was a Make-or-Buy policy or other market-oriented and network-based pressures on the labs in the 1980s and 1990s.

The insights gained are important for generating a better understanding of the rich diversity that exists among Canadian government laboratories and also within them.

However, each of the case studies also helped reveal the problems and challenges that arose as varied institutional forms evolved.

These problems too have been revealed and captured in the summary above and in more detail in the separate case study chapters. The problems include those inherent within hierarchy as its tentacles extend into the laboratories. Examples here include: the severe budget cuts of the Program Review era and its continuing aftermath; the rules and procedures of the public service human resources system; the lags in dealing with aging laboratory equipment and facilities. Similarly, the quasi-market elements of change produce both some sensible experiments with service delivery and a greater sensitivity to performance, certification and clients but also the very problematic or even contradictory notions of encouraging intellectual property rights in realms where public goods science is and ought to be the norm. Networks, too, are beneficial and even self-evidently needed as part of both science and governance in the modern era but they also can produce new forms of transaction costs, procedural and reporting requirements, and, as the case labs suggest, a shift of efforts away from core mandates of the labs.

II. THE UTILITY OF A COMPLEMENTARY INSTITUTIONAL DESIGN SPACE TYPOLOGY

The analysis above suggests both the value and some of the limitations, conceptual and empirical, of the initial hierarchy, quasi-market, and network typology. In this section, I elaborate a useful and needed complementary institutional design space typology that can support further research and potentially aid policy analysis regarding

government laboratories. In particular, the institutional design space typology advanced here provides a complementary and rich approach to understanding government laboratories and the full spectrum of “make, buy, or collaborate” choices available to the policy maker.

As the second part of the overall framework employed in this study, the design space typology draws from the first part of the framework—the basic hierarchy, quasi-market and network typology—and also in direct and indirect ways from the main streams of the literature reviewed in Chapter 1. It is also informed by both the general evolution of these organizations in Canada and elsewhere as summarized in Chapter 3 and the specific cases presented in Chapters 4, 5 and 6 and comparatively analysed above. A number of figures help to illustrate the typology.

The design space typology is anchored in the three-category framework that examines institutions as hierarchies, quasi-markets and networks. Importantly, however, it recognizes further that these categories are ideal types. It would be rare if not impossible to find an institution that was organized as a pure hierarchy, quasi-market or network. Rather, as this study has demonstrated, institutions typically exhibit a blend of features of all three types, with the specific mix potentially changing over time. Moreover, as stressed above, there are empirical evidence and boundary problems regarding some of the examples of activities under each institutional heading that could belong to more than category. Though building on a simple three-category world, the institutional design space typology captures a more complex and multi-dimensional

design space within which government laboratories can make, buy or collaborate to deliver on their mandates.

As we have seen, a strong pressure on federal laboratories in Canada has been to become more market-oriented—i.e., to move to some extent from Hierarchy to Market. What this means in practice varies depending on which institutional design characteristic is being examined. But to illustrate the point one could look at basic ownership characteristics. Far from being a binary choice between public and private ownership, there is in fact a broad spectrum of ownership possibilities for government laboratories. These possibilities range from the hypothetical “fully public” to the “fully private” (see Fig. 7-1). Between the two endpoints the intermediary arrangements proceed from, at the more “public” end of the ownership continuum, an organization that is a direct line unit of a federal department through to departmental agencies and more arms-length special operating agencies. Further along the continuum, laboratories will exhibit greater degrees of independence from their parent hierarchies and ownership/management arrangements can include hybrid structures such as the U.S.-style government-owned but contractor-operated (GOCO) laboratories, contract research organizations, Crown corporations, and partially or fully privatized organizations. The study has demonstrated a recurring policy preference to move government labs in the direction of the arrow in Fig. 7-1, from more public ownership to quasi-market and networked partnerships and in the direction of, although not necessarily to actual, private ownership. For the purposes of developing the design space typology, however, the essential point is that there is a continuum in

ownership terms between pure Hierarchy and, in our case, Quasi-Market (or even fully private) forms.

Figure 7-1. A range of ownership possibilities exist between the Hierarchy and Market ideal types.

In addition, we have seen that federal laboratories in Canada have often been criticized for being too insular and insufficiently engaged with the broader national science and innovation system. Policy and political-managerial pressure has consequently been in the direction of increasing integration both through network-based organizations and quasi-markets. But again, with regard to the nature and degree of engagement and networking with external players, there is a range of possibilities (see Fig. 7-2). Between the hypothetical endpoints of “fully isolated” and “fully integrated,” this continuum includes, for example, “open hierarchies” that make use of teams, task forces, workgroups and informal networks between individuals for information exchange. Further along the continuum, one finds what Agranoff (2007, 83) refers to as “collaborarchies” or networks that go beyond informal networking among individuals to

“interorganizational entities that emerge from interactions among formal organizations.”

In the context of government laboratories these interorganizational interactions can include collaborative research arrangements, formal partnerships, co-location and co-governance arrangements. Again, the specific location along the continuum of these various forms of interaction is less important than the insight that there is, in fact, a continuum of choice, a space.

Figure 7-2. A range of arrangements exists between the Hierarchy and Network ideal types.

Thus, the analysis suggests that policy makers and research managers do not face a dichotomous choice between merely Hierarchy and Market or Hierarchy and Network. Rather, there exists a more complex Hierarchy/Market/Network design space that allows organizations to exhibit a mix of hierarchy, quasi-market and network characteristics. This institutional design space can be represented by joining the Hierarchy-Market and Hierarchy-Network continuums at their common Hierarchy anchor (see Fig. 7-3).

Figure 7-3. The institutional design space.

It can be expected that the actual position of a laboratory within the design space at any given time will be influenced by its particular mandate and other institutional characteristics. An advantage of this approach is that it does not inherently presume a preference for one institutional design over another. Such an institutional design space typology is in this sense descriptive and largely neutral in nature, although, as was the case in the basic hierarchy, quasi-market, and network typology, it is also partly

normative in that each core type of institutional form is anchored in its traditional values and valued attributes. For example, laboratories engaged in national security R&D or regulatory science may be required to maintain a high degree of independence, even isolation, for reasons of ensuring secrecy, safety or public confidence. It would follow that such laboratories would tend to cluster closer to the origin of the design space, a region characterized by more public ownership and less permeable organizations. However, at least one analysis (Brooks 2006) suggests that this reasoning may not hold true and should be tested empirically. The institutional design space typology can facilitate such empirical testing.

On the basis of my study it is possible to further delineate the institutional design space concept into four quadrants as illustrated in Fig.7-4. Clearly, the boundaries between the quadrants are not rigid and are thus illustrated with dashed lines. Nonetheless, institutions within each quadrant will tend to have institutional design characteristics that can be categorized as hierarchies, quasi-markets, intra-networks and inter-networks. The characteristics of hierarchies and quasi-markets have already been discussed but it is necessary to explain what is meant by the distinction between intra-networks and inter-networks.

By *intra-networks*, I am referring to organizations that exhibit network characteristics but where the members and other characteristics of the network are still predominantly within a single sector (in this case, the federal S&T community). In this context, intra-networks involve government laboratories from different federal

departments and agencies collaborating on research, delivering a program, or sharing a common campus or facility, etc.

Figure 7-4. A four-quadrant institutional design space typology.

Inter-networks, by contrast, refer to organizations enmeshed in inter-sectoral collaborations and networks. Organizations near the boundary between intra- and inter-networks will have collaborations within the broader public sector including with academic partners. Farther into the Inter-networks quadrant, organizations will be engaged in highly complex public-private networks involving a mix of academic

institutions, private sector firms, non-government organizations or other actors. All of the case labs in this study are involved in inter-sectoral networks, albeit with differing sectors as key partners.

The institutional design typology thus consists of a four quadrant space that can be used initially to map (albeit with previously discussed boundary problems) an organization's design elements as hierarchies, quasi-markets, intra-networks or inter-networks.

III. APPLYING THE COMPLEMENTARY DESIGN SPACE TYPOLOGY

The institutional design space typology can be usefully applied at both a conceptual level to aid policy thinking and at an empirical level to support further research and analysis. I begin with an exploration of its conceptual application.

Figure 7-5 shows a notional representation of the distribution of federal government laboratories within this design space. Based on the historical review in Chapter 3 and the case laboratories, one could hypothesize that a mapping of government laboratories in this design space would result in a heavy clustering of laboratories near the Hierarchy origin, with relatively fewer laboratories as Market or Network outliers, as emphasized by the red curve. It is important to reiterate that the distribution of laboratories in Figure 7-5 is notional only and not based on empirical evidence of the Canadian situation, an issue to which I return later.

Figure 7-5. A notional representation showing that most federal labs likely fall below the curve in the institutional design space.

While the taxonomy assumes no preferred institutional design, it is clear from the research study that policy and managerial preferences exist and that each institutional type has normative elements. As indicated, the historical trends have been to shift federal laboratories away from traditional hierarchy designs in the direction of quasi-markets, on the one hand, or in the direction of network-based integration, on the other, or both. Figure 7-6 represents these twin policy-managerial pressures as arrows pointing in the direction of moving labs further out along the Quasi-Market or Network axes.

Figure 7-6. Traditional policy pressures imply shifts along the axes.

However, what emerges from the study and what these diagrams imply and illustrate is that it is not necessary to view either hierarchies, quasi-markets or networks as exclusively or timelessly preferable institutional designs for government laboratories. To the extent that policy preference is to reform government laboratories away from Hierarchy, it might be more useful to think in terms of policy action that shifts laboratories further out into the institutional design space, e.g., from curve A to curve A' to curve A'', where each successive curve represents a higher degree of orientation toward, and engagement with, the broader national science and innovation system (see Fig. 7-7). Indeed, the current federal S&T Strategy indicates the federal government's

interest in having government laboratories more engaged with other S&T-performing sectors for the many benefits that it can potentially bring (Government of Canada 2007).

This policy pressure is represented by the arrow in Fig. 7-7.

Figure 7-7. Increased engagement with the broader science and innovation system can be achieved by pushing federal labs further out into the institutional design space, as indicated by the arrow.

Within this policy context, the important institutional design consideration for a government laboratory is not so much its proximity to either the Market or Network axis but its distance from the Hierarchy origin, as illustrated by the A-curves. The suggestion here is that policy makers should be initially indifferent to the position of a laboratory on

an A-curve. That is, from a policy standpoint, where a lab sits *along* an A-curve should be less important analytically than *on which* A-curve it sits, with the policy preference being for a laboratory to be on a curve consistent with its mandate and with the problems being addressed at any given time.

Thus, there may be situations in which a Hierarchy design is appropriate for particular government laboratories. The institutional design space typology itself is neutral with regard to preferred institutional designs and helps practically to highlight how mandates and institutional designs interact in practice. Therefore, the institutional design space typology can be applied to guide a more empirical approach to understanding these important institutions.

Applying the typology to the consideration of alternative institutional designs and management arrangements for government laboratories requires empirical evidence regarding the laboratories' roles and institutional designs. In Canada, as chapters 1 and 2 have shown, such empirical evidence as exists on government laboratories (including the author's in this study) is largely of the case study variety. The case studies have been quite useful in developing the typology by providing insights about the roles and institutional designs of the laboratories studied. But the sheer number and dynamic nature of federal laboratories militates against an approach to applying the typology to policy analysis that relies exclusively on static, in-depth case studies.

In Canada, the top ten S&T-performing departments and agencies account for nearly 80 percent of all federal intramural S&T spending (Statistics Canada 2008b, Table

6-2). Within these departments and agencies, there are approximately on the order of 100-200 government laboratories. These institutions should be better understood, monitored in the core statistical surveys, and a primary focus of public policy analysis related to federal intramural S&T. To better understand them, the institutional design space typology could be employed as a complement to the basic hierarchies, quasi-markets and networks typology to guide the data collection and analysis of the institutional design of government labs.

IV. CONCLUSIONS

This chapter has analyzed the three case study laboratories using first the basic hierarchies, quasi-markets and networks typology that guided the previous three case study chapters. It has provided a concluding view of the utility and limitations of this first part of my two-part analytical framework, based not only on some of the quandaries initially previewed and anticipated in the Chapter 2 discussion of the conceptual issues inherent in this framework but also the empirical evidence of the case studies. The broader context of Canadian science and science policy history reviewed in Chapter 3 has also informed this summary analysis.

The chapter also provided a more detailed development of the second part of the study's analytical framework, the institutional design space typology. This institutional design space framework has been presented as a needed and useful complementary analytical extension to draw out conceptually, descriptively and to some extent

normatively the more complex range of institutional designs, particularly regarding types of networks but also other features of hierarchies and quasi-markets.

This full application of both parts of my analytical framework has enabled me to further answer the first two research questions posed in the Introduction and to elucidate institutional characteristics of Canada's federal government laboratories and how these have evolved in the face of quasi-market- and network-oriented policy and institutional pressures.

The chapter has shown that, in relation to the first research question, the labs have been reconfigured so as to force, induce or give greater room for quasi-market and network-based modes of organization. The quasi-market pressure came initially in the mid-1970s from the Make-or-Buy Policy discussed in the Introduction and Chapter 3. The case studies, however, further bear out the first main argument advanced in this analysis, namely that the traditional "make or buy" and related quasi-market analytical lens employed in analyses of government labs does not adequately capture their increasingly formal network-based approaches. To better understand these labs, the cases show that, at a minimum, this analytical lens should be extended to a "make, buy or collaborate" set of choices.

In addition, as the chapter shows, network-based approaches exhibit attributes of both formal and informal networks. The emphasis in this study is on formal networks as a federal policy preference in recent years. However, the case studies also reveal, not unexpectedly, that informal networks permeate the labs and have been a persistent

approach even before the budget-cutting and New Public Management pressures on the labs increased in the 1980s and 1990s.

The chapter also helps to present a consolidated summary view of the problems and challenges that arose from the case studies as varied institutional forms evolved. The problems include those inherent within hierarchy that persist, despite the pressure and presence of other institutional forms. Examples include: the severe budget cuts of the Program Review in the mid-1990s and its continuing aftermath; the procedural bureaucracy associated with the public service human resources system; the lack of support for government science infrastructure and problems related to aging laboratory equipment and facilities. With respect to quasi-market elements of change, these have produced some interesting experiments with service delivery and a greater sensitivity to performance, certification and clients but have also led to problems associated with reliance on “soft money” and intellectual property-related revenues that may conflict with notions of independent, public goods science. Similarly, networks are both beneficial and necessary in the conduct of modern science and governance but network-based configurations can also produce new transaction costs, new forms of procedural and reporting requirements, and the potential for “mission drift” as research efforts gradually shift in the direction of the networks’ agendas and away from the labs’ core mandates.

The chapter also helps answer the third research question and accordingly is a further major contribution of the research project. While the institutional design space typology is anchored in the initial three-category framework of hierarchies, quasi-markets

and networks, it complements and extends the basic typology. Employing an institutional design space approach allows for greater differentiation of the increasingly important network category into intra-sectoral and inter-sectoral network types, resulting in four general design types, namely hierarchies, quasi-markets, intra-networks and inter-networks. And, perhaps more importantly, the design space typology makes explicit the multi-dimensional design space within which policy makers can choose to make, buy or collaborate.

The chapter also suggests how the design space typology could guide policy analysis by further illustrating what the four institutional designs represent with respect to government laboratories. The findings suggest that it should not be assumed that mandate is necessarily the key causal variable that determines the other institutional design characteristics, i.e., that form inflexibly follows function. The relationship between a government laboratory's mandate, functions and design characteristics should be explored empirically and with greater conceptual subtlety. It is argued that adopting the design space typology and monitoring government laboratories in the government's core S&T statistical surveys will provide a manageable and more effective focus for public policy analysis related to federal intramural S&T.

CONCLUSIONS

I. PURPOSE, RESEARCH QUESTIONS, MAIN ARGUMENTS AND CONTRIBUTIONS

The purpose of this study has been to critically examine Canadian federal government laboratories with a view to understanding better their institutional variety and changes in institutional form, and the institutional design space for government laboratories. The study has addressed three central research questions: 1) how have the institutional forms of government laboratories been reconfigured during the period 1990-2005? 2) what are the laboratories' mandates and how do these reconfigurations affect the labs' abilities to fulfill their mandates? and 3) how might Canadian science policy analysis better take account of the importance, diversity and complexity of government laboratories?

The study has been built mainly on institutional analysis where institutions are defined in an overall sense as entrenched systems of behaviour centred around strong values and systems of norms and rules. The analysis, however, has also had to take into account as context, features that are exogenous to the government laboratory as an institution, including in particular the ongoing changes in government policies that impact on the labs and also in the policies of the parent government department, Environment

Canada. The focus of the dissertation has been on the institutional variety and form of federal government laboratories and on issues regarding institutional design space.

Central to answering the first research question has been an examination of the institutional forms of government laboratories and how these have evolved in the face of policy pressures to be more market-oriented and network-based, but where hierarchy-related characteristics also remain a key aspect of these organizations. The study has shown that while economic and commercial concerns have always been a part of Canada's government science evolution, the initial emergence of a more concerted quasi-market push can be traced to the Make-or-Buy policy of the early 1970s. Its continuing presence through the 1980s and 1990s was due to concerns about economic competitiveness, fiscal deficits and also the rise of New Public Management. The analysis has also shown that network-based approaches exhibit both formal and informal network attributes. While informal networks permeate the labs and have done so throughout their histories, the analysis has shown the rise of more formal, policy-induced forms of network-based organization in recent years. At the same time, however, the study has made clear the persistence of hierarchies despite years of policy preference and emphasis in the direction of other institutional modes.

The study has also addressed the second research question regarding the problems created by these institutional design types and the tensions among them. The analysis has shown that substantively these problems include: severe budget cuts of the Program Review era and its continuing aftermath, maintaining core capacities and mission focus,

the rules and procedures of the public service human resources system, and the lags in dealing with aging lab equipment and facilities. Similarly, the quasi-market elements of change produce both some interesting service delivery experiments and a greater sensitivity to performance, certification, and clients but also the very problematical or even contradictory notions of encouraging intellectual property rights in realms where public goods science is and ought to be the norm. Networks too have been shown to be encouraged and to be beneficial and even self-evidently needed as a part of both the normal conduct of science and new forms of governance but they also can produce new forms of transaction costs, procedural and reporting requirements, and, as the case labs suggest, an actual or potential shift or drift away from core mandates.

The third research question of the study has been addressed mainly by developing and employing the complementary institutional design space typology. This approach has importantly highlighted the existence of four general design types for government laboratories, namely hierarchies, quasi-markets, intra-sectoral networks and inter-sectoral networks. More importantly, however, the design space typology emphasizes the multi-dimensional institutional design space for government laboratories.

In summary, the three main arguments set out in the Introduction have been advanced and validated throughout the analysis of both the evolution of Canadian science policy and the three case studies of federal laboratories. The first argument, namely, that the traditional “make or buy” and related quasi-market lens on policy analysis related to government laboratories does not adequately capture the increasingly formal network-

based approaches to the delivery of government science, has been demonstrated as relevant and important. As stressed, this suggests the need for a policy lens that focuses on a broader set of “make, buy, or collaborate” institutional design choices.

The study offers a solid validation of the second argument, that government laboratories as institutions exhibit a remarkable degree of complexity and diversity but that this multi-dimensionality is often poorly reflected in Canadian S&T policy. This includes a failure to understand the multiple (and potentially conflicting) mandates of government laboratories; to appreciate that formal policy-induced networks are not necessarily the same as the informal networks that have long characterized scientific activity; and, to recognize that formal networks and quasi-market approaches can create problems for the labs in carrying out their diverse mandates.

The third argument of the study has been that science policy analysis requires an analytical approach to government laboratories that captures their multi-dimensionality, guides data collection and analysis, and makes explicit the range of institutional design options available to policy makers. The institutional design space typology developed in this study can assist the formulation of a more informed Canadian science policy by providing a middle path for policy analysis. This path navigates between top-down sector-based stereotypes, market failure arguments, or generic New Public Management concepts and bottom-up but static case studies of individual government laboratories. It is argued that the institutional design space typology of government laboratories can be useful in gathering more policy-relevant information about these important institutions.

The study has also shown overall that government science is critically important to Canada's science and innovation system and, therefore, government laboratories as the key instruments for delivery of government science are important institutions. Whether viewed from the perspective of levels of investments, of personnel or the unique roles that it plays, government science and its institutions are worthy of greater in-depth analysis and policy attention.

The analysis has shown that the overall use of a two-part institutional analytical framework in relation to case studies of three labs of Environment Canada has been useful, while also locating these institutional design issues in the broader context and history of Canadian science policy and government science. Ultimately, it is argued that the research can assist the design of more informed and more appropriately targeted policies for the provision of government science.

The study has thus made contributions at both the empirical and conceptual levels. Empirically, it has expanded the base of knowledge about the Canadian government laboratory system. Employing a dual institutional framework, the study has developed three case studies of government laboratories that to date have not received much attention in the academic literature, namely the diverse labs that exist within Environment Canada as a crucial public science-based department. The case studies provide a rich source of information about these institutions' roles, structures and evolution that goes beyond the kind of aggregate data on funding, personnel, and outputs that is typically all

that is available to the analyst, particularly those who have studied federal laboratories as part of official government or advisory reports.

At a conceptual level, the research contributes to a deeper understanding of government laboratories as institutions in two overarching ways. The first way is by placing them at the centre of the analysis. The study's review of the literature made clear that government laboratories have not been a particular focus of much of the policy scholarship across a variety of disciplines. The study went to some length to make the case for why these institutions deserve greater focussed attention. The second overarching conceptual contribution of the study derives from its extension of the application of institutional conceptual tools to government laboratories in Canada through the two-part analytical framework employed.

The analysis has provided a view of the utility and limitations of the first part of my two-part analytical framework, based not only on some of the conceptual and boundary problems initially previewed and anticipated in Chapter 2 but also the empirical evidence of the case studies. Overall, the study of the case study labs has shown that the laboratories exhibit more quasi-market and formally networked features (albeit to varying extents) and that some of these institutional changes flow from explicit policy requirements and inducements. But the case studies also show that it is empirically difficult to tightly differentiate formal from underlying informal networks that are inherent in the conduct of science and in the relations among scientists. The analysis also shows that there is a need for, and analytical room for, the capture of different kinds of

networks, which is partly why the second part of my analytical framework is needed as a useful complement to the basic three-category hierarchy, quasi-market and network typology. The second part of the study's analytical framework, the institutional design space typology, has helped draw out conceptually, descriptively and to some extent normatively the more complex types of institutional design, particularly regarding types of networks.

II. LIMITATIONS

The contributions and arguments summarized above should be considered in the context of the inevitable limitations of any complex research study. The limitations flow from both the institutional design conception and the study methodology, particularly with respect to the case studies.

One potential limitation of the study is its fundamental conception of “institutional design” in the sense that one needs to consider whether government laboratories as institutions are “designed” as such. Clearly, government laboratories exhibit characteristics of hierarchies, quasi-markets and network organizations. As we have seen, these characteristics often become overlaid on top of previous characteristics yielding the present complex mix within an organization. These mixes are not always literally “by design” in the sense of being a rational choice of policy makers or lab managers. They also emerge and evolve in unintended and non-prescribed ways. Thus, it is important to keep in mind that the institutional design space typology in the overall

two-part framework is not intended as a prescriptive crib for policy makers but rather as a useful analytical device for the policy and institutional analyst to grapple with the diverse natures of these organizations.

With respect to methodology, key limitations flow from the decision to employ a case study approach. Using case studies as the primary source of empirical evidence supports a fundamental contribution of the study; namely the expansion of “ground truthed,” policy-relevant knowledge about federal government laboratories in Canada. I chose to rely on them more than, say, a statistical approach for several reasons. First, case studies help us understand what these laboratories are really like rather than what some organization chart, mission statement, policy document or economic theory says they are like. As indicated, there is very little institutionally-focussed evidence of this kind that exists in Canada, particularly for labs of Environment Canada. Second, even if one were interested in employing a statistical approach, developing case studies provides a useful “on the ground” understanding of what statistical indicators would be most appropriate. Third, a purely statistical approach would also have limitations given the small population size. Statistically valid survey analysis, for example, would require high response rates among government laboratories. For all these reasons, a more qualitative and descriptive approach was appropriate at this stage. However, while case studies can communicate the complex realities of these organizations, they also present limitations.

The in-depth nature of the case study approach necessitates a smaller sample of organizations than what could be handled in a statistical approach. This smaller sample,

along with the general limits of induction, means there is consequently less basis for generalization of the results from such an approach. The hope, of course, is that this cost is repaid by more rich, reliable data about the organizations being studied. As Rogers and Kim (1985, 101) put it, by employing a case study approach, “the researcher learns more about less, rather than less about more.” The case studies, though in-depth, are not intended to be exhaustive organizational analyses. Rather, they seek to explore those organizational characteristics and trends that illuminate the key issues of institutional design.

Other approaches are also possible and have positive features that recommend them. For example, Rosenblatt (2004) employed surveys of lab staff researchers and related statistical analysis in his study of three laboratories of Natural Resources Canada. It is important to stress that for much of his study his unit of analysis was individuals within the laboratories, not the laboratories as complex institutions.

Within the methodological choice to employ case studies, further limitations are imposed by the decision to select three case labs from a single department, in general, and Environment Canada, in particular. Again, this was done in order to hold constant any departmental context that could confuse the analysis. Early work had indicated that the specific policy and management context of the parent department could influence the institutional designs of laboratories, and it was thought prudent to isolate these influences in order to better understand the broader institutional pressures towards more market-oriented and network-based forms. Environment Canada was chosen because it has a

number of government laboratories with diverse mandates and functions that have not been the focus of much scholarship.

Given the interest, however, in developing a general typology that could be used to guide policy analysis regarding all of the federal laboratories, it must be considered that a broader selection of labs may have altered the findings and conclusions. As we have seen, the institutional designs of the three Environment Canada labs tend to reflect their largely public goods science mandates and the longer term historical tendency in Canada to organize such institutions along traditional bureaucratic lines. To test the robustness of the overall two-part analytical framework used, more information is needed about laboratories from departments and agencies with more explicit “economic competitiveness” mandates (such as Agriculture and Agri-food Canada, Natural Resources Canada, the National Research Council, or Industry Canada), and from departments and agencies with more explicit “security” mandates (such as Defense R&D Canada, Public Safety Canada, etc.). This leads us to the discussion in the next section of potential areas of future research.

III. SUGGESTIONS FOR FUTURE RESEARCH

It has been argued that without a richer understanding of government laboratories, policy pressure for uniformly applied market-oriented or network-based approaches can lead to a sub-optimal mix in the institutional designs of these institutions and negatively impact their abilities to fulfill their diverse mandates. Through the case studies and

through the development and initial examination of the institutional design space typology, this study has made some contributions toward increasing our knowledge about Canadian government laboratories. But much more research is needed. This final section will summarize some suggested areas for future research that emerge from this study.

As indicated in the section above, some obvious suggestions flow from the limitations of this study, particularly the need to further test the institutional design space typology against additional empirical data. Thus, the most obvious next steps could involve employing the proposed institutional design space typology in the conduct of additional laboratory case studies. In selecting additional cases, one would want to examine laboratories that might exhibit different institutional characteristics than those studied here to ensure the robustness of the typology. Selecting laboratories belonging to federal departments other than Environment Canada would make sense.

Future research should also involve complementing the case study approach with other empirical approaches. One potential area for future research related to Canadian government laboratories is the closer examination of the nature of their network relationships through bibliometric analyses. Many scholars, particularly in the “science of science” stream championed by Derek de Solla Price (1963, 1965 and 1970) employ bibliometric and other quantitative indicators to study scientific establishments. For example, citation analysis is often used as a measure of research collaborations and can provide important evidence of inter-organizational networking (Robitaille and Godin 2002, Bertrand and Côté 2006).

The use of bibliometrics is not without its own associated problems and criticisms. Some sociologists of science view informal networks as the dominant mode of communications among scientists and treat the formal literature as epiphenomenal. Consequently, these scholars tend to discount the relevance of citation analysis. In addition, the unit of analysis in citation analysis focuses attention on individuals whereas the approach being proposed in this study is explicitly institutional, not individual. And, much of the output of government science is not in published form or in the gray literature and would not be picked up by standard bibliometric analysis. Nonetheless, it would seem that a natural area for further research regarding Canadian government laboratories would be the use of bibliometric and similar quantitative approaches.

But the major suggestion for further work that flows from this study relates to the need to better understand the entire system of federal government laboratories. It is suggested that what is needed is more research on a larger group of laboratories through surveys and associated statistical analyses. In support of this approach, further research would be required to refine the design space typology, design appropriate survey instruments, identify the population of labs to be studied, etc. Given the recurring policy interest in the roles and institutional designs of government laboratories over the past four decades, in the face of an appalling lack of policy-relevant information about the labs, the need for focussed, systematic data collection and analysis seems apparent.

In summary, public policy related to government laboratories in Canada has been hampered by too little information about these entities as institutions. It may be the case

that individual departments have a rich understanding of the S&T labs within their portfolios. But greater information is needed at the centre of government and beyond if the laboratories are to be the strategic assets that they could and should be.

With over \$5 billion invested annually in the R&D and RSA performed by the federal government laboratories, government science still represents a major part of the Government of Canada's total direct investment in science and technology. Public policy related to this investment, including implementation of the commitments and principles outlined in the latest federal S&T Strategy (Government of Canada 2007), would benefit from a better understanding of the federal S&T establishments, the functions they serve, their institutional designs and their interrelationships. Systematic data collection and analysis with respect to government laboratories would facilitate this understanding, and the approaches developed and used in this study can provide a useful framework for this further and much-needed empirical work.

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