<u>The Future of Aquatic Science in Canada</u>

(Freshwater Emphasis)

The Turquoise Paper

Prepared by Bob Beecher and Evan Thomas
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1.0 Introduction

Conservation and management of aquatic resources in Canada involves a wide array of government agencies and stakeholder organizations. As environmental, social and economic changes occur with ever increasing frequency these organizations are all required to re-evaluate and adjust their activities to address emerging realities. It is important that these adjustments be made within the context of an informed long-range view of the future, and that change occur as proactively as possible.

The purpose of this paper is to stimulate informed thinking in an effort to forecast the future of freshwater fisheries and aquatic sciences in Canada in 2020 as it relates to the long term needs of Canadians and to the future programs of Fisheries and Oceans Canada (DFO). DFO recently set out its scientific strategy for the near term (5 years) in its *Scientific Strategic Plan* (2000). This paper is intended to look further out to anticipate the specific drivers of freshwater aquatic science over a longer timeframe and consider DFO's roles in a broader context. This is being done in preparation for a national aquatic science futures workshop to be held in May 2003.

First, the major drivers, or anticipated conditions, of what the Canadian public will expect of freshwater aquatic sciences in 20 years are identified. Some are consequences of environmental change and some of societal change, with the two frequently intertwined. These drivers determine the kinds of science support society will demand, and these demands, in turn, determine the things that freshwater fisheries and aquatic sciences will have to address in 20 years. Contrasting these needs in 20 years with what is done now will reveal the shifts in focus that will be required.

2.0 Background

2.1 Importance of Canada's Freshwater Aquatic Resources

Canada's freshwater resources are fundamental to the overall health of the environment and to the quality of life in this nation. In addition to providing for the most basic needs such as drinking water, they provide habitat for aquatic communities, food, social and ceremonial use by aboriginal people, transportation, hydropower, recreation, and processing water for society.

Freshwater fisheries resources are important in Canada. Recreational fishing involves about 20% of the population, and results in expenditures of several billion dollars annually, primarily in relation to freshwater activity. As well, freshwater fish are harvested commercially, with the Great Lakes boasting the world's largest freshwater commercial fishery. Freshwater fisheries also play a significant nutritional and cultural role in the lives of many aboriginal people. Canada's growing aquaculture industry generates millions of dollars in sales and they are increasing. Entire communities depend on fisheries for their economic and social wellbeing. Clearly, Canada's freshwater fisheries resources continue to play a significant role in shaping the nature of many parts of this nation.

Canadians also spend billions of dollars on recreational boating, and the country's economy relies heavily on commercial shipping, another growing industry.

2.2 Scope and Role of Science

Canada contains hundreds of thousands of inland waterbodies (approximately 8% of its total area), with countless thousands of kilometres of freshwater lake and river shorelines. DFO's mandate requires knowledge of freshwater fisheries resources, aquatic environments, navigation, and ways to ensure the sustainability of fishes suitable for human consumption.

DFO's freshwater clients are as diverse as recreational anglers; the commercial fishing industry; aboriginal people drawing subsistence from and expressing their heritage in aquatic ecosystems; shipping and recreational boating, aquaculture, and tourism industries; industries such as energy exploration and development, forestry, mining and agriculture that may affect the quality of aquatic habitats; environmental organizations; and citizens concerned about Canada's natural resources and how they are used.

Science can generally be considered to be systematic and formulated knowledge, in this case pertaining to freshwater ecosystems and fisheries resources. The Canadian government's vision for science and technology (Appendix 1) states that "*The federal government's science and technology efforts will identify emerging issues that matter to Canadians, and refocus in response to changing needs in areas such as health and safety, public security, natural resources and the environment, and the growth of the knowledge economy.*" Canada's Council of Science and Technology Advisors (CSTA) identifies the four roles of government-performed science and technology (Appendix 1), insisting that Departments and agencies should be performing only science and technology that is needed to support the minister's mandate and cannot be obtained more effectively from other sources. For freshwater science in Canada, DFO acknowledges all of these roles for government, as reflected in its *Vision Statement*, *Strategic Plan*, and mix of programs.

3.0 Freshwater Jurisdiction & Legal Mandate

The first step in predicting the future of freshwater science as it relates to DFO and its key partners is to consider current commitments in law, agreements and policy. DFO's legislated responsibilities include protection and conservation of Canada's fisheries and fish habitat (Section 91(12) of the *Constitution Act*, 1982, and the *Fisheries Act*), pollution protection (*Fisheries Act*, *Shipping Act*), and many aspects of safe navigation (*Navigable Waters Protection Act, Oceans Act*). Sections 36 to 42 of the *Fisheries Act* (aspects dealing with control of pollutants affecting fish) are administered by Environment Canada, with DFO cooperation in establishment of federal priorities for protection of fish and their habitats from deleterious substances. DFO's activities are also guided by Acts such as the *Canadian Environmental Assessment Act,* the *Species at Risk Act, and the Pest Control Products Act,* where other Departments may have an overall lead, but DFO has key roles with respect to freshwater ecosystems. DFO also has legal responsibilities under aboriginal land claim settlements related to fresh water and fish.

Despite significant delegation of fisheries management administration to provinces, the federal government remains responsible and accountable for all aspects of the *Fisheries Act* in fresh water.

Environment Canada also plays a significant role in protecting the health of freshwater ecosystems in Canada with responsibilities as outlined in the *Canadian Environmental Protection Act* (*CEPA*) (Part 3, Sections 43, 44, 46, etc.). In addition, as lead for coordinating Canada's Canada – U.S. *Great Lakes Water Quality Agreement* (*GLWQA)* contributions and related programs, Environment Canada counts on DFO as a key partner in the Federal Great Lakes Program (GLP). Moreover, DFO is also a signatory, along with Environment Canada, to the *Canada – Ontario Agreement respecting the Great Lakes Basin Ecosystem (COA)*, a key instrument for supporting domestic commitments to the *GLWQA.*

DFO's legislated responsibilities are accompanied by a suite of fundamental departmental policies and strategies, along with significant commitments to bi-lateral and multi-lateral treaties, agreements, and instruments (Appendix 2).

While DFO's mandate relates to activities stemming from the federal constitutional responsibility to protect Canada's fisheries and fish habitat, that mandate must be interpreted broadly in light of the need to take an ecosystem approach to conservation. The expansion of the fish habitat protection program in freshwater areas and new responsibilities with respect to species at risk clearly require a broad view of DFO's freshwater science.

4.0 Anticipated Conditions/Expectations for Freshwater Aquatic Science in 2020

Drivers influencing freshwater fisheries and aquatic sciences in 2020 will be defined by existing conditions at that time and the resulting expectations of society for government leadership and action. Effective management decision-making will continue to be based on high quality science. Significantly increased public interest in, and concern for the health of fisheries and the environment in recent years is expected to further amplify in coming decades. Science will be needed to support DFO's mandated responsibilities (e.g., fish habitat protection, environmental assessment, fishery management, charting, etc.) and specifically for research/modeling/analysis, monitoring and provision of advice. Such advice must often be provided in the absence of definitive information (i.e., risk management), and in the absence of a clear understanding of the full range of cumulative effects.

4.1 Human Population Demands

4.1.1 Demographic Change

By 2020, human demographics will be having an even greater impact on freshwater resources than they did at the turn of the century. Canada's population in 2021 is projected to be 35.4 million, an increase of 14% from 31 million in 2000. This population growth will be largely dependent on immigration, not births, making Canada the most ethnically diverse nation in the world. Canada's ageing population will see over 40% of Canadians over 50 years old then, compared with just 29% in 2000. This will affect uses of resources, economic conditions, tax revenues, and the available scientific workforce.

Urbanization will have continued, and over 80% of Canadians will live in non-rural areas. This will concentrate development pressures in specific high-density locations such as southern Ontario, Vancouver, Montreal, the National Capital Region, and the Calgary-Edmonton corridor, along with many others. The fastest growth rate will actually occur in the territories, as improved access and economic opportunity moves people north, although actual numbers will still be relatively small.

The overall growth in population will have further intensified the need to protect aquatic resources from development activities, including residential and industrial development, highway construction, and recreational developments (e.g., golf courses, ski hills). Population growth will have also increased harvesting pressures on wild stocks. Moreover, a wealthier world will see Canada as a place to come to experience nature and go fishing. Arctic and sub-arctic lakes and rivers, in particular, will receive a level of fishing that will be difficult to manage. However, people will pay for the opportunity to come to Canada to be part of an environment that will have been lost in their home location. Significant new regulatory controls on effort and catch will be required (recreational, commercial, subsistence fisheries).

Following declines in recreational fishing participation during the 1990s, interest will increase as a result of focused promotional efforts. Participation will be higher, particularly in urban settings where extensive programs will have been implemented to attract youth and immigrants to this activity. As the Canadian population ages and more people move into retirement, interest and participation in recreational fishing can also be expected to increase. As well, increased interest in enhanced fish production will have developed, similar to such enhancement practices now regularly used in agriculture and forestry. Recreational fisheries in urban areas will have been targeted for enhanced production in order to meet demands of expanding public interest and tourism.

Economic and environmental arguments will have shifted freshwater fishing activities increasingly away from commercial to recreational, particularly for popular sport species such as walleye and lake trout. It is expected that aquaculture production will serve to fill a substantial portion of the growing demand for fish to eat. Opportunities will be available and promoted to harvest abundant populations of invasive species as alternatives to diminished native stocks. These will provide non-traditional sources of fish protein that will be readily accepted by members of expanding ethnic populations who are familiar with some of these species, and by others due to innovative marketing techniques.

Recreational boating will continue to expand due to population growth and extensive promotion of the activity. As a result of this interest, demand for interactive electronic navigation aids and accurate paper charts will increase. With the growth in boating activity will have come wide-spread public concern regarding impacts from wakes and general disruption to aquatic habitats and species. Outboard motors will be increasingly more fuel efficient and environmentally acceptable due to rigid new regulations and the advent of new technologies. However, due to the overall level of activity, regular monitoring of boating-related pollutants and physical disturbance will have to be carried out.

Increased demand for cottage development will place additional pressure on relatively "pristine" environments as well as on those under a variety of existing stresses. The challenge will be to maintain the health of these ecosystems, along with their associated social and economic values (aesthetics, tourism and property values). Moreover, the ecotourism industry will have grown significantly, based on the activities of an ageing population and their interest in educational vacations focused on learning about their natural world. With this activity will come the need to assess impacts of increased access and associated disturbance, particularly in sensitive northern environments.

4.1.2 Economic Development

New or expanded economic development activities underway by 2020 will have significant implications to Canada's freshwater resources. Sound scientific information will be required if they are to be carried out in an environmentally sustainable manner, and in compliance with the regulatory framework. The most significant development activities with respect to fresh water are described below.

4.1.2.1 Urban Development

Increased construction of residential and industrial buildings, roads, and waste treatment facilities will be taking place as Canada's population continues to grow, particularly in large urban centres. Urban sprawl will continue with much of the population commuting long distances to work places, or working remotely in home offices as part of the well-emerged information era. Treated sewage discharge volumes (with hormone disrupting contaminants, pharmaceuticals, and nutrients) will increase correspondingly in focused geographic areas.

4.1.2.2 Hydroelectric Power Generation

Expanding need for power will continue to tax existing facilities and "clean" electricity alternatives will be sought, consistent with federal and provincial commitments to Kyoto targets. As a result of shutdowns of major coal-burning facilities, and only modest growth in alternative technologies such as wind, solar and nuclear power, hydroelectric power will continue to be the primary Canadian electricity solution. Economic opportunities presented by lucrative U.S. markets will also drive this interest. Canadian hydroelectric generation currently represents about 65% of its assessed economic potential of 523 TWh/year. The main alternative energy solution will be hydrogen fuel cell technology. Between 2015 and 2020 it will undergo an extraordinary expansion in use, primarily by the automotive industry. It will drive what will become the "hydrogen economy," seen as a replacement to the carbon based oil industry. While production of hydrogen from water by electrolysis will continue to require significant amounts of electricity, substantial declines in the burning of fossil fuels will be realized.

4.1.2.3 Agriculture

Global and Canadian population increases will have driven demand for a wide variety of food products and associated agricultural activity. Global warming will have resulted in increasingly frequent droughts and establishment of arid regions in parts of Canada and the U.S., while productive growing seasons in some areas will have expanded. Intensive agriculture will be practiced on the most fertile lands. Critical needs for agricultural irrigation will have placed significant demands on freshwater resources. Increased nutrient inputs and physical impacts to watersheds will have resulted from expanded production of food crops, despite marked progress on "green" farming and environmental farm plans. Climate change in marginal areas for current crops will drive major changes in types of crops grown in extensive areas of Canada. Widespread conversion from grain crops to feed lots, particularly for hogs, will have occurred throughout the prairies. Use of an expanding array of herbicides and pesticides will have continued to create concerns for health of natural watercourses.

4.1.2.4 Aquaculture

The need for wholesome food and significant economic and employment opportunities, coupled with a general decline in commercially harvested wild freshwater stocks, will have resulted in the continued expansion of aquaculture in Canada. Currently, water farming and aquafeeds are the two fastest growing production systems on the planet and by 2020 this will have continued at an unprecedented rate. Public concern regarding introduced species, local habitat degradation and risk of disease will have declined as science-based protocols and guidelines have been adopted. However, given the expanding economic magnitude of the industry, which will now have far surpassed freshwater commercial fish landings, the need for careful monitoring and adaptation will continue. Aquatic animal health issues will have increased in prominence, and environmental perturbations due to invasive species and climate change will result in increased risk of new diseases (previously undetected). The variety of species raised, and their numbers, will continue to increase, requiring continued assessment of risks regarding species, genetic composition, pathogens and impact on aquatic ecosystems.

4.1.2.5 Transportation and Navigation

The shipping industry will have continued to grow, particularly on the Great Lakes and St. Lawrence River. As demand for cheap bulk transportation continues, renewed interest by the U.S. government and the shipping industry will have focused on increasing the minimum depth for navigation on the Great Lakes (from 27 to 35 feet), allowing larger vessels with even greater cost advantages. This would, however, create environmental challenges due to risks of sedimentation, release of contaminants, ballast water (exotics), and hydrologic disturbances. The shipping industry will require precise and "real time" electronic navigation aids to allow safe passage in light of regular water level fluctuations on the Great Lakes, driven increasingly by global warming effects.

Global warming is expected to have allowed an expansion in shipping to the Port of Churchill on Hudson Bay, and an opening of a Northwest Passage shipping route for several months of the year. Risks to freshwater (and marine) ecosystems created by this will include introductions of invasive species through ballast water, spills of high risk cargoes (toxic substances, petrochemicals), and physical disturbances by ships. Improved access to the Port of Churchill will increase development of the north – petroleum exploration and production, pipelines, mining (e.g., diamonds, metals), roads, railways, housing and related infrastructure, in conjunction with additional economic development. Regular shipping will also be occurring on the Mackenzie River and into Great Slave Lake, with expected growth in population and similar development pressures. Increased road construction will include major corridors such as one currently being considered to link Winnipeg to Rankin Inlet. Increased interest in commercial, sport, tourism-related and subsistence fishing, in conjunction with increased access, will place additional pressure on fish stocks.

4.1.2.6 Other Resource Development

Economic development will also continue in **forest management**, with a northward progression and impacts associated with access, harvesting, and regeneration. **Oil and natural gas exploration and production** will have continued in Canada. The economic importance of **mining** in the far north will continue. With over 130 metal mines that discharge into freshwater systems currently in existence in Canada, challenges regarding risk assessment, mitigation, compensation and monitoring will continue to grow. For example, concerns related to gold and uranium mining and their associated contaminants (arsenic, nickel, and selenium) will increase. New technologies will be applied in traditional areas to harvest forests, extract petroleum resources and mine locations that were previously considered marginal or economically unfeasible.

4.2 Priority on the Environment and its Sustainability

4.2.1 Environmental Risks to Human Health

In 2020, public concern about environmental risks to human health will continue to be a primary issue for Canadians. The air we breathe, the water we drink, the food we eat, the radiation we encounter and the products we use, will all be the subject of strict quality standards and political accountability. Public concern for safe drinking water will drive broader environmental health concerns and will require a closely scrutinized partnership of water and health agencies (Health Canada, Environment Canada, DFO, provincial agencies). Mandates of responsible agencies will be clearly defined, as will accountability contracts to ensure essential safeguards are in place. Specific partnership configurations may shift and change, but collaboration will be the standard operating model. The development of a national water strategy will have served to focus the efforts of a broad coalition of partners to avert a looming freshwater ecological crisis.

Environment Canada has identified the range of current threats to drinking water and aquatic ecosystem health. While progress will have been made on many of these by 2020, all categories will require significant additional scientific understanding. Although pollution and deleterious substances are the purview of Environment Canada, their impacts occur not only in relation to human health, but directly on aquatic ecosystem health, and therefore require close scientific collaboration. The identified threats include: waterborne pathogens; algal toxins and taste and odour; pesticides; persistent organic pollutants and mercury; endocrine disrupting substances; nutrients – nitrogen and phosphorous; aquatic acidification; ecosystem effects of genetically modified organisms; municipal wastewater effluents; industrial point source discharges (pulp and paper, mining, petrochemical); urban runoff; landfills and waste disposal; agricultural and forestry land use impacts; natural sources of trace element contaminants; and impacts of dams/diversions and climate change (water quantity).

Degradation of ground and surface waters from agricultural and sewage waste and industrial contaminants, along with potential for water supply sabotage, will remain prominent health concerns.

In terms of fish consumption guidelines, mercury will remain a significant issue in Canada. Climate warming may actually increase the amount of mercury found in aquatic fauna. Herbicides, pesticides, residues from pharmaceuticals, and endocrine mimics will increasingly be entering waterways as a result of population growth, an ageing population, climate change and increased water use. Continued global industrialization will produce a wider array of new chemical compounds and increased burning of coal in China will result in continued and increasing mercury contamination problems in northern Canada via atmospheric transportation and deposition. Transport of persistent organic pollutants, known to be problematic for fish and human use of fish, will also add to public concerns regarding contaminants in fish, resulting in fishery closures and intensive scrutiny of sampling program results. Pathogens introduced into waterways from ship ballast water will raise public concern.

Generally, ambient receiving water quality objectives for contaminants, used in regulations to protect aquatic life and to prevent adverse effects to fish and their habitats, will continue to be more stringent than those used for drinking water standards. Canadians will increasingly appreciate that waters kept safe for fish survival, growth and reproduction will be waters that are safe for human consumption.

4.2.2 Competing Demands for Water

By 2020, increased population, urbanization, and global warming will result in significant competing demands for fresh water, particularly in mid-continent and southwestern U.S. regions. These demands for fresh water (including commercialization) will be for purposes beyond environmental health, including, primarily, safe drinking water and hydroelectric power production, along with irrigation, shipping, industrial processes, pulp mill and metal mining developments, and waste treatment.

Numerous smaller scale diversions within and from the Great Lakes Basin will supply fresh water for municipal consumption and for waste disposal into neighbouring watersheds. A contemplated plan to pipe irrigation water from the Missouri River into northwestern North Dakota would pose potential risks to waters in Manitoba and the Hudson Bay watershed. Major freshwater diversions, such as the GRAND Canal Project diverting fresh water from the James Bay drainage basin to the Great Lakes, and the North American Water and Power Alliance (NAWAPA) project that would transport water from the Yukon to Washington State, will increasingly be considered for water supplies and waste treatment.

4.2.3 Conservation of Natural Biodiversity

4.2.3.1 Aquatic Biodiversity in Canada

Canadians will be concerned about maintaining and restoring natural aquatic biodiversity in 2020. They will have witnessed several decades of assaults to their natural world through introductions of invasive species and constant changes brought about or threatened by development, global warming, genetic engineering, pollution and contaminants. Slow progress will have been made in relation to the *1995 Canadian Biodiversity Strategy*, and environmental advocates will demand more concrete action. Formal monitoring and reporting mechanisms will have been called for and tracking programs will be in place. One of the most immediate areas of concern will be for species at risk, particularly since enactment of the *Species at Risk Act* (*SARA*) and regulations in 2003.

4.2.3.2 Species at Risk

An increased number of aquatic species will have become at risk as invasive species expand and habitat losses due to development impacts and climate change continue. Implementation of *SARA* will have resulted in the development and implementation of several aquatic species recovery plans, particularly as a result of coordinated stewardship efforts, but there will be continuing work to do. Limited success in recovery plans will have resulted in celebration of de-listing for some species, but there will be growing frustration over the net increases in species at risk in Canada, despite the fact that *SARA* gives rights to species. The existence of *SARA* will create new issues, such as interactions with fisheries using models of risk. Questions will emerge as to when fishing and other water uses must cease if a species at risk is associated with an active fishery or other significant water use.

4.2.3.3 Ecosystem Approach

The use of a holistic ecosystem approach is fundamental to preserving biological diversity, and steady progress will have been made by 2020 as new science and integrative technology have developed. Assessment of ecosystem status and health will have moved from piecemeal assortments of existing data to structured monitoring and reporting of community assemblages, which was begun early in the century. This in turn will require integrated planning and policy approaches. DFO's freshwater research has historically included use of an ecosystem approach to explore impacts on fish and their habitats caused by such stressors as excessive nutrient addition, acidification and physical alteration (reservoirs). Work begun at the Experimental Lakes Area (ELA) in the 1970s will serve as a model for future experimental ecosystem areas with strong educational links. The continuing challenge will be to garner funding needed for the extensive information systems that support this approach.

Government agencies will still be required to manage harvested fish stocks in a sustainable manner, but under increasingly intensive scrutiny. Harvests will be managed on the side of caution in light of previous collapses, significant disruptions to ecosystems, and severe public reaction. Decisions will be based on the best ecological science available. Further, increased use will be made of no-harvest "aquatic protected areas" to preserve biodiversity of ecosystems and to provide reservoirs to support sustainable harvests. Science will be needed to select the most appropriate freshwater "protected areas," and to monitor their function on a long term basis.

Tracking and reporting of ecosystem status and biodiversity, consistent with public and agency demand to protect healthy aquatic ecosystems, and to monitor and report on their status, will become commonplace. Crucial to this, however, is the prompt establishment, now, of standardized long term baseline programs, against which change can be measured. The importance of existing long term data sets to this monitoring will be recognized and supported (e.g., ELA, Turkey Lakes Area, etc.). An official network of strategically located monitoring stations covering Canada, with a common sampling protocol, would involve federal, provincial and territorial government agencies. Data would be deposited in a common data centre and made widely available through the Internet.

Standardized approaches that provide predictive capability through indicators, monitoring, and modeling will be in place in some areas, although more will be required. The public will expect governments to ensure environmentally responsible practices are in place to regulate development activities. Most industries will have moved to "green" operating codes of practices, given public demand in the marketplace to do so, but ongoing monitoring by government will be required. Municipalities will be slower to bring their wastewater and storm water operations into environmental compliance, although there will be several shining stars for others to emulate. Public interest in valuation of non-monetary benefits/costs will be high.

Integrated resource management (IRM) plans, watershed management and source water protection plans will have become normalized across Canada. These will contain fishery management plans as sub-components. Fisheries management will be risk-based, and structured around quantitative objectives and conservation reference points. Decisions will be made on pre-agreed harvest control rules and objectives. The degree of acceptable risk will be the subject of debate and will require means to resolve value judgments.

4.2.3.4 Fisheries Act and Fish Habitat Protection

Fish habitat protection will continue to be enshrined in the federal *Fisheries Act* and fish habitat policy. It will occur through partnerships between federal habitat and science staff, and with provincial agency, industry and stakeholder support. The habitat protection mandate of the *Fisheries Act* actually drives the need for DFO to apply an ecosystem approach.

Codes of practice and best management practices for industries involved in urban development, agriculture, aquaculture, mining and forest management, will provide, together with a regulatory backstop, reasonable assurance of fish habitat protection. Regular monitoring and reporting will be required of government, and the precautionary approach and adaptive management principles will be applied. Fish habitat science priority areas will continue to include ecosystem structure and function (including species identification, distribution monitoring, relationships between habitat and populations, and understanding of system-scale processes that create and maintain habitats), effects of habitat alteration; habitat restoration methods; impact and recovery indicators; and synthesis and information transfer, despite good progress over the preceding two decades. Successful fish habitat management will depend on a serious commitment to develop the science required to support critical decision-making. The need for assessment of, and refinements to, the classification of habitats will have emerged, particularly given its importance with respect to streamlining of habitat decisions.

The control of nutrients in water, such as phosphorous and nitrogen, will have met with widespread success, given public acceptance, effective technology and strict regulation. However, there will still be serious freshwater nutrient problems to address, and in the case of the Great Lakes, abatement programs will have increasingly created issues regarding insufficient lake-wide productivity.

4.2.3.5 Invasive Species

By 2020 the shipping industry will operate under strict environmental controls (prescribed by international convention), given the legacy of environmental disruption and economic impacts that has taken place over the preceding four decades. A widened and deepened St. Lawrence Seaway (as proposed) would see even larger vessels arriving from more locations. Movement of live aquatic species for the food and pet (aquaria) markets will also be strictly regulated and enforced. However, there will be a constant need to conduct risk assessments on species proposed for distribution in Canada. Water diversion projects will continue to pose a risk for the introduction of invasive species and effective means to eliminate that risk may not be available. Freshwater ecosystems will have become even more permeable to new alien invasive species as increasing numbers of new species have become introduced, and intensive fishing has continued. For a period of time, large freshwater systems such as the Great Lakes will exist in a chaotic state, as new species arrive and disrupt already destabilized aquatic communities.

4.2.4 Climate Change Impacts

Some of the greatest threats to freshwater ecosystem stability over the next century are anticipated to result from the influences of climate change on the terrestrial and hydrological components of Canadian watersheds. While the rate of change continues to be the subject of debate, it is clear that non-linear change is occurring, and that even minor warming will impact the quality and quantity of Canadian freshwater ecosystems in significant ways. The following are some possible projections and their consequences.

Canada's watercourses will change in response to increased air and water temperatures as well as to altered precipitation patterns in spatially and temporally complex ways coupled with changes in the landscape. Water supplies, lake levels, renewal times and connectivity are all likely to change from current conditions for many bodies of water. Wetlands will disappear and water tables will decline. The timing of state changes will also be altered; for example, ice-covered periods are expected to decrease and less precipitation will arrive as snow. Regular and relatively rapid fluctuations in lake levels (especially in the Great Lakes) will present challenges for commercial and recreational navigation, related boating support facilities (harbours, marinas), and hydropower generation. In western Canada, a reduction in water yields from shrinking snow and ice fields will affect stream flows. Changes in flows will mean a heavier reliance on reduced base flows, and corresponding intensified conflicts over water use. The effects of acidification will be increased in poorly buffered environments, and decreased water renewal rates will result in advanced eutrophication. Dissolved organic carbon will decrease in lakes as a result of climate warming and acidification which will allow greater penetration of ultraviolet radiation into waterbodies. Thermoclines in lakes will deepen, thereby reducing habitat available for cold-water species, and warming of streams may eliminate species such as brook trout from southern parts of their range.

The nature of the many changes in our watercourses will be further modified because of linkages to changes in the landscape. At the ecozone level for example, global warming will further melt ice fields and permafrost increasing "isostatic rebound" (uplifting the earth's crust) causing changes in waterways and endangering fisheries resources. The terrestrial portions of watersheds will also be modified by more local, climatically induced 'natural' disturbances (e.g., by increased fire frequency), which will alter the receiving waters. The watersheds will also be affected by altered human and wildlife pressures (e.g., northward migration of populations where climatic conditions become more hospitable), and will be subject to increased national and international demands for supplies of water.

Many aquatic food webs will become increasingly southern in character as warming proceeds. Food webs will be responding to increased surface water temperatures and to decreased cold-water habitat (including decreased ice-covered periods, decreased hypolimnetic volumes, and increased hypolimnetic temperatures). Such pressures will primarily impact cool- and cold-water biota, which will face additional stresses caused by competition from invading warmer southern species and the establishment of these exotics; for example, displacement of indigenous species will be the norm in major watersheds such as the Great Lakes. These changes will cause rapid and large-scale fluctuations in aquatic resources (i.e., increased instability), often with deleterious results for stakeholders and dependent economies, placing additional pressures on resource and political governance.

Global warming effects and increased developmental impacts on the Arctic will have stimulated public demand for scientific expertise on Arctic resources. This will be particularly evident with respect to freshwater fisheries and aquatic sciences, given the lack of academic attention they have received and the consequent dearth of technical expertise in the area.

4.3 Rapid Technological Advances

Remarkable advances in technology drive societal demand for new products and services as well as supporting scientific breakthroughs. ENGOs and the public expect governments to make use of current technologies to acquire and share the best possible scientific information. This allows effective public participation in decision-making. The following technological advances are expected to influence freshwater fisheries and aquatic sciences and the services that DFO provides in 2020:

Over the next two decades, science will increasingly be used to shape the future rather than solely to respond to issues. The five federal departments responsible for natural resource matters (5NR) will embrace the ecosystem approach by developing integrated geomatics applications for all major watersheds in Canada, in cooperation with a variety of essential partners (provinces, municipalities, academia, others). These systems will house water quality, water quantity, land-use activity, and fisheries thematic layers that can be referenced to document existing conditions and assess impacts of potential development. This technology, together with seamless access to shared data resources, will become essential in managing via complex partnerships and will improve data analysis capability for all partners. Further, GIS applications will allow new understanding of spatial relationships regarding resource components at various scales, and will improve ability to manage meta-data sets (e.g., ecological process modeling), by linking them to geospatially referenced attributes.

The world will have undergone a revolutionary expansion in its “connectivity,” the ability to share extensive knowledge between individuals regardless of geographic location, increasingly via wireless technology. This will allow a transfer of information amongst interested stakeholders at levels that are currently without precedent. However, obtaining, maintaining and managing extremely large data sets is very expensive and will require significant research and development funding. Nonetheless, increased use of integrative tools for holistic understanding of ecosystems, coupled with increased geospatial modeling/analysis of regional-scale patterns and other leading edge technological approaches, will generate quantum leaps in freshwater aquatic science and its contributions to effective decision-making.

Availability of advanced remote sensing technology (e.g., remote monitors, satellites, hydro acoustics) will drive public and agency demand for ecosystem monitoring. Such technology will become increasingly common on large inland lakes, and will significantly expand predictive capability regarding weather events and aquatic productivity. Moreover, demand for real-time information (e.g., navigation, weather, fish stocks, quota achievement) and availability of leading edge hydrographic technologies such as multi-beam scanners, coupled with laser and GPS technology, will combine to allow detailed representation of bottom topography and water depths for navigation, rapid management interventions, and precise fish habitat documentation. Expanded public use of new technologies (e.g., GPS equipped fish finders, underwater cameras, sonar and innovative tackle) will increase recreational and commercial fish harvesting efficiency and resulting catch.

On another front, increased use of “molecular” techniques for bio-monitoring (e.g., gene probes, biomarkers) and nanotechnology that allows minute instruments to explore internal conditions of organisms, will permit aquatic science to become much more effective and efficient in pursuing solutions to difficult problems. Biotechnology will play a major role in new methodologies for stock identification; it will also provide means to produce new vaccines, new organisms for habitat remediation, and of course genetically modified organisms. Another example will be significantly advanced fish aging technology that uses objective scientific tools (e.g., stable isotopes, etc.). Freshwater fisheries and aquatic science capability will benefit from related technologies developed by fields with much greater research capacity, such as health, the military, etc.

New technologies and methodologies will provide for rapid assessment of three critical aquatic population measures – abundance, production, and turnover. The relationship between greater fisheries exploitation rates (managing at the edge of sustainability) and increased cost of science will be well understood. In fact, in the entire aquatic science field, the complexity of resource issues, public demand for information, and availability of new technology will drive development of international consortia to share costs and knowledge/expertise.

The advent of the hydrogen economy, based on emerging fuel cell technologies and applications, will result in substantial environmental quality improvements due to reductions in fossil fuel emissions. Government agencies will be expected to lead the way in converting their equipment to more environmentally acceptable models. Canada will follow the (currently) proposed U.S. regulatory lead in requiring a significant proportion of all federal government vehicles and buildings to be powered and heated by hydrogen technology by the year 2020.

By the mid 2020s most of the developed world will have national climate services, functioning much as national weather services do now. Emphasis on global warming will have allowed development of capability to forecast climate impacts as general trends 5 – 10 years in advance and as annual impacts. Among other things, these services will assist in forecasting freshwater climatic conditions that may precede extreme events that impact on ecosystems and human activities and will provide advice on adaptation measures.

4.4 Governance and Accountability

By 2020, a significant shift in freshwater **governance** will have taken place, as the federal government has moved toward a more collaborative and inclusive model based on shared stewardship and responsibility. Issues centred on respective federal/provincial/territorial roles and responsibilities will have largely been rectified as a result of concerted efforts under an inter-jurisdictional agreement on cooperation. Aboriginal rights will continue to be of prime importance, and significant progress will have been made in establishing cooperative approaches to resource management. Public involvement in freshwater issue resolution will have become regularized as a normal way of doing business. Individual citizens, communities, interest groups, and industry will have become involved to a much greater extent in decision-making. In order to do this, resource information will have become much more accessible to them, and they will be able to contribute more effectively as a result.

Governments will still be at the centre of decision-making, and will be held accountable for the public trust, but will not be viewed as the sole sources of information. It is therefore important to build the capacity of governments to lead, and stakeholders to engage in the process of managing freshwater resources, now. Government science will have to be perceived as being fully independent of policy bias, thorough, objective and inclusive in its development.

DFO will work in close collaboration with other federal departments (Environment, Health) and provincial agencies in safeguarding water quality**,** given the strength of the *Fisheries Act* to protect freshwater environments, and societal needs and demands for such protection. Clarification of roles and responsibilities with respect to freshwater science will have continued to be a challenge during the early part of the century, given the number of federal and provincial agencies charged with mandates to address interrelated environmental and resource matters; but these issues will have been addressed through a variety of collaborative efforts and discussions. It is important that these discussions occur as soon as possible in order to be properly aligned for addressing the critical issues of the future. What will be clear, however, is the federal government responsibility and accountability for all aspects of the *Fisheries Act* in fresh water. Routine consultation with partners as part of inclusive, integrated decision-making will benefit from highly organized and professional non-government organizations and community groups, many of whom employ staff technical advisors. Aboriginal fishers will have assumed greater responsibility for managing and protecting freshwater fisheries, particularly in the far north, and will need scientific support and advice.

Resource agencies will prepare long-range strategic forecasts, including reviews of where they are, and where they will need to be, regarding a number of policy matters. Policy and supporting science initiatives will be well integrated into a "Total Policy Approach" that incorporates management, policy and supporting science, rather than each being developed in relative isolation.

The public will demand an even higher standard of government **accountability**, both to Canadians and to the international community. International (e.g., NAFTA; possibly Americas Free Trade Agreement) and legal challenges will require Canada to demonstrate adherence to environmental legislation and policies, and to provisions prohibiting unfair trade practices or subsidies. This will be accompanied by an onslaught of environmentally based litigation against development proposals or activities (past, present and future). Requests for access to information by environmental non-government organizations (ENGOs) will increase and information will have to be provided according to legislated requirements (e.g., ATIP), consuming staff resources.

Public outrage will focus on government and industry responsibilities following a major environmental catastrophe, affecting marine and/or freshwater resources in Canada. The question will be asked, *"Who is responsible, and have they been adequately prepared, as required by law?"* Complexity of issues and high profile crises such as this will diminish public confidence in government science and decision-making. Further, issues such as the perceived lack of application of the "no net loss" guiding principle with respect to certain development activities (e.g., whole lake dewatering for mining, hydropower rule curves) will result in the need for increased scientific consideration of these practices. Uneven application of habitat provisions of the *Fisheries Act* by DFO across provinces will also be a source of complaint by the public of poorly serviced jurisdictions.

Science programs of ENGOs will have continued to increase in quality and sophistication. In addition to advocating for specific perspectives, ENGOs also will be regularly reporting their results and interpretation of data to decision-makers and the public. Further, government science will be carefully scrutinized by outside groups and industry who will seek government (and all other relevant) data more regularly for their own analysis and application, potentially drawing different conclusions. Science certification programs will have been initiated in order to ensure standardization in approaches. An impartial review body will be required to do this, such as is the mandate of the National Academy of Science in the United States. The Royal Society in Canada has regularly advocated this approach.

Society and ENGOs will insist on establishment of environmental objectives and indicators, along with monitoring and reporting on the state of the environment/resources. This will be accompanied by demands for achieving net gains in quantity and quality of freshwater fisheries and aquatic resources, rather than on simply protecting what is left. Examples include increased use of aquatic protected areas for this purpose.

Canadian support to aboriginal communities and developing countries for subsistence fisheries and freshwater management will increase, particularly in expanding capacity in resource sectors.

4.4.1 Partnerships

By 2020, advanced technology will have amplified the capacity to integrate massive and diverse sets of data, and to translate that information into useful knowledge. The drive to optimize benefits from available expertise and funding will continue to foster partnerships. For example, new partnerships with health science practitioners will yield significant technological benefits. While financial considerations will continue to figure prominently, partnership formation and adjustment will increasingly be driven by dominant science needs (e.g., Great Lakes, Arctic). Research teams, including non-DFO experts, will contribute to resolving issues associated with partnering.

Although government will have a significant responsibility for collection of resource baseline data, others including industry will have a role to play in this function, particularly as it relates to environmental assessment obligations. Accordingly, social sciences will increasingly be an accepted source of knowledge for conservation and management of aquatic resources. Along with assessments of the value of resources, this will assist in demonstrating the full societal consequences of management decisions. Once linkages are built with social scientists, the impact and use of this information will expand. This brings with it the challenge that there will be more partisan debate about all science results. In turn, this will require formation of decision-making bodies that function under high-level policies as administrative tribunals to reach transparent and consistent decisions in disputed cases.

These arrangements will require responsive and enabling financial and administrative processes. New approaches to funding will continue to be required, such as that needed for regular support of research done by other partners, as practiced by DFO in the Experimental Lakes Area in Northwestern Ontario. While this will still result in federal science staff seeking funds, significant advances will have been made in developing funding models (e.g., centres of excellence; funding specialists; supportive administrative policies), that will allow scientists to optimize time spent on research versus administration by 2020.

It must also be recognized that some science will require adaptive management at a broad scale. This needs multi-agency planning involving policy/management and science, and a willingness to use multiple locations to increase the opportunity to learn. Habitat science, in particular, needs to be designed as a series of complementary experiments, taking full advantage of mitigation and compensation conditions that are imposed every year.

4.4.2 Scientific Expertise, Recruitment and Career Development

Challenges in recruiting and retaining aquatic scientists will exacerbate increased loss of aquatic science specialists through retirements and shifting careers. Many of the needs for skilled aquatic scientists are in fields for which there will continue to be a dearth of university programs. Close linkages between resource agencies and academic institutions will be extremely important to ensure strategic science priorities inform graduate programs' designs, to produce the scientific expertise required (e.g., ecosystem functioning and modeling, biodiversity understanding, Arctic ecosystem monitoring and modeling). At the same time, aquatic science will need to continue as part of the culture of resource management agencies, both for the in-house scientific advice this provides, and for the sound understanding of resource issues faced by the agency.

The federal government will need to strive to provide attractive career opportunities to maintain a cadre of the brightest and the best, at a time when aquatic science agencies will target young researchers' interests and aspirations. In order to do so, it will have to offer not only competitive salaries, but well equipped facilities and adequate operating budgets. There will be a whole new way of doing science and measuring/rewarding performance. There will be unprecedented opportunities for discovery, which will be realized by extremely talented researchers.

Aquatic scientists and their organizations will benefit from rotations between employers (government, industry, academia), and from marine/freshwater position rotations. While they currently do not conduct much work on biology and taxonomy, well before 2020 universities will be responsible for providing basic knowledge about species of interest (e.g., biology, taxonomy, SAR) and for training scientists in these areas, as governments focus more broadly on long term science required to support ecosystem, community, population and habitat decisions.

5.0 Science Needs and Expectations for 2020

The science that will be needed in 2020 will be based on the set of formal commitments in place that oblige governments to take action (legislation, agreements, accords), and the primary social and environmental drivers of the day, as described above. Science will be needed to support a risk management framework for decision-making. The science needed will involve both a continuation of current efforts that will have to be expanded, as well as science in new and prominent areas.

5.1 Using an Ecosystem Approach

By the year 2020 it is expected that significant advances in employing an ecosystem approach to aquatic resource protection and management will have been made. This is based on the prevalent drivers of meeting specific legislative requirements, conserving natural biodiversity (habitat protection, addressing species at risk and invasive species challenges), addressing environmental risks to human health, and competing demands for water. Significant progress will have been made due to rapid advances in supporting technology, which will have assisted with improved ecosystem understanding and modeling.

Scientific activities that will be required to deliver and continually refine an ecosystem approach are far-reaching and complex, crossing departmental and jurisdictional mandates, and requiring input and collaboration from all involved stakeholders (governments, aboriginal people, academia, industry and NGOs). Key activities/knowledge relevant to DFO include:

- Development of indicators, standards and monitoring programs to measure and document freshwater ecosystem health, and prepare state of the environment reports;
- Science to support management planning decisions such as setting objectives for fish production, habitat requirements and sustainable development needs;
- Improved models of ecosystem form and function to improve predictive capability in the following areas:
  - to assess the impacts of cumulative development (municipal, industrial, cottage, recreational, water power, resource extraction) on a water body and a watershed scale, and how to mitigate their effects;
  - to assist in the ecologically sound allocation of water resources;
  - to assist in determination of minimum volume, flow and quality standards for sustaining aquatic resources;
  - to predict the impacts of various aquatic community shifts due to fish harvesting, introduced species and productivity changes;
  - to understand how introduced species change food webs (energy flow through the system) and how this impacts contaminants and sustainable harvest levels of target species;
- Improved understanding of small scale and large scale hydroelectric power generation impacts (e.g., reservoir production, water level and flow regimes);
- Assessment of the cumulative impacts of proposed water diversion schemes (flow alteration, contaminant discharges, species introductions, barriers to fish movement, changes to oxygen and temperature regimes);
- Development and use of cost effective integrating technology to collect on-going data (e.g., monitors employed on remote hydrographic platforms);
- Scientifically sound monitoring programs to define baselines that will allow detection of change in aquatic ecosystems over time (these programs are needed immediately for comparison by 2020), including continuation of existing long term data sets at established locations (e.g., Experimental Lakes Area – NW Ontario, Turkey Lakes – N Ontario);
- Improved understanding of Canada's hydrologic landscape and how it will be altered by climatic change, especially in response to changes in precipitation patterns and geomorphic responses brought on by retreating snow/ice cover and permafrost; and
- Understanding how climatic forces and their consequences will cumulatively interact with other stressors (e.g., contaminants such as pharmaceuticals and mercury, eutrophication, acidification and invasive species) that aquatic ecosystems are already subjected to.

These activities will require expertise in the following specialty areas: system modeling, aquatic ecology, contaminant flow modeling, hydrology, limnology, watershed science, taxonomy, toxicology, electronic engineering, climatology, and geomatics.

<u>Fisheries and Aquatic Ecology in the Arctic</u>

Application of an ecosystem approach will be particularly important in Canada’s northern areas where ecosystems are especially sensitive to disturbance, and subject to significant modification as a result of climate change. Science activities that will be required include:

- Baseline biodiversity data establishment (as reference benchmarks) for areas that are likely to undergo anthropogenic disturbance (e.g., access roads, mining, new shipping activity, ecotourism);
- Identification of locations for ballast water exchange that pose minimal environmental risk, particularly to freshwater ecosystems;
- Assessment of the environmental impacts of shipping traffic, particularly those with high risk cargoes (e.g., petroleum products) that may impact freshwater river systems, or migratory stocks of fish;
- Science to support increased pressure on Arctic resources due to human population growth and tourism (e.g., habitat protection, management of fishing pressure); and
- Long term core Arctic research commitments.

Areas of expertise that will be required to meet DFO science needs in the Arctic include: northern applications of limnology, ichthyology, aquatic ecology, risk assessment, population biology, and environmental impact assessment.

<u>Contaminants in Freshwater Ecosystems</u>
Provision of strong scientific information by DFO and its partners on the existence and dynamics of contaminants in the aquatic environment will include such science activities/knowledge as:

- Continued research on the presence of mercury and a range of other contaminants, their effects on fish and aquatic ecosystems, mitigation techniques, and detection in fish intended for human consumption;
- Ways to analyze effects at early stages of exposure to contaminants (e.g., herbicides, pesticides, endocrine mimics, pharmaceutical residues, etc.) by fish and their habitats in order to prevent catastrophic disruption of ecosystems, including collapse of fish populations and aquatic communities;
- Improved understanding of contaminants in reservoir water; and
- Improved understanding of groundwater and surface water dynamics in relation to human impacts and environmental risks.

Specific areas of expertise that will be required to provide this science include: contaminant modeling, biochemistry, physiology, and limnology.

5.2 Freshwater Aquatic Populations and Habitats

Canada's well-developed stewardship ethic will drive strong expectations for environmental protection in the face of unprecedented economic development and use of natural resources in 2020. The public will expect government to understand very clearly, the aquatic resources and values at risk with respect to development and the use of lands and waters. Clear and effective scientifically based regulatory standards, supported by industry sector codes of practice/ethics and best management practices (developed by industry in cooperation with government) will form the basis for environmentally responsible economic development. DFO and its partners will be expected to manage and protect aquatic populations and habitats through such science based measures and knowledge as:

- Understanding how fish productivity is affected by changing water quality and over-fishing, as a result of increased activity;
- Evaluation of environmental impacts of increased boating, including physical damage, pollutants, contaminants, and dockage; and assessing the risks to fish habitat and productivity from a variety of development activities;
- Inventories of habitats and fish populations before, during and after development activities;
- Capability to rapidly assess fish stock abundance and growth potential including population dynamics modeling; and
- Monitoring programs, diagnostic tools, etc. to address new diseases in aquatic species (previously undetected), resulting from environmental perturbations (e.g., invasive species, climate change).

<u>Population Management</u>

- Improved understanding of how to manage fishing effort to maintain sustainable wild stocks;
- Techniques to assess efficiencies of new recreational technologies and to manage their use;
- Enhancing recovery of severely over-exploited recreational fisheries caused by increased effort and catching proficiency;
- Where and how enhanced fish production (prime fishing sites) could be established and maintained;
- Potential harvesting strategies for introduced species, as they become established, and on their role in the aquatic community;
- Understanding of where "aquatic protected areas" would be most effectively located, their size, characteristics and functionality, once established;
- Biological inventories of species at risk; and
- Improved understanding of the level of protection and monitoring required before species become at risk.

<u>Habitat Protection</u>

- Fish habitat research priorities including tools to quantify impacts, that will stand up in court for prosecutions under the *Fisheries Act* (e.g., effectiveness of compensation and mitigation measures; quantitative assessment tools to determine In-stream Flow Needs (IFN); methods to quantify habitat productivity and link fish to habitat through functional and mechanistic modeling; impact of physical alterations on habitat productivity; cumulative impact assessments; and riparian plantings and buffer zone guidelines). While some of these examples are current priorities, the habitat management program will still require scientific input for the tools that are used to assess development proposals. These tools will need to be refined and made applicable to a wide range of geographic locations as industry expands, particularly in the north;

- Understanding of impacts on productivity involving conversions from river to reservoir ecosystems and science to support decisions on acceptable flow regimes;
- Assessments of risk regarding new proposals, fate of various contaminants and discharges on ecosystems, particularly in the north;
- Evaluation of the effectiveness of compliance and decommissioning practices;
- Science will still be needed with respect to pre and post development nutrient levels, nutrient loading and methods to control it, and it will also be important in establishing predetermined, desirable levels and how to maintain productivity in light of phosphorous controls and organisms such as zebra mussels;
- Full understanding of the linkage between agricultural land-use practices and downstream impacts for both nutrients and a wide range of chemicals used to manage crops and animals;
- Determination of aquatic habitats most vulnerable to climatic-based changes, and the nature of these vulnerabilities, to assess whether protection of ecosystems is required or possible, and to identify those habitats and species that need additional protection; and
- Increased scientific understanding of certain development activities (e.g., whole lake dewatering for mining, hydropower rule curves) to assist in policy formulation.

Areas of expertise that will be required by DFO to address population and habitat science needs include: physical and chemical limnology, population dynamics, aquatic ecology, production modeling, presentation of court evidence, risk assessment, fish health/disease, and environmental assessment.

5.3 Freshwater Species

Science will be needed with respect to individual freshwater species as a result of strong public demand to conserve natural biodiversity, recover species at risk, and prevent the introduction of further alien invasive species. This need will be exacerbated by climate change, as ecosystems and habitats change, and species occurrences are modified.

Science activities that will be required in 2020 in order to gain an improved understanding of individual species include:

- Biological investigations for hundreds of freshwater species (to prevent additional species from becoming at risk, and to effectively recover species that are already at risk), including habitat requirements at various life stages, natural history documentation, impacts of various disturbances, and susceptibility to fishing gear (along with degree of acceptable risk if fishing is to continue);
- Sound science to evaluate the risks of species introductions, development of preventative techniques, and potentially, control measures in the face of constant threat of introductions of additional alien invasive species via ballast water, the live food fish and aquaria trade, and the bait industry (this will be particularly true in the Arctic, once increased shipping begins to occur in formerly pristine areas); and
- Assessments of risk with respect to aquaculture will be required in order to respond to new technologies (net culture, pump-a-shore), proposals to raise additional non-indigenous species, genetically engineered organisms, and water farming in new locations.

Areas of particular expertise that DFO will be required to apply include: taxonomy, ichthyology, systematics, limnology, natural history, and risk assessment, much of which can be acquired through collaborative efforts with academia and industry.

5.4 Information Management and New Technologies

The public will expect improved management of scientific information to support new governance models that call for open, transparent partnerships and full accountability for expenditures and management decisions. Partners will be aware of the need for and will insist on comprehensive data systems to support implementation of an ecosystem approach. The public will also demand use of state of the art technologies by governments for effective decision-making, and will want to have information such as hydrographic data delivered using the latest technology available.

The scientific activities that will be required in order to meet expectations for improved information management include:

- Ready electronic provision of scientific data to management partners and the public immediately following its collection and analysis;
- Continued improvements in technical approaches to large data set management;
- Increased emphasis on securing scientific data, once collected;
- Improved understanding of spatial analysis and staff trained to do this;
- Provision of aquatic information for value-added product development (e.g. hydrographic map production for specific areas, once data is collected) for public and business interests;
- Geomatics standards and guidelines to develop specific resource data layers; and
- Increased understanding of the linkage between measured parameters and management decisions (harvest levels, annual production).

Scientific activities that will be expected to occur as a result of the availability of new technology will include:

- Application of remote sensing technology that allows “real time” monitoring and rapid techniques to report on resource status and/or ecosystem health;
- Research on how to effectively apply new hydrographic techniques for habitat management purposes;
- Use of nanotechnology, or use of minute recording instruments within organisms to better understand their habits and physiological needs;
- Development and use of capacity/fora for discussions and decisions regarding ethical considerations about such new technology as genetically modified organisms, and aquatic animal health issues;
- Continued research on the implications of improving technologies (e.g., depth sounders, cameras, attractants) in order to manage commercial and recreational fisheries on a sustainable basis; and
- Refinement and communication of emerging new tools.

The key areas of expertise that DFO will require in order to address scientific expectations with respect to information management and new technologies include: data management (entry, manipulation, storage, archiving, and retrieval), information management, systems operation, geomatics, electronics, remote sensing, nanotechnology and spatial analysis.

5.5 Socio-Economic Understanding

Public expectation for increased socio-economic understanding of freshwater fisheries and aquatic ecosystem management issues will be driven primarily by the demands of an increasing Canadian population, demographic change, and society’s priority on the environment and its sustainability. Given that climate change will be noticeably advanced, and Canadians and their management of freshwater ecosystems will increasingly need to continue to adapt, the types of socio-economic information/ understanding that will be expected in 2020 will include much greater emphasis on:

- Relationships between freshwater ecosystem alterations and socio-economic impact on commercial and recreational fisheries, aboriginal communities, resource-based tourism operations, various industries, shoreline property values, etc.;
- Social and economic assessments of new technologies perceived to present potential risks/benefits to fisheries and the aquatic environment (e.g., fishing gear, aquaculture “pump ashore” facilities);
- New approaches to provide valuation of non-monetary benefits/costs to assist in the fair valuation of water resources for their ecological as well as socio-economic importance;
- Decisions on “best use” of aquatic ecosystems in light of competing requirements/interests; and
- Economic research to support resource allocation policy decision-making.

Increased reliance on these non-traditional activities, particularly in relation to social sciences, in the management of freshwater fisheries and aquatic ecosystems will demand that DFO and its partners incorporate in their problem-solving and decision-making, excellence in such skills as: application of social and economic impact analyses to issues related to development, deterioration, protection, and/or restoration/enhancement of aquatic resources (environmental economics is one such emerging discipline); and “full cost accounting” (inclusion of all non-monetary benefits/costs, along with economics) for application of new technologies.

5.6 Hydrography

Public expectation for advanced hydrographic information will be driven primarily by an increase in shipping and recreational boating activity, along with the availability of improved technology. It will be heightened due to significant fluctuations in water levels associated with climate change and resulting risks to safe navigation.

The types of information that will be expected from the Canadian Hydrographic Service at this time will include:
- Full bottom images covering all shipping areas, provided both digitally and on high quality laminated charts;
- Regular chart updating/notices based on risk assessment priorities; and
- Significant new approaches in providing "real time" water depth, tide and current data generated and distributed electronically for navigational purposes, both for main routes and alternative emergency routes; this will include charted approaches to alternative deep-water service ports, particularly in the Arctic; all of this will support “trip-long” planning.

Scientific disciplines and specialty areas required for DFO to deliver this science will include: hydrography, electronic engineering and cartography.

5.7 Scientific Collaboration and Approaches

Society’s priority on the environment and its sustainability, coupled with rapid technological advances, and realities of demographic change and economic development pressures in 2020, will drive public expectations for holistic, open, and transparent collaboration amongst those determining aquatic science priorities, and those responsible for implementing them.

Canadians will expect DFO and its partners to have developed and implemented new collaborative approaches and skills in the following areas:
- Systems of institutional incentives to stimulate multi-disciplinary/multi-agency ecosystem management science teams and scientific collaboration between organizations inside and outside of government, removing barriers (e.g., funding eligibility, travel restrictions to meetings and conferences) and employing financial/administrative processes that support needed science partnerships;
- Codified regular review of roles and responsibilities for fresh water amongst federal agencies to clarify mandates and ensure effective processes exist to maintain and encourage meaningful collaboration;
- Advanced understanding of how to integrate a broad range of information and develop coordinated strategic approaches (“total policy approach” – management, policy, science);
- Systematic, well refined, multi-disciplinary tracking of aquatic parameters to provide baselines and early indications of climate change impacts;
- Established Arctic science priorities amongst government agencies, with universities supporting research and graduate programs in these areas;
- Certification systems for science-related decision processes (i.e., transparent and inclusive approaches for considering the issues and determining priorities for allocation of effort/funds); environmental risk assessment models; data acquisition, management, and accessibility standards; and peer reviewed publications;
- Ability to objectively forecast long-range science needs, and a regular process to adjust priorities to bring science capability in line with anticipated needs; and
- Integration of social and economic science, and traditional ecological knowledge (TEK) (through increased aboriginal participation in fisheries) with other scientific knowledge.

It will also be expected that science will continue to and increasingly include the following approaches:
- Sustained efforts to demonstrate the relationship between human health concerns and more general aquatic ecosystem health and management (what is good for fish is good for humans);
- Emphasis on the common public good in science to support recovery projects rather than a sole focus on benefits to a single resource use;
- Teams of scientists that are both flexible and nimble so they can shift between priorities, using available funding sources, including increased use of “centres of excellence” developed

collaboratively between governments and academic institutions (recognizing that a great deal of aquatic science requires focus and long term commitment to advance understanding appreciably);
- Collaborative fisheries science support and advice for aboriginal fisheries;
- Efficient and timely provision of information in response to public requests under Access to Information legislation (ATIP); and
- Aquatic science capacity to articulate needs/commitments including funding requirements, to establish priorities for them, to deliver them, and to report on their progress and value for money.

6.0 Aquatic Science Shifts by 2020

Science capacities required in 2020 to meet the needs envisioned in this paper represent a considerable divergence from current strengths in Canadian aquatic science. New areas of scientific excellence will be required, and strengthening of several current activities will be needed.

It is important, however, to recognize that the shifts are in large part additive, and will not replace the science that is done today by DFO. The requirement for data on fisheries resource and habitat status, as well as reliable hydrographic charting will continue to be a pressing need. Research needs for economically important fish species, fish population dynamics, human use patterns, genetics and taxonomy, contaminant models and models of developmental impacts on fish and fish habitats, including water quality and quantity, will continue to increase in importance and urgency. Work will have to occur on a broader range of species (species at risk, additional ecosystem components, introduced species), critical abundance thresholds, and systems under stress that are experiencing dramatic fluctuations. Initiation of many of the required shifts cannot wait as they will take time to mobilize.

Major new areas of freshwater science that are required include:

1. <u>Application of New Technologies to Freshwater Resource and Environmental Management</u>

Application of rapidly emerging technologies first requires the capability to identify them, so they can be matched to priority science challenges. Having determined the potential "fit," expertise is then required to apply the optimal mix of technologies and techniques to the problem at hand. Strategic investment must be made in leading edge technology development, and application to aquatic science issues and opportunities. The needed expertise must also be available to apply that technology effectively. Emerging new technologies that appear to offer exciting potential for application to the aquatic science needs of 2020 include: integrating information management technology (geomatics, extremely large data processing capability); advanced remote sensing technology (high resolution satellite imagery, hydro-acoustics, GPS); multi-beam sonar; gene banks (for *SARA*); genetic probes/ biomarkers; nanotechnology, and molecular techniques for bio-monitoring and tissue analysis.

2. <u>Practitioners Skilled in Freshwater Resource and Environmental Information Management</u>

Emerging data standards, information management protocols and the need for information sharing with partners will require a shift towards practitioners skilled in these matters in order to keep pace with and capitalize on growth in new technologies, science, innovative approaches, and societal needs.

3. <u>Integration of Social Sciences and Traditional Ecological Knowledge into Aquatic Science</u>

The inclusive governance environment envisioned in 2020 will demand a holistic approach to the prevailing aquatic ecosystem issues. The high value placed on sound science will be followed closely by the value ascribed to contributions from the social sciences, and from traditional ecological knowledge (TEK), where it is available. In fact, the way to do this business will be regarded widely as a healthy blend of pertinent contributions from all three sources. There will be a premium on scientists who can effectively work across these fields and integrate the strengths of each into a systematic whole. A broadly shared understanding of a hierarchy of values, along with associated ethical considerations, will be major changes to the *status quo* in bridging between social, economic, and aquatic sciences.

4. Government Accountability and Partnership Models

Despite its many challenges, the use of partnering to acquire freshwater science will be driven by the needs and willingness of partners to collaborate to meet their individual and collective mandates. For DFO, that means fulfilling its stewardship role for Canadians to conserve and protect fishery resources (i.e., fish, fish productivity, fish habitats, and aquatic ecosystems, all intertwined but with fish as the nexus).

Holistic and inclusive approaches to aquatic science, derived from a maturing ecosystem approach and participative governance model, will demand effectively functioning multi-disciplinary teams of scientists. The breadth of expertise required for any given situation could well span several government departments and jurisdictions, and bridge to academia, outside science organizations, ENGOs, and industry. Clearly, partnership arrangements will have to be easily facilitated and not bound up in red tape within and between the various organizations involved. Practitioners in this field will have to be adept at recognizing value-added partnering opportunities and possess the aptitude and inclination to thrive in such an environment. Early development of improved partnership and funding/administrative models (e.g., centres of excellence model; or staff trained to develop partnerships and assist scientists in submitting funding proposals) will be required, as will substantially improved administrative guidelines for funding and implementation. Effective interagency and inter-disciplinary partnerships and protocols will optimize benefits from the talents, technology, and fiscal resources available.

Despite the strong need for more enabling administrative arrangements, government will still be accountable (as will partners) to their constituencies for cost effective expenditures, and for making valid, well-informed decisions for aquatic resource management. At the same time, partnerships will not absolve governments of accountability for their mandated responsibilities, nor others of their respective regulatory or contractual obligations.

5. Collaboration with Universities

By 2020, it will be critical that aquatic science organizations maintain enhanced working relationships with universities. Close collaboration will be required to ensure that graduates skilled in the priority areas for aquatic science will be available. Key needs will include practitioners in emerging areas of aquatic science (e.g., system level, high tech) and undersupplied but critical fields (e.g., Arctic systems, taxonomy, species biology, toxicology, limnology), as well as basic fisheries and environmental science. Close collaboration in ensuring the needed supply of talent through graduate programs will yield additional benefits. Graduate programs will be focused on specific aquatic science problem areas while still being ecosystem based and holistic. The results of the graduate work will contribute to the body of science in particularly challenging areas. Synergistic efforts between government and academic scientists should be supported through co-operative research networks to produce integrated designs and synthesis of independent studies.

Strengthened activity and commitment to current areas of aquatic science will also be important and include:

1. Conservation of Natural Biodiversity and the Ecosystem Approach

The science needed for successful protection of natural biodiversity and effective application of the ecosystem approach in fisheries and environmental management in 2020 will require a much better understanding than presently exists. This applies to a suite of critical components including 1) determination/confirmation of indicators for fisheries and aquatic ecosystem health; 2) design and implementation of monitoring systems to track these indicators; 3) cost-effective data gathering technology and techniques that permit "real time" geo-referenced data streams; 4) effective communications capacity to rapidly transmit this data; 5) rapid information management and geomatics capacity to translate "real time" data streams into useable information ("near real time"); and 6) skilled scientists to do all of this and to analyze and collate the information into useable knowledge for application to prompt reporting on the state of the resource/environment, provision of advice to decision-makers, and advancement of the science.

2. Water Use and Allocation Models

Ultimately, aquatic science is about uses of water. Society's ever-increasing need for fresh water for a variety of essential purposes, including maintaining healthy aquatic ecosystems, will drive the requirement for development and maintenance of sophisticated water allocation models. Climate change will escalate the urgency. Equity and sound science will be the cornerstone imperatives of these predictive models and knowledgeable practitioners must be available to deliver them.

3. Species at Risk

Building on the first science shift listed above, effective science-based strategies to provide early warning of species heading for trouble will be in high demand. Further, strategies to then prevent such species from becoming threatened or endangered will depend on sound science, including evaluation of results over time, backed by courageous policy making. Science to assist in minimizing impact of invasive species on species at risk also will be critical. Development and delivery of science-based recovery plans for species at risk will be a common activity. The current lack of expertise in these areas will require a significant shift in focus, starting immediately.

4. Arctic Science

Given the rapid expansion in development activities expected to occur in the Arctic over the next two decades, it is critical now to begin to develop an expanded scientific capacity to acquire information and provide advice on sustainable development approaches in this less productive and fragile environment. Such capacity is extremely limited at this time, and governments and academia will have to refocus efforts very soon to avert disaster.

5. Aquaculture

A much larger aquaculture industry will have embraced new technologies and will have significantly expanded its potential influence on the landscape by 2020. Increases in the use of genetically altered organisms and an increasing number of cultured species will place greater demands on scientific understanding of how best to foster this industry's development, but at the same time, elicit confidence that the aquatic environment will be protected from potentially negative impacts.

6. Recovery of Over-exploited Fisheries

Over-exploited fisheries will be common in 2020, resulting from years of reduced water flows and unrelenting fishing pressure. These fisheries will be concentrated in highly accessible and urban areas, but will extend well beyond. Recognizing that many species live longer than twenty years, the science of managing to restore such depressed fisheries will require the integrated efforts of basic fisheries management science together with the best social science and TEK. This challenge will require the ability of scientists and managers to function effectively in often politically volatile situations.

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9.0 Appendices

Appendix 1. **Vision and Roles of Science and Technology in the Canadian Government**

Appendix 2. **Jurisdiction and Legal Mandate**

Appendix 1. Vision and Roles of Science and Technology in the Canadian Government

VISION FOR CANADIAN GOVERNMENT LEADERSHIP IN SCIENCE AND TECHNOLOGY : *WORKING TOGETHER FOR SCIENCE EXCELLENCE AND SERVICE TO CANADIANS*

The Government of Canada will enhance its research, development and scientific services in order to secure Canada's place as a world leader in innovation, opportunity and quality of life.

The federal government's science and technology (S&T) efforts will identify emerging issues that matter to Canadians, and refocus in response to changing needs in areas such as health and safety, public security, natural resources and the environment, and the growth of the knowledge economy.

Federal scientists will mobilize science resources in the search for innovative and lasting solutions to the challenges ahead. They will sustain their efforts until solutions are found and adopted.

Recognizing that teamwork sparks creativity and improves the use of resources, the Government will better integrate its scientific activities across departments and disciplines, including the natural and social sciences and policy analysis. It will also build more research teams with partners such as Canadian universities, Canadian industry and with scientific institutions in other countries. And it will work with the private sector to develop knowledge and technologies that serve the greater public good.

These combined efforts will contribute consistently to the development of better policies and the delivery of superior services throughout the federal government.

The Government values its outstanding scientists, engineers and technologists, and will invest the resources necessary to attract, develop and support them in the performance of consistently excellent work.

Federal scientists will build on their reputation as prime sources of credible, useful and trusted information for Canadians, because science is valued by Canadians and should be part of everyday life in a confident and successful nation.

Council of Science & Technology Advisors' Roles for Science & Technology

Canada's Council of Science and Technology Advisors (CSTA) has identified the four roles of government-performed science and technology as:

- support for decision-making, policy development, and regulations, for example, stock assessment, climate change, and sustainable development;
- support for public health, safety, environmental, or defense needs, for example, the protection of fish habitat and endangered species and monitoring of toxic algal blooms;
- development and management of standards such as the resolution of trade disputes, genetically modified food, and organisms; and
- enabling economic and social development, for instance, sustainable aquaculture development.

Appendix 2. Jurisdiction and Legal Mandate

DFO's future aquatic science responsibilities will still be built on the core legislation and instruments that set its present jurisdictional mandate. These include:

Legislation

- Section 91 (12) of the *Constitution Act*, 1867 (followed by the *Constitution Act*, 1982), which gives the federal government exclusive jurisdiction for Sea Coast and Inland fisheries. The federal government has responsibility for the protection and conservation of all fisheries.

- The *Fisheries Act* regulates the management of marine and inland fisheries, including commercial, recreational, and aboriginal fisheries, across Canada. The Act also sets out responsibilities with respect to the protection of fish habitat and pollution prevention, enforcement and regulation-making powers. Over the years, significant delegation of fisheries management administration to provinces has taken place through a range of instruments that vary in scope and format from jurisdiction to jurisdiction. The federal government has chosen to retain its responsibilities for the conservation and protection of fish habitat, working in cooperation with the provinces and territories.

- *Canada's Oceans Act* gives DFO overall responsibility for management of the Oceans and activities therein, and mandates that DFO apply an ecosystem approach, the precautionary approach, and integrated, inclusive planning and decision-making.

- *The Navigable Waters Protection Act* generally requires that any work built in a navigable water have DFO (Coast Guard) approval prior to construction, unless it does not interfere substantially with navigation.

- *The Canada Shipping Act*, 2001 (Part 8 – Pollution Prevention and Response; Part 10 – Pleasure Craft) addresses DFO's responsibilities regarding regulation/prohibition of discharge of pollutants from pleasure craft.

Many other federal Acts add to DFO's mandate, and the demands on aquatic science. Key among them are:

- The *Canadian Environmental Assessment Act (CEAA)* requires an environmental assessment (EA) of projects before a federal authority (e.g., DFO) issues a permit or approval. The *CEAA* Law List Regulation identifies federal statutory approvals that trigger and environmental assessment (EA). Sections of both the *Fisheries Act* and the Navigable Waters Protection Act trigger an EA under the *CEAA Law List Regulation*.

- The *Species at Risk Act (SARA)*, which is expected to come into effect in 2003, specifies a process for identifying species at risk of extinction, and assigns DFO, as jurisdictional authority for marine, anadromous and some freshwater fishes and marine mammals, responsibility for ensuring protection and recovery of listed species.

- *The Pest Control Products Act*

- The *Canadian Environmental Protection Act (CEPA)*, which provides authority to the Minister of Environment in many areas of relevance to freshwater, particularly dealing with pollution prevention and ecosystem health.

International Treaties and Agreements

These are augmented by a number of international treaties and instruments to which Canada subscribes. Some are sweeping in scope and broad in impact, including the *United Nations Convention on the Law of the Sea* (UNCLOS), Agenda 21 of the *United Nations Conference on the Environment and Development* (UNCED), the *Convention on Biological Diversity*, and the resolutions of the *World*

Symposium on Sustainable Development (2002). Others focus on particular regions, such as the *Pacific Salmon Treaty* and the *Northwest Atlantic Fisheries Organization* (NAFO) *Convention*, or specific activities such as the *Straddling Stocks Treaty*. Several address key freshwater concerns, such as the Canada – U.S. *Convention on Great Lakes Fisheries*, the Canada-U.S. *Boundary Waters Treaty*, and the *Great Lakes Water Quality Agreement* with the U.S. These bi-lateral and multi-lateral agreements, in turn have enabled a number of Commissions, such as the Great Lakes Fishery Commission, International Joint Commission, Pacific Salmon Commission, NAFO, and many others. All these Commissions address tasks requiring science support, often through their own Scientific Councils comprised of scientists from DFO and other member states/jurisdictions.

Article 14 of the *North American Agreement on Environmental Cooperation* (NAAEC) provides for submissions on enforcement matters. Any non-governmental organization or person may make a submission that a Party to the agreement is failing to effectively enforce its environmental law, and thus creating unfair trade practices. The scientific justification for enforcement decisions (either action or inaction) can therefore have profound international trade implications.

All of these instruments and their supporting Commissions have similar fundamental objectives of promoting sustainable economic uses of aquatic resources and conservation of aquatic ecosystems. Importantly, as highlighted in the recommendations in the *2001 Report of the Commissioner of the Environment and Sustainable Development* (Auditor General's Office), they also reinforce the requirement of strong and ongoing Canadian aquatic science support to achieve their goals of sustainable use and conservation.

Aboriginal Relationships

In addition to these international instruments, federal legislation, and federal-provincial agreements, Canada's aboriginal people have a crucial place in jurisdictional landscape relevant to aquatic sciences. The relationships between governments and aboriginal people are complex and continue to evolve through legal channels and other means. Aboriginal and treaty rights are protected under the *Constitution Act*, 1982 and have been elaborated on in a number of Supreme Court of Canada decisions. As partners in understanding and managing aquatic ecosystems, and as users of scientific advice and products, the evolving role of aboriginal people, too, brings greater demands for science support from DFO and its partners.

Policy Framework

Federal and departmental policies augment the legal foundation of DFO's mandate and the consequent demands for aquatic science. We are more likely to see changes in these policies than in the legislative framework, but the changes are likely to be adaptive, and not major repudiation of the course they lay out. The principles of the Social Union Contract will remain the basis for the relationship between government and civil society. The federal policy on Risk Management, the *Principles and Guidelines for Science Advice for Government Effectiveness* (SAGE), and for application of the Precautionary Approach/Principle will still be the basis for the role of science in governance. Governance will be participatory; science will inform and support.

Strategic Direction

DFO directs its medium-term planning within the legal and policy framework with its series of strategic plans, such as: 1) *Fisheries and Oceans Canada Strategic Plan: Moving Forward with Confidence and Credibility, 2000;* 2) *Setting a Course for the New Millennium: A Scientific Strategic Plan for Fisheries and Oceans Canada; and* 3) *Fisheries and Oceans Canada Sustainable Development Strategy: Building Awareness and Capacity – An Action Plan for Continued Sustainable Development 2001-2003*. These undergo significant revision at least twice a decade, and hence will determine much less about the expectations of aquatic science in 20 years. However, major department policies are more durable, such as *The Department of Fisheries and Oceans Policy for the Management of Fish Habitat, 1986*. Major policy overhauls of Atlantic and Pacific fisheries (*Atlantic Fishery Policy Review, Wild Salmon Policy, New Directions for Pacific Fisheries*) when implemented, may lay out the nature of fisheries and hence the needs for science information and advice, for many years to come. The *draft National Freshwater Fisheries Strategy, 2002* may do likewise for responsibilities and demands on science in freshwater systems. Some other areas of importance to the Department are currently addressed through strategy documents, such as the *Aboriginal Fisheries Strategy* and the *Aquaculture Strategy*, which may evolve over time into more formal policies. At all these stages, however, these areas, too, require significant science support for program and industry development and decision-making.

Interjurisdictional Agreements in Canada

The Government of Canada and DFO work with other levels of government to achieve their mandates, sometimes formalizing these arrangements in inter-jurisdictional agreements, which also translate into commitments for dedication of aquatic science program effort. Examples of these arrangements include the *Agreement on Interjurisdictional Cooperation with Respect to Fisheries and Aquaculture, 1999*, the *draft National Freshwater Fisheries Strategy, 2002*, and bilateral agreements on various themes with Alberta, British Columbia, New Brunswick, Ontario, and the Yukon. The special status of Wildlife Management Boards in the North is yet another aspect of the conservation and management of Canada's aquatic resources, and another area where aquatic sciences have a necessary role in provision of information and advice. The 2002 *Canada – Ontario Agreement respecting the Great Lakes Basin Ecosystem (COA)*, as a further example, supports domestic commitments under the Canada – U.S. *Great Lakes Water Quality Agreement*. DFO, along with Environment Canada and provincial agencies, has made specific commitments (requiring aquatic science support) to contribute to delivery of *COA* goals, results, and deliverables.