An Overview of Environmental Monitoring and its Significance in Resource and Environmental Management

February, 2011

Sarah Weston
Master of Resource and Environmental Management Candidate, School of Resource and Environmental Studies, Dalhousie University, CURA H_2O Project Coordinator, Saint Mary's University, 923 Robie Street, Halifax, Nova Scotia, Canada, B3H 3C3, Sarah.Weston@smu.ca

1.0 Introduction

Environmental monitoring can be defined as the systematic sampling of air, water, soil, and biota in order to observe and study the environment, as well as to derive knowledge from this process (Artiola *et al*., 2004; Wiersma, 2004). Monitoring can be conducted for a number of purposes, including to establish environmental "baselines, trends, and cumulative effects" (Mitchell, 2002, pg. 318), to test environmental modeling processes, to educate the public about environmental conditions, to inform policy design and decision-making, to ensure compliance with environmental regulations, to assess the effects of anthropogenic influences, or to conduct an inventory of natural resources (Mitchell, 2002). A list of additional purposes for monitoring is presented in Box 1, and this list helps to underscore the importance of monitoring and how its results are ubiquitous in our daily lives (Artiola *et al*., 2004).

Environmental monitoring programs can vary significantly in the scale of their spatial and temporal boundaries. For example, an endangered fish in a small stream and the viability of its short-term fate will require monitoring on short and localized temporal and spatial scales, while the management of natural resources that span a nation will require monitoring programs that are much broader in scale (Artiola *et al*., 2004). Monitoring programs can vary significantly in scope, ranging from community-based monitoring on a local scale, to large-scale collaborative global monitoring programs such as those focused on climate change (Conrad & Daoust, 2008; Lovett *et al*., 2007). A summary of spatial and temporal ranges of scale relevant to environmental monitoring is presented in Appendix A. Environmental monitoring is conducted by stewardship organizations, concerned individuals, non-governmental environmental organizations, private consulting firms, and government agencies.

In order for monitoring activities to be effective and to culminate into high quality sets of data, it is important to identify focused, relevant, and adaptive questions that can be used to guide the development of a monitoring plan (Lindenmayer & Likens, 2009; Lovett *et al*., 2007). The "seven habits of highly effective monitoring programs" have been identified by Lovett *et al*., 2007, and are presented in Appendix B of this paper. The successful management of an efficient monitoring program can be challenging, and environmental monitoring has been criticized as being ineffective, costly, and unscientific (Artiola *et al*., 2004; Lindenmayer & Likens, 2009; Lovett *et al*., 2007). However, it is also argued that monitoring can be conducted under a rigorous application of the scientific method (Artiola *et al*., 2004) and that it is a "fundamental component of environmental science and policy" (Lovett *et al*., 2007, pg. 253). Other fundamental components of effective monitoring programs include: the application of quality assurance and quality control measures during the data collection process, data storage and access, and the consultation of experienced statisticians during the sampling design process (Lindenmayer & Likens; McDonald, 2003; Wiersma, 2004).

• Protection of public water supplies • Weather forecasting • Hazardous, non-hazardous and radioactive waste management • Natural resources protection and management • Global climate change	• Urban air quality • Economic development and land planning • Population growth • Endangered species and biodiversity

Box 1: Knowledge-Based Regulation and Benefits of Environmental Monitoring
Source: Artiola et al., 2004, pg. 3

2.0 Environmental Components of Monitoring

The five spheres of the Earth System include the atmosphere, hydrosphere, biosphere, lithosphere, and cryosphere (De Blij *et al.,* 2005). This concept is illustrated in Figure 1. Environmental monitoring can be conducted on biotic and abiotic components of any of these spheres, and can be helpful in detecting baseline patterns and patterns of change in the *inter* and *intra* process relationships between and within these spheres. The interrelated processes that occur between the five spheres are characterized as physical, chemical, and biological processes. The sampling of air, water, and soil through environmental monitoring can produce data that can be used to understand the state and composition of the environment and its processes (Artiola *et al*., 2004; Wiersma, 2004).

Environmental monitoring uses a variety of equipment and techniques depending on the focus of the monitoring. For example, surface water quality monitoring can be measured using remotely deployed instruments, handheld in-situ instruments, or through the application of biomonitoring in assessing the benthic macro invertebrate community (CBEMN, 2010). In addition to techniques and instruments that are used during field work, remote sensing and satellite imagery can also be used to monitor larger scale parameters such as air pollution plumes or global sea surface temperatures (Mitchell, 2002; Artiola *et al*., 2004).

3.0 The Application of Environmental Monitoring

3.1 Community Level

The occurrence of organized, community-based environmental monitoring has been increasing in the last decade owing to an emerging global emphasis on the importance of sustainable

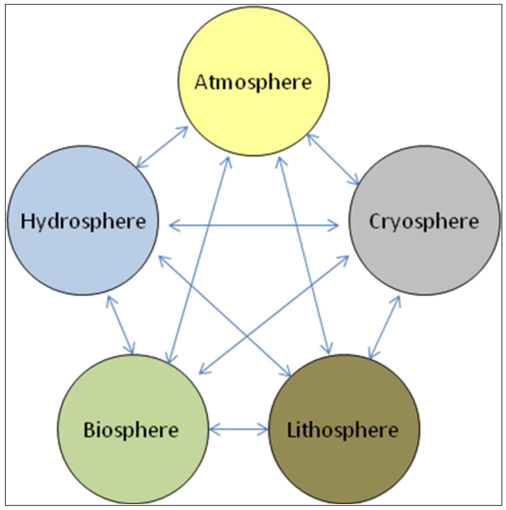

Figure 1: The five spheres of the Earth System
Source: De Blij et al., 2005

development (Conrad & Daoust, 2008). There is a global recognition that "environmental issues are best handled with the participation of all concerned citizens", a principal first articulated in the United Nation's Earth Summit Agenda 21 (UN, 1992). This principal was strengthened further in July, 2009, with the formal ratification of the Aarhus Convention which mandates participation by the public in environmental decision-making and access to justice in environmental matters (UNECE, 2008).

The Charles River Watershed Association (CWRA) in Massachusetts is one example of a stewardship organization that has established formal linkages with government in order to provide comprehensive data that is used by the Massachusetts Department of Environmental Protection in the decision-making process (CRWA, 2008). The CWRA has been conducting water quality monitoring on the Charles River since 1995, and the data set that has been compiled will assist managers in addressing harmful nitrogen and phosphorous loads present in the river (CRWA, 2008). Quality assurance and quality control measures have standardized the data collection process, and thus facilitated the compilation of an extensive, credible data set that would otherwise be beyond the reach of government resources alone.

3.2 Canada

In Canada, environmental monitoring on the national level is conducted by federal departments such as the Department of Fisheries and Oceans, Natural Resources, Environment Canada, and Parks Canada. On the provincial level, monitoring is conducted by parallel provincial government agencies.

The Ecological Monitoring and Assessment Network (EMAN) was established in 1994 in order to monitor and report on ecosystem changes at a national level (Environment Canada, 2010). A national network is capable of facilitating the central coordination of monitoring initiatives from all government agencies, and of providing comprehensive data to aid in effective, adaptive setting of policies and priorities (Vaughan *et al*., 2001). In 2008, EMAN was "reorganized within the Wildlife and Landscape Science Directorate" (Environment Canada, 2010). EMAN significantly enhanced national conservation and sustainability initiatives through comprehensive data collection and the potential for well informed decision-making (Vaughan *et al*., 2001), and its reorganization has resulted in an unfortunate loss of coordination and support for national scale environmental monitoring. An important component of EMAN's research that is still available following the reorganization are the standardized monitoring protocols that have been developed for marine, freshwater, and terrestrial ecosystems (Environment Canada, 2010). These protocols are available in the Ecological Monitoring section of Environment Canada's website (Environment Canada, 2010).

3.3 United States

In the United States, environmental monitoring is conducted by government agencies organized in an administrative structure similar to that found in Canada. Monitoring is undertaken by relevant state and federal departments, such as natural resource and environmental protection agencies (Artiola *et al*., 2004).

The Environmental Monitoring and Assessment Program (EMAP) was established by the national Environmental Protection Agency in 1990 in order to assess and monitor the trends and status of national ecological resources (Stevens, 1994; USEPA 2010). Field data was collected from 1990 until 2006 (USEPA, 2010). It is unclear why the EMAP program no longer exists and is no longer collecting data. Similar to EMAN in Canada, the EMAP program was intended to coordinate information sharing between all government agencies that are involved in conducting the monitoring of natural resources (Artiola *et al*., 2004). The discontinuation of the EMAP program is likely a loss of coordination and support for national scale environmental monitoring similar to the unfortunate loss of EMAN in Canada.

3.4 Internationally: Sweden as an example

The Swedish Environmental Protection Agency's (SEPA) national monitoring program is a comprehensive, ongoing, national monitoring program that facilitates knowledgeable state of the environment reporting and the nationwide protection of natural resources and the environment (SEPA, 2010). The SEPA has compiled valuable observation series that span the longest timescale of any existing observation series in the world, and the agency provides national coordination of monitoring initiatives in order to maximize the efficiency of monitoring programs across the country (SEPA, 2010). Monitoring data collected by national and municipal government agencies, private industry consultants monitoring for regulatory compliance, and non-governmental organizations is all vetted through SEPA to ensure quality and accuracy and is used to provide a comprehensive national data set that would be otherwise unfeasible to achieve through government resources alone (SEPA, 2010). Detailed monitoring guidance criteria and regulation are provided by SEPA to ensure consistency and quality assurance and quality control of data collected by different agencies and organizations (SEPA, 2010).

An additional strength of this program is that data records have been consistently maintained and are readily available through the Agency's website (SEPA, 2010). The national monitoring program has been divided into ten programme areas, each containing sub-programmes, in order to provide a comprehensive description and inventory of the state of the Swedish environment (SEPA, 2010). The ten programme areas include air, mountain areas, forests, agricultural land, landscapes, wetlands, freshwater, seas and coastal areas, health-related environmental monitoring, and toxic substances coordination (SEPA, 2010). Highly coordinated, national environmental monitoring is essential in order to maximize the efficiency of monitoring that is being conducted in separate government departments. National coordination can help to ensure that all areas of concern are being monitored and that there is no duplication of costly data collection by different departments. This type of national monitoring initiative presents a logical approach to addressing global environmental change that is occurring at an unprecedented rate and on an unprecedented scale, and Canada and the United States could certainly benefit from similarly structured national monitoring programs.

3.5 Global-Scale Monitoring Initiatives

There are several global-scale organizations that are responsible for the collection and distribution of environmental data internationally (Artiola *et al*., 2004). For example, there are multiple programs operated by the United Nations that participate in global environmental monitoring activities, such as the World Meteorological Organization (WMO), the Global Atmosphere Watch, and the World Conservation Monitoring Centre (Artiola *et al*., 2004; UNEP, 2011). The WMO, the World Weather Watch, and the World Health Organization collectively manage the Global Environment Monitoring System (GEMS), which is responsible for monitoring and reporting on the "global state of water, air, climate, atmosphere, and food contamination" (Artiola *et al*., 2004, pg. 7). Through the administration of these programs, the United Nations is providing a valuable mechanism for data collection and dissemination on a global scale, making it possible to address global scale issues such as water security and climate change (GEMS, 2011).

4.0 DISCUSSION AND CONCLUSIONS

Environmental monitoring is a necessary component of environmental science and policy design (Lovett *et al*., 2007). Despite criticisms that environmental monitoring can be ineffective and costly when programs are poorly planned, well-planned monitoring programs cost little in comparison to the resources that can be protected and the policy design that can be informed (Lovett *et al*., 2007). Successes and failures of monitoring programs in the preceding decades have been thoroughly analyzed by the scientific community, and practical solutions for addressing the standard challenges of monitoring programs are readily available in the scientific literature (Lindenmayer & Likens, 2009; Lovett *et al*., 2007). In order to achieve valuable results from environmental monitoring activities, it is necessary to adhere to sampling processes that are supported by the traditional scientific method (Artiola *et al*., 2004), and any effective monitoring program must include focused and relevant questions, appropriate research designs, high quality data collection and management, and careful analysis and interpretation of the results (Lovett *et al*., 2007).

Long-term monitoring programs are often faced by the challenge of securing long-term funding that will remaining stable in a dynamic political environment (Lindenmayer & Likens, 2009; Lovett *et al*., 2007). In light of the increasing frequency and magnitude of environmental issues that are emerging in this era of globalization, government funding institutions are encouraged to commit to meaningful, stable, and long-term funding of monitoring programs in acknowledgement of the cost savings associated with the protection of natural resources and the improved efficiency of policy design (Lovett *et al*., 2007). In order to encourage a greater commitment to monitoring on behalf of funding agencies, management relevancy, as well as the quality and effectiveness of monitoring programs, program design should include a collaborative effort on behalf of scientists, statisticians, policy makers, and natural resource managers (Lindenmayer & Likens, 2009).

Despite the challenges that are faced by environmental monitoring, monitoring remains an important tool in the achievement of major advances in environmental science (Lovett *et al*., 2007). One of the most prominent examples of the significance of environmental monitoring is in the record of atmospheric CO_2 concentrations recorded in Mauna Loa, Hawaii by Charles David Keeling (Lovett *et al*., 2007; Vaughan *et al*., 2001). This long-term record has led to an increased understanding and awareness of global climate change, one of the greatest environmental challenges that has ever been faced in human history. The relevance of environmental monitoring in environmental science and policy design is well-established. Environmental monitoring will continue to improve its methodology through advancements in modern science, and government and other funding institutions should increase meaningful, long-term funding towards the establishment of effective monitoring programs distributed from the local to global scales.

5.0 References

Artiola, J.F., Pepper, I.L., Brusseau, M. (Eds.). (2004). *Environmental Monitoring and Characterization*. Burlington, MA: Elsevier Academic Press.

The Charles River Watershed Association. (2008). *Science-Based Management*. Retrieved from http://www.crwa.org/aboutus.html

The Community-Based Environmental Monitoring Network (CBEMN). (2010). *The Environmental Stewardship Equipment Bank*. Retrieved from http://www.envnetwork.smu.ca/equipment.html

Conrad, C. and Daoust, T. (2008). “Community-Based Monitoring Frameworks: Increasing the Effectiveness of Environmental Stewardship” *Environmental Management 41*(3): 358-388

De Blij, H.J., Muller, P.O., Williams, R.S., Conrad, C., Long, P. (2005). *Physical Geography: the Global Environment*. Don Mills, ONT: Oxford University Press.

Environment Canada. (2010). *Ecological Monitoring*. Retrieved from http://www.ec.gc.ca/faunescience-wildlifescience/default.asp?lang=En&n=B0D89DF1-1

Global Environment Monitoring System. (2011). The world of water quality. Retrieved from http://www.gemswater.org/index.html

Lindenmayer, D.B., Likens, G.E. (2009). Adaptive monitoring: a new paradigm for long-term research and monitoring. *Trends in Ecology and Evolution, 24*(9), 482-486.

Lovett, G.M., Burns, D.A., Driscoll, C.T., Jenkins, J.C., Mitchells, M.J., Rustad, L., Shanley, J.B., Likens, G.E., Haeuber, R. (2007). Who needs environmental monitoring? *Frontiers in Ecology and the Environment, 5*(5), 253-260.

McDonald, T.L. (2003). Review of Environmental Monitoring methods: survey designs. *Environmental Monitoring and Assessment, 85*, 277-292.

Mitchell, B. (2002). *Resource and Environmental Management* (2^{nd} ed.). Harlow: Pearson

Education Limited.

Stevens, D.L. (1994). Implementation of a national monitoring program. *Journal of Environmental Management, 42*, 1-29.

(SEPA) Swedish Environmental Protection Agency. (2010). *Environmental Monitoring*. Retrieved from http://www.naturvardsverket.se/en/In-English/Menu/State-of-the-environment/Environmental-monitoring/

United Nations Economic Commission for Europe. (2008). *"Vision and Mission" of the Aarhus Convention Strategic Plan*, paragraph 4, adopted by the Meeting of the Parties to the Aarhus Convention, in Riga, Latvia, on 13 June 2008. Retrieved from http://www.unece.org/env/pp/

United Nations. (1992). *Earth Summit Agenda 21: the United Nations Programme of Action from Rio*. New York, New York, USA.

United Nations Environment Programme. (2011). *World Conservation Monitoring Centre*. Retrieved from: http://www.unep-wcmc.org/aboutWCMC/

United States Environmental Protection Agency. (2010). *Environmental Monitoring and Assessment Program*. Retrieved from http://www.epa.gov/emap/

Vaughan, H., Brydges, T., Fenech, A., Lumb, A. (2001). Monitoring long-term ecological changes through the Ecological Monitoring and Assessment Network: Science-based and policy relevant. *Environmental Monitoring and Assessment 67*: 3–28.

Wiersma, G.B. (Ed.) (2004). *Environmental Monitoring.* Boca Raton, FLA: CRC Press.

APPENDIX A

Spatial and Temporal Scales in Environmental Monitoring
Source: Artiola et al., 2004

Spatial:	**Temporal**:
Global – Earth - >10,000km	Geologic - > 10,000 years
Meso-continent, country, state - >100 km	Generation – lifetime – 20 to 100 years
Intermediate – watershed, river, lake - >1km	Annual > 1 year
Field – agricultural field, waste site > 1m	Seasonal - > 4 months
Macro – animal, plant, fungi, bacteria - > 1 µm	Daily - > 24 hours
Ultra-micro – virus, molecules - >1 nm	Hourly - > 60 minutes
Atomic – atoms, subatomic particles, < 1nm	Instantaneous - < 1 second

APPENDIX B

The seven habits of highly effective monitoring programs
Source: Lovett et al., 2007

Panel 1. The seven habits of highly effective monitoring programs*

(1) Design the program around clear and compelling scientific questions. Questions are crucial because they determine the variables measured, spatial extent of sampling, intensity and duration of the measurements, and, ultimately, the usefulness of the data.
(2) Include review, feedback, and adaptation in the design. The guiding questions may change over time, and the measurements should be designed to accommodate such changes. The program leaders should continually ask, "Are our questions still relevant and are the data still providing an answer?" The program should have the capacity to adapt to changing questions and incorporate changing technology without losing the continuity of its core measurements.
(3) Choose measurements carefully and with the future in mind. Not every variable can be monitored, and the core measurements selected should be important as either basic measures of system function, indicators of change, or variables of particular human interest. If the question involves monitoring change in a statistical population, measurements should be carefully chosen to provide a statistically representative sample of that population. Measurements should be as inexpensive as possible because the cost of the program may determine its long-term sustainability.
(4) Maintain quality and consistency of the data. The best way to ensure that data will *not* be used is to compromise quality or to change measurement methods or collection sites repeatedly. The confidence of future users of the data will depend entirely on the quality assurance program implemented at the outset. Sample collections and measurements should be rigorous, repeatable, well documented, and employ accepted methods. Methods should be changed only with great caution, and any changes should be recorded and accompanied by an extended period in which both the new and the old methods are used in parallel, to establish comparability.
(5) Plan for long-term data accessibility and sample archiving. Metadata should provide all the relevant details of collection, analysis, and data reduction. Raw data should be stored in an accessible form to allow new summaries or analyses if necessary. Raw data, metadata, and descriptions of procedures should be stored in multiple locations. Data collected with public funding should be made available promptly to the public. Policies of confidentiality, data ownership, and data hold-back times should be established at the outset. Archiving of soils, sediments, plant and animal material, and water and air samples provides an invaluable opportunity for re-analysis of these samples in the future.
(6) Continually examine, interpret, and present the monitoring data. The best way to catch errors or notice trends is for scientists and other concerned individuals to use the data rigorously and often. Adequate resources should be committed to managing data and evaluating, interpreting, and publishing results. These are crucial components of successful monitoring programs, but planning for them often receives low priority compared to actual data collection.
(7) Include monitoring within an integrated research program. An integrated program may include modeling, experimentation, and cross-site comparisons. This multi-faceted approach is the best way to ensure that the data are useful and, indeed, are used.

*With apologies to Covey (1989)