Canada's Stewardship Agenda: The Role of Satellite Imagery in Watershed Management

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NOTE TO THE READER

The purpose of this short paper is to provide a practical introduction to remote sensing for individuals and organisations involved with watershed management. Some readers will already be familiar with the strengths and weaknesses of satellite data products and their use in geographic information systems. Others, particularly those with a non-mapping" background, will need a more general approach to the use of satellite technology. Consequently, the paper has been divided into a non-technical discussion of satellite applications to watershed management and an Appendix that is more detailed, but still not heavily technical.

The Main Report (available here) provides the results of the survey of ongoing and planned watershed management operations across Canada, together with an analysis of "who-does-what.

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1. INTRODUCTION

For millennia the landscape changed under the influence of fire, flood, drought, and other natural forces. Since man arrived on the scene, and especially since he established permanent settlements, he has had an increasing impact on the landscape. Population increases and the need to meet the increasing need for food, has led to the drainage of wetlands, damming and diversion of rivers, conversion of natural grasslands and the clearance of forests to provide more and more land to grow crops and graze animals. At the same time, increasing amounts of surface and ground water have been drawn on to meet the needs of the agricultural and other industrial sectors and the needs of urban centres. For the last decade it has become widely accepted that many of these landscape changes have led to the degradation of soils and both surface and ground water resources and a growing recognition among Canadians that the environment is a shared responsibility.

Canada's Stewardship Agenda recognises the need for a more integrated, ecosystem-based approach to landscape and water resources management. The agenda is a federal-provincial-territorial initiative based on consultations involving industries, landowners, communities and environmental organisations across the country. The stewardship agenda's vision calls for "a nation where Canadians are actively working together to sustain the natural life-support systems" and recognises that the diverse social, economic and environmental conditions across Canada requires that the agenda must be implemented at the local level and that it should involve all stakeholders.

Many agencies with responsibility for management or restoration of the environment have banded together into stewardship partnerships to deliver on their respective mandates. The makeup and objectives of these partnerships may differ, but they commonly include representatives from federal departments, provincial ministries, municipalities, health districts, a wide variety of industries, schools and public interest groups. Most of these organisations are finding that stewardship and watershed management is about education and changing people's behaviour at all levels.

There is now a recognition amongst environmental managers that the environment is best managed on the basis of place or area, and that point based monitoring is insufficient to accomplish this end. There is also agreement that this geographic unit should be the watershed (also referred to as the catchment are or river basin).

As the need for information on past changes in watershed land use and land cover becomes more important, there is a growing recognition that resource mapping and meteorological satellites can provide a unique, cost-effective source of data. Neils Christensen, Vice Chair, BC Watershed Stewardship Alliance points out that "Where a manager or stewardship partnership is trying to establish a 'community of interest' amongst government, industry and residents, everyone has to have a common understanding. Image maps are particularly good at showing the drama and impact of land use changes" (*pers. comm*)

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2. UNDERSTANDING THE IMPACTS OF CHANGE

Most governments in Canada and elsewhere now realise that understanding the impact of change requires frequent measurement of key indicators. The Global Environmental Outlook (GEO) published periodically by the United Nations Environmental Program (UNEP) uses indicators in trying to answer the following questions

- What is happening to the world's environment?
- Why is it happening?
- What are we doing to address the problems?
- How would alternative decisions affect the future?

The Consultative Group on Sustainable Development Indicators (International Institute for Sustainable Development, Winnipeg) has gradually settled on a framework that uses three "clusters" of indicators that have gained broad acceptance within public policy circles.

They encompass the following:

- Environment (*e.g.* quality of water, air and soil)
- Economy (*e.g.* employment, investment, productivity, income distribution)
- Society (*e.g.* crime, health, poverty, education, governance)

The questions posed by UNEP and the clusters suggested by the Consultative Group are the same as those confronting a local watershed manager. For example, the maintenance or improvement of water quantity and quality within a watershed can be measured and provide two such indicators. Others include the growth of impervious surface through urbanization, changing land cover and land use, for example forest clearance or the development of recreational areas. For such a set of indicators to be realistic, they should be based on historical trends that accurately reflect changes, especially those induced by man's activities, within a particular watershed. Once established, such indicators can provide key information on the likely impact of decisions on land use and water use licensing made by the management authority.

Many of these indicators can be provided by Earth Observation. An example of dramatic changes in land use over a thirteen year period in the Rideau valley watershed, south of Ottawa, Ontario can be seen in the pair of true colour Landsat Thematic Mapper (TM) images in figure 1. Between August 1987 and July 2000, the urban area expanded to the south towards the Jock River, and along both banks of the Rideau River with consequent changes to the run-off patterns for both rivers. The bright areas adjacent to built up areas are construction sites.

The first satellite designed specifically for monitoring the Earth's surface was launched by the U.S. government in 1972. The currently operating Landsat-7 is the seventh in this series. The Thematic Mapper aboard Landsat senses the electromagnetic radiation from the Earth's surface at seven different frequencies in the visible to infrared parts of the spectrum with a spatial resolution of 30 m (see the Appendix for more details)

Figure 1. Land cover changes in Barrhaven, Ontario using Landsat-5 (11 August 1987, left), and Landsat-7 (5 July, 2000, left), shown here at a scale of 1:100,000

In this example, the satellite imagery is used as photography with no manipulation or 'processing' other than can be done in a simple 'Paint' program. No particular skills are required. With more technical human and computing resources, more detailed information can be derived from satellite imagery. Figure 2 illustrates changes in a forested area near Prince George, BC, resulting from forestry operations over a nine year period. It is simple to calculate the areas of regeneration and newly logged areas.

Satellite imagery can be obtained in TIF (Tag Image File) Format, that is readily used in CAD, GIS, and office programs such as drawing, paint or word processors.

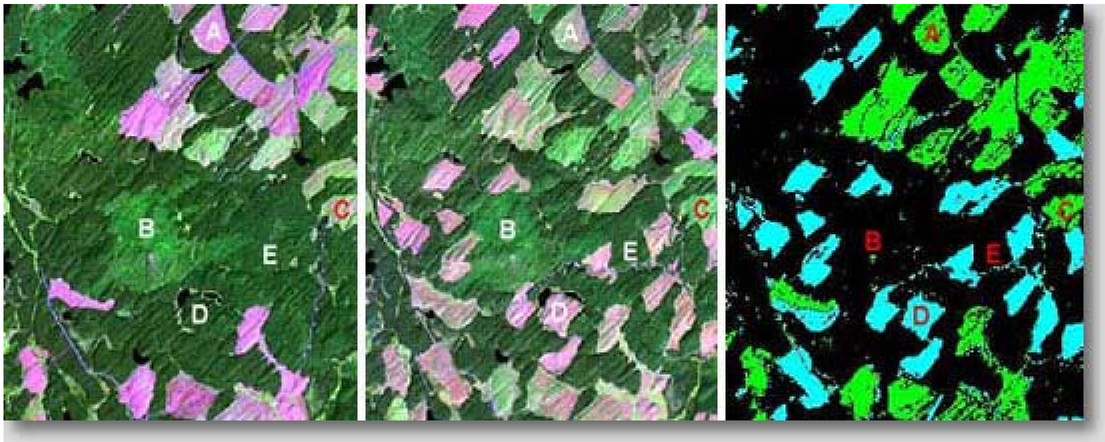

Figure 2. Forest cover change from Landsat images near Prince George, BC: August 12, 1990 (left) and September 12, 1999 (centre)

The image on the right shows the changes that have occurred. Green represents cut blocks prior 1990 and light blue indicates changes that occurred between 1990 and the 1999 image dates. The 1999 image shows signs of regeneration as a green colour is beginning to appear. The area shown at "B" was cut some years prior to 1990 and is almost fully regenerated in the 1999 image. At "C", harvesting activities took place shortly before 1990. The change in image colour from a light green to a bright green colour indicates the cut block is restocked and regenerating well. In 1990, a mature forested stand appears at "D." It was harvested prior to 1999 and shows as pink, a characteristic colour of low vegetation density. Construction of a road between 1990 and 1999 is shown at "E." (Earth Observation for Sustainable Forests, Change Monitoring using Optical Satellites).

With access to image processing software, appropriate expertise and information about the land cover for some representative areas on the ground, the multispectral nature of the imagery can be exploited to derive a thematic classification for very large areas. Sequences of one or more images can be used to monitor the changes in types of land cover over time. Figure 3 illustrates a study in which a 16,000 ha shift in production from cropland to grasslands and forage was documented for Swan Lake Basin, Manitoba between 1990 and 1999 – attributed to loss of transportation subsidy, low grain prices and strong cattle prices. A 6000 ha increase in forest cut-blocks was also recorded in the same period (Keystone Agricultural Producers and Prairie Farm Rehabilitation Administration, 2001)

In all three examples, changes over time are an important component of the indicators.

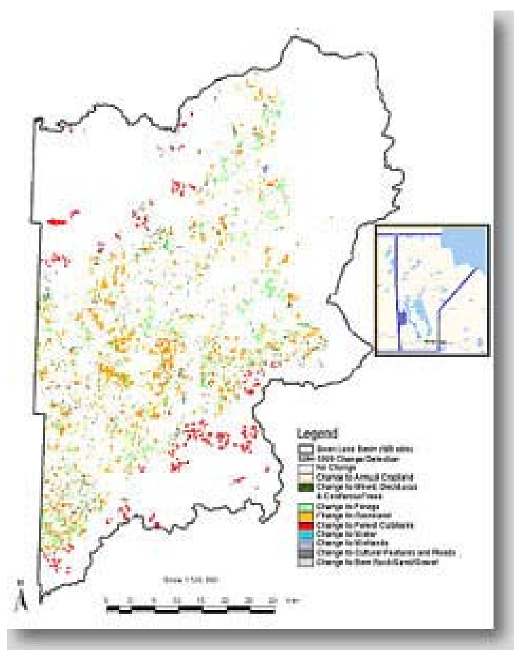

Figure 3. Land use change in the Swan Lake Basin, Manitoba 1990-1999

3. APPLICATION OF SATELLITE DATA TO WATERSHED MANAGEMENT

There are several areas in which spatial information is needed to support landscape and water resource planning and decision support systems. Table 1 (next page) lists some of the information needed by those responsible for watershed management and possible satellite-based sources of data that could provide the basis for the information products and services.

Some of the sensors (e.g. the Landsat series operating in the visible and near infrared parts of the electromagnetic spectrum) can provide information on both current conditions and a 30 year history of land use/land cover. The data each type of sensor can provide must be evaluated by managers against the type of information they need (e.g. specific indicators), their needs for spatial resolution (map scale), frequency of updates, and timeliness of delivery.

At present, the major users of the satellite-based data received at Canada's ground stations at Prince Albert, Saskatchewan, and Gatineau, Quebec, are the federal and provincial departments and agencies, and the major resource industries, such as forestry. The government uses the data as a basis for public services (e.g. weather forecasts) and in support of departmental mandates (*e.g.* natural resources monitoring and regulation and/or research).

The visible, near-infrared, and microwave frequencies referred to in Table 1 represent different parts of the electromagnetic spectrum at which the Earth's atmosphere is transparent (i.e. the signals are not absorbed by the atmosphere between the satellite sensor and the ground). See the Appendix for more details.

Table 1. Types of satellite sensors capable of providing data in support of specific information needs

Information Needed (current conditions or evidence of change over time)	Satellite Sensor Operating Frequency		
	Visible-Near Infrared	Active Microwave	Passive Microwave
1. Water quality (lakes and reservoirs)	●		
2. Water temperature	● (Landsat)		
3. Fish habitats	●		
4. Wetlands	●	●	
5. Riparian vegetation	●	●	
6. Land forms (stream locations; slopes and elevations)	●	●	
7. Extent of urban area	●	●	
8. Forest cover	●	●	
9. Agricultural areas	●	●	

10. Wildlife habitats	●	●	
11. Snow-water equivalent estimates		●	●
12. Soil moisture estimates		●	●
13. Precipitation forecast (rain and snow)			●

Earth Observation data are frequently used by federal departments and provincial ministries to meet their specific needs to map land cover. However, integrated or holistic ecosystem-based watershed stewardship by definition usually involves many partners. In recognition of the need for more data sharing, there are on-going, co-operative federal-provincial plans for national forestry, agriculture and wetlands inventories based on satellite imagery.

For example, the Earth Observation for Sustainable Development of Forests (EOSD) initiative is a federal, provincial partnership to develop a land cover map of the forested areas of Canada. The Canadian Forest Service, in partnership with the Canadian Space Agency is using Landsat TM data from 1999 and 2000 to create products for forest inventory, forest carbon accounting, monitoring sustainable development, and landscape management. This project will produce land cover maps of all of the forested areas of Canada by 2005 – the first land cover maps are now available for a few locations. Funding is now in place to expand the EOSD Initiative to cover the agricultural areas of the country, and discussions regarding the area north of the tree-line are taking place (Mike Wulder, Canadian Forest Service, *pers. comm,* April 2003).

4. ACCESSING SATELLITE DATA

The Canada Centre for Remote Sensing (CCRS) maintains an archive of Landsat, SPOT (the French Système Pour l'Observation de la Terre), AVHRR (Advanced Very High Resolution Radiometer – on the NOAA weather satellites), ERS-1 and 2 SAR (European Earth Resources Satellite) and Canadian RADARSAT satellite data over Canada (Natural Resources Canada, 2003). The full Landsat and SPOT archive and higher resolution IRS, commercial IKONOS and Quickbird imagery can be purchased from a growing list of Canadian or other national governments or companies acting as resellers. The easiest way to access Earth Observation data is now via the Internet. Most data providers now have easy to use on-line map-based browsers through which it is possible to locate and order cloud-free imagery available for a specified location. Delivery is either via direct file transfer protocol (ftp) or mailed CDs.

The data can be requested in a variety of file formats. Natural colour imagery can be ordered for simple analysis or use as a Geographic Information System (GIS) backdrop. However in order to extract the maximum amount of information from the data, all spectral bands are required (see Appendix). Full analysis of such data requires staff experienced with specialised image processing and the use of GIS software.

Not all watershed stewardship groups will have the staff and resources needed to undertake satellite data analysis or GIS operations in house. However, the federal and/or provincial partners in watershed management groups may be able to provide such services. Alternatively, there are a large number of remote sensing and GIS companies across Canada already familiar with their local landscape and water resource management issues that can undertake detailed customised mapping tasks on contract.

5. FREE DATA SOURCES

Limited funding resources, lack of in-house experience and lack of awareness of what is available are restricting some stewardship groups (particularly those with little federal or provincial government involvement) from taking advantage of the opportunity offered by use of Earth Observation data products. The stewardship organisations with day-to-day responsibility for watershed management need to be able to take full advantage of the satellite-based data that is already available and can help meet their information needs in a cost-effective manner.

The cost of visible and near infrared data is discussed in more detail in the Appendix, but it is important to point out that there are now sources of free Landsat data for Canada and large parts of the world. At least one complete Landsat Enhanced Thematic Mapper coverage of Canada, (all spectral bands, geometrically corrected in map co-ordinates and in a format suitable for image processing) is available for the 1999-2000 time frame from the Geoconnections Discovery Portal. Older data is available for much of the country for 1990 and 1980, thus allowing some change detection studies. The University of Maryland's Global Land Cover Facility (GLCF)also offers free Landsat data for Canada and for most of the world. For simple preliminary studies Natural Resources Canada's Geogratis and Toporama websites also have natural colour images in TIF format suitable for use in Office 'paint' or 'drawing' programs, or for use as backgrounds in CAD or GIS programs.

6. CONCLUSIONS

1. Multi-stakeholder stewardship operations are becoming the norm for landscape and water resource management on a watershed basis across Canada.
2. Indicators are being identified as a way of measuring and monitoring the impact of natural change and human activities on river basin ecosystems.
3. Much of the spatial data (both current and historical) needed to track these indicators can be obtained from satellite sensors and already exists in government archives.
4. Some of the moderate resolution data from such resource mapping satellites as Landsat is now freely available via the Internet, and the cost of the remainder of the archive is negligible. There are no copyright restrictions on its use.
5. For some kinds of simple analysis, freely available Landsat imagery may be useful to show present conditions. For more complicated analysis some expertise and image analysis or GIS resources will be required. Some watershed managers or stewardship partnerships will have access to GIS and image analysis expertise via their industrial or government partners, but involvement is not always possible even between ministries and departments of the same government.
6. For most stewardship operations it will not make business sense to invest in staff training and image analysis and GIS software. However, there are many established remote sensing and GIS companies throughout Canada that can meet their needs for spatial information services in a cost-effective manner
7. Future Earth Observation satellites, whether they are operated by governments or the private sector, will offer better spatial resolution and more (and often narrower) frequency bands for improved spectral analysis.

APPENDIX – TECHNICAL ASPECTS

A1. CONFUSING SPECIFICATIONS?

It can be difficult for a casual user to understand the many variables associated with Earth Observation sensors and systems. Fortunately, the visible and infrared sensors, that are the most useful for mapping vegetation, land cover and simple measures of water turbidity, are also the most common and the least expensive. Table A1 summarises the salient points for four commonly used sensors.

Table A1. Summary of specifications for *some* satellite sensors operating in the Visible and Infrared range. (Bracketed text in the title block indicates latest sensor in the series.)

Latest in Series: Satellite/Sensor		Landsat series (7 ETM+)	Spot series (SPOT 5)	IRS LISS-3 (IRS 1D)	IKONOS 2
Swath (the width of the ground path seen from the sensor)		183 km	60 – 80 km (pointable)	131 km	13 km (pointing)
Revisit (or the period of time for the satellite complete its orbit cycle)		16 days at 0^{o}N ~8 days at 49^{o}N ~8 days at 60^{o}N	26 days at 0^{o}N 26 days at 48^{o}N ~18 days at 60^{o}N	20 days at 0^{o}N ~20 days at 48^{o}N ~5-10 days at 60^{o}N	3 days at 40^{o}N *– but with tilt*
Operational History		1972-present	1986-present	1988-present	2002-present
Contiguous global archive?		yes	yes	yes	No – only small targeted areas
Band	Use	Ground resolution or Pixel size (m)			
Blue	Differentiation of soil from vegetation, affected by haze	30	NA	NA	4
Green	Vegetation vigour assessment	30	20	20	4
Red	Vegetation cover discrimination	30	20	20	4
Near Infrared	Determining biomass and delineation of water bodies	30	20	20	4

Short Wave Infrared	Vegetation and soil moisture	30	20	20	NA
Short Wave Infrared	Discrimination of soil types	30	NA	NA	NA
Thermal Infrared	Vegetation heat stress, soil moisture, water temperature	60	NA	NA	NA
Panchromatic	Detail for sharpening	15	10 (2.5m for SPOT 5)	5	1

A2. SPATIAL RESOLUTION

As technology has improved, the spatial resolution of commercially available Earth Observation satellite data has improved since the launch of Landsat MSS in 1972. Figure A1 shows decreasing pixel size for the multispectral imagery. Beginning in the mid-1980s with the SPOT series, the use of a simultaneously recorded higher resolution Panchromatic channel to 'sharpen' the multispectral data has become common. In this technique, the brightness variations in the higher resolution channel are used to modulate the colour of lower resolution multispectral channel, giving the visible impression of a much sharper colour image.

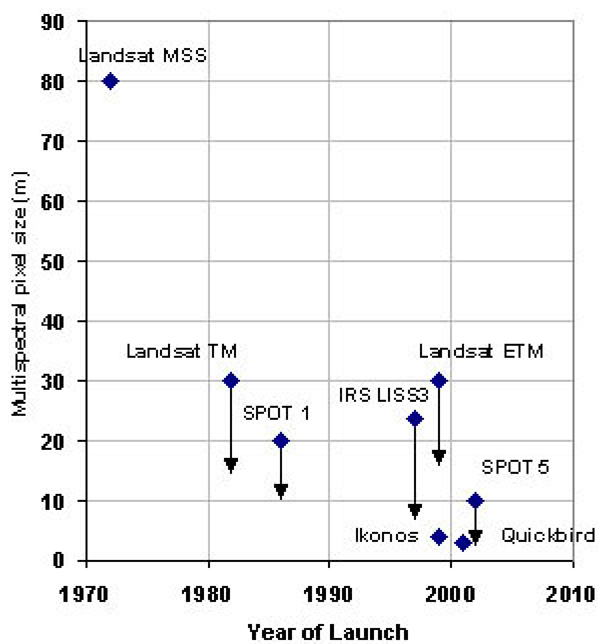

Figure A1. Reduction in Multispectral Pixel Size over time.
Arrows indicate the pixel size of the Panchromatic Channel recorded simultaneously

A3. USEFUL SCALES

Digital data does not really have a scale, since it easily be re-projected at different scales, but people accustomed to working with maps or aerial photos often ask about the scale of the different systems. Table A2 provides an approximate description of the useful scales of digital imagery

Table A2. Approximate scale of some digital Earth Observation sensor systems

Sensor	Multispectral pixel size (Panchromatic pixel size)	Maximum map scale (with resampling or 'sharpening')	Area covered by a resampled image map with area (km2) of 50 cm x 50 cm
Landsat MSS	80 m	1:150,000	675,000
Landsat TM	30 m (15 m)	1:66,000 (1:35,000)	36,750
SPOT1-4	20 m (10 m)	1:50,000 (1:25,000)	18,750
SPOT 5	10 m (2.5 m and 5 m)	1:25,000 (1:15, 000)	6,750
IRS LISS	23 m (5.8 m)	1:48,000 (1:12,000)	4,450
IKONOS	4 m (1 m)	1:8,000 (1:2,500)	185
Quickbird	3.8 m (0.6 m)	1:8,000 (1:2,400)	170

A4. ARCHIVES OF HISTORICAL IMAGERY FOR CHANGE DETECTION

Landsat, SPOT and the IRS satellite are continuing series and can be relied on for future operational services. They also have very large (millions of images) and global archives that are necessary for studies of historical change detection.

IKONOS and Quickbird are new commercial satellites and it has yet to be seen whether they will become part of a continuing series. More importantly, they do not continuously record imagery as the other sensors do. They are 'targeting' sensors that are tasked on demand – their very limited archives are therefore relatively small and focussed on 'popular' targets.

A5. TEMPORAL RESOLUTION OR REVISIT TIMES

Remote sensing satellites, such as Landsat are in polar orbits, traversing the Earth at a slight angle to lines of longitude. Because of the physical limitations of these orbits, imaged swath and data transmission band-widths, the moderate resolution Earth Observation sensors commonly used for watershed management do not provide full daily coverage of the earth. Instead, they acquire narrow strips (usually 14) each day, and the orbits for one day are slightly offset east-west from the day before. Thus, their revisit time for a particular location depends on the width of the imagery and the latitude of the site, since the orbits converge near the North Pole. In southern Canada, the shortest possible repeats are on the order of a 10 days to 3 weeks, while above latitude 60o N, the interval between repeats becomes much shorter.

A6. CLOUD AND THE MOVE TO RADAR IMAGING

One has to remember that the repeat cycles quoted for each sensor do not reflect the probability of obtaining useful imagery. Using the Landsat/SPOT/IRS family of sensors, it is not always possible to obtain an image for a particular day, or at short intervals – they are more suitable for studies requiring monthly or seasonal coverage. The highest resolution commercial satellites overcome the limitations of cloud and repeat cycle by tilting the sensor during viewing (rather than looking straight down). However, the oblique view obtained can sometimes be difficult to interpret and map.

Active Microwave Frequency Sensors (Radar). In recognition of the cloud limitations on optical sensors (a particular problem in equatorial areas), there has been considerable recent emphasis on the development of radar imagers. Recently launched satellite radar instruments operate at C-band (about 5 GHz) in the microwave region and can provide data in darkness and through cloud cover. These include the European ERS-2 and the ASAR instrument aboard Envisat, and Canada's Radarsat-1. Radarsat-1 has a number of different operating modes, and can be tasked to provide resolutions ranging from about 25 to 100 m.

Unlike optical imagery, Synthetic Aperture Radar (SAR) imagery is not intuitive to most people. Radar is sensitive to surface roughness at particular length scales determined by the frequency of the radar and several other factors. In 2003, SAR imagery is being used operationally for ice mapping, but most other applications are still in or just emerging from the research phase. There are a number of promising applications emerging. SAR imagery is particularly useful for distinguishing land and water areas (as in wetlands), and can also provide crop type and crop condition information.

Passive microwave. These sensors are low resolution (one or more km), generally on meteorological satellites and so part of an operational, continuing satellite series. The data from these types of sensor are vital to weather forecasting in support of agriculture and many other operations including snow cover and snow-water equivalent for spring run-off forecasts provided by various government agencies.

A7. COSTS

Operational users of satellite data are very cost-sensitive. Data from the low resolution meteorological satellites are free but are generally received by such organisations as Environment Canada's Meteorology Service (EC/MSC) that then provides public weather forecasts that also take into account ground-based measurements. (EC/MSC also provides special forecasts for agriculture and other industry sectors, generally on a fee-for-service basis.) The data themselves are also freely available at several websites, but generally have limited use for watershed managers.

Cost of recent Earth Observation data in the visible infrared range varies inversely with the spatial resolution (Figure A3). Landsat-7 ETM+ multispectral data are popular as they are the least expensive (Cdn$1000/scene), have no copyright limitations on secondary use of the data, and wide area coverage. Data older than about 10 years is about half the cost of recent data.

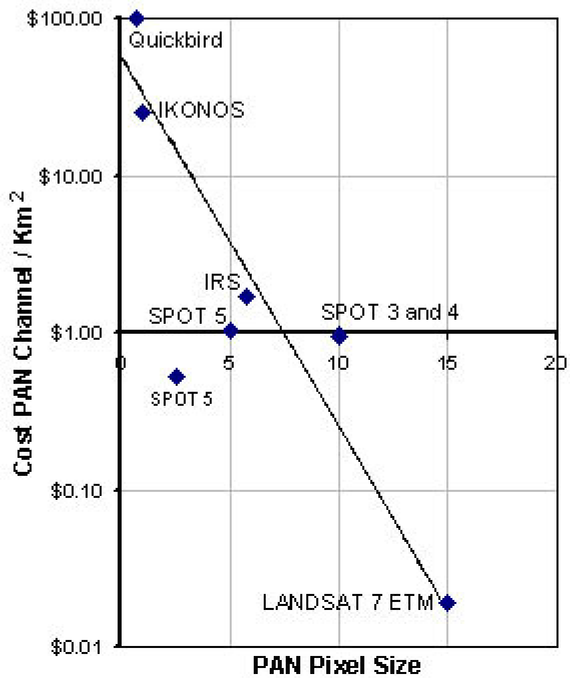

Figure A3. Cost of Panchromatic Imagery in 2003

High resolution or time critical data requirements are in a different category than can be met by Landsat, and both are expensive. Increasing competition is driving the cost of high resolution down. SPOT Image announced new pricing for newly launched SPOT 5, which severely undercuts the high resolution IKONOS and Quickbird imagery for some applications. SPOT, IKONOS and Quickbird imagery is made available as smaller 'imagettes' or sub-scenes as a way of making the data less expensive.

Radarsat offers the very considerable advantage of being able to meet time critical requirements in spite of cloud or darkness. The cost of the data has slowed applications development, especially outside the research community that can take advantage of cost shared programs. The solution to this problem may be in partnering with government agencies that already have access to the data.

A8. SOME SOURCES OF FREE EARTH OBSERVATION DATA

Canadian Geoconnections Discovery Portal

GeoConnections is an important national partnership initiative working to build the Canadian Geospatial Data Infrastructure (CGDI), that is making Canada's geospatial databases, tools and services readily accessible on-line. The GeoConnections web site provides a single access point for its seven Programs (including the Discovery Portal, the Atlas of Canada, GeoGratis, and GeoInnovations projects), and many other Canadian and International Portals, provincial/regional Networks and the CGDI Development Network.

The Geoconnections Discovery Port is the primary discovery and access point for the Canadian Geospatial Data Infrastructure Program. The Discovery Portal provides a unified central access point for a broad range of government and commercial suppliers and consumers of Geospatial information products and services. For example, Canadian and global catalogues of Landsat image archives are accessible via this site. The Geoconnections site also offers access to a large amount of free Earth Observation Landsat TM data, maps and GIS vectors through GeoGratis and associated web and file transfer protocol (ftp) site. Several types of full resolution satellite imagery suitable for use with image processing software are on-line and available for download, without charge and without copyright restrictions. Vector mapping data is also freely available in scales ranging from 1:50,000 to 1:30,000,000 in a variety of file formats.

Toporama provides on-line access to raster national topographic system (NTS) maps and Landsat imagery (as TIF files) covering entire country. Canadian Data Alignment Layer and Ground Control Database provides on-line access to image and co-ordinates of control points for image mapping. Framework Data provides on-line access to selected framework datasets within the National Topographic Data Base (NTDB) and some provincial digital topographic base mapping.

The Global Land Cover Facility

Another very important source of free Landsat data for Canada and much of the globe is the Global Land Cover Facility at the University of Maryland. This website provides an easy to use interface through which to search for and download fully mapped cloud-free Landsat data from 1972 to the present time. It does not represent the complete archive, but in combination with Geogratis provides at least two complete coverages of Canada spanning about a decade. For many parts of Canada, three or more images spanning 30 years could be assembled with no data cost in this way.

A9. THE FUTURE

Increasing number and variety of satellite sensors.

In the past decade there has been a large increase in the number of satellite equipped with visible-infrared sensors commercially available for Earth Observation. From early dominance by systems from the United States, systems from France, Canada, India, Germany, Russia, Korea, China, Argentina and others are being launched. However, for practical purposes, Canadian watershed managers are most likely to make most use of a much smaller number – represented by the American Landsat series, the French SPOT series and the Indian IRS series. Some will make use of the more expensive commercial high resolution satellites, such as IKONOS and Quickbird, for detailed studies around cities. Also, the Canadian Radarsat series is proving useful for coverage of frequently cloudy areas, such as the East coast of Canada.

Unlike the current generation of synthetic aperture radars (SAR), future space-borne SARs such as Radarsat-2 to be launched in 2004 will provide imagery in multiple polarisations. These sensors promise to significantly improve the amount of crop information provided in a single pass and will be exciting new tools for crop monitoring (Figure A4).

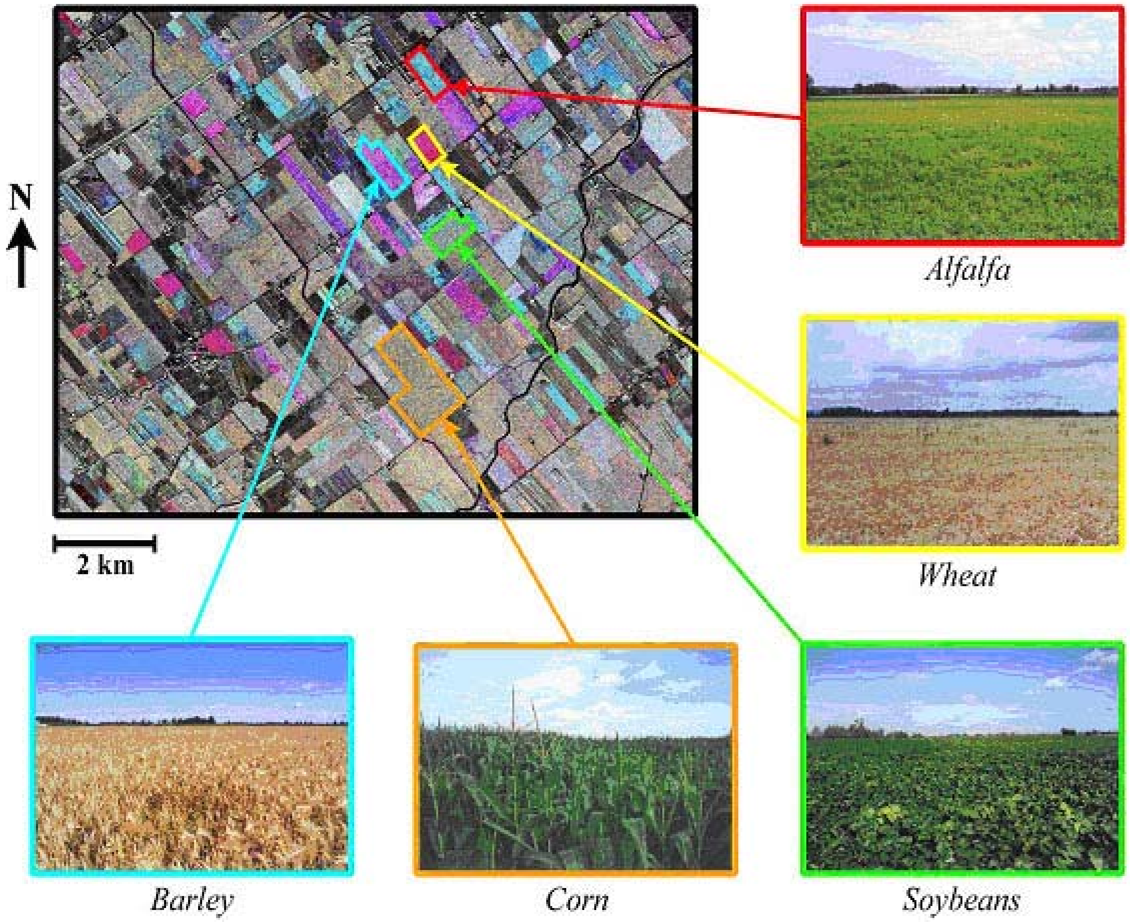

Figure A4. Simulated SAR imagery for Radarsat-2 from the airborne CV-580 C-band from South of Ottawa, 9 July 1998 (Linear Polarisation Composite: R = HH; G = HV; B = VV). Courtesy of Heather McNairn, Remote sensing Applications for Agriculture. Research and Development in the Canada Centre for Remote Sensing

Future passive microwave include L-band (1.4 GHz) radiometers aboard Europe's Soil Moisture and Ocean Salinity (SMOS) sensor and NASA's Hydrospheric States (HYDROS) system that is also designed for salinity and soil moisture measurements with spatial resolutions in the order of 40 km for hydroclimatology, 10 km for hydrometeorology, and 3 km for freeze-thaw conditions. Global coverage will be obtained on a three day cycle, and the projected lifetime for the system is three years.