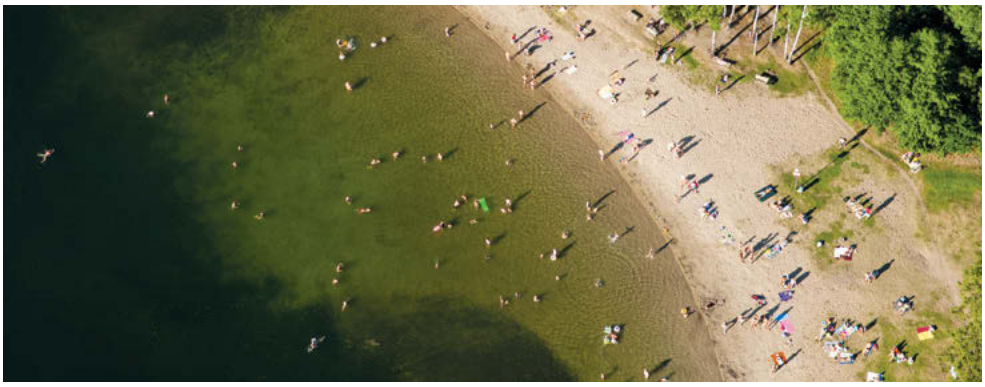
RISK ASSESSMENT OF MICROBIAL CONTAMINATION OF RECREATIONAL WATERS IN CANADA USING SATELLITE IMAGERY:

PILOT PROJECT ON PUBLIC BEACHES IN SOUTHERN QUEBEC



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RISK ASSESSMENT OF MICROBIAL CONTAMINATION OF RECREATIONAL WATERS IN CANADA USING SATELLITE IMAGERY:

PILOT PROJECT ON PUBLIC BEACHES IN SOUTHERN QUEBEC

PROJECT CARRIED OUT BY THE
PUPLIC HEALTH RISKS SCIENCES DIVISION OF THE LABORATORY FOR FOODBORNE ZOONOSES

PUBLIC HEALTH AGENCY OF CANADA

MARCH 2013

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PURPOSE OF REPORT

This report summarizes the key scientific activities of the tele-epidemiology project Risk Assessment of Microbial Contamination of Recreational Waters in Canada Using Satellite Imagery: Pilot Project on Public Beaches in Southern Quebec. This project was carried out thanks to the funding from the Canadian Space Agency (CSA) Government Related Initiatives Program (GRIP). The work was completed within the three years of CSA-GRIP program funding, specifically from 2009 to 2012.

PUBLIC HEALTH AGENCY OF CANADA MISSION AND PRIORITIES

Swimming in natural waters can pose a public health risk due to the possible presence of harmful bacteria in lake and river waters. One of the missions of the Public Health Agency of Canada (the Agency) is to better understand the scope and implications of this risk in order to promote and protect the health of Canadians and to develop targeted prevention initiatives for this issue. In terms of risk management, the Agency emphasizes the need to strengthen its abilities to anticipate or respond to potential or real health risks. One of its priorities is the development of knowledge and tools as a basis for recommendations of ways to avert these risks to the population.

RESEARCH TEAM

This work was carried out by the Public Health Risks Sciences Division of the Agency, Laboratory for Foodborne Zoonoses (PHRS-LFZ), in collaboration with Université de Sherbrooke's applied geomatics department. All members of this team are part of the Epidemiology of Zoonoses and Public Health Research Unit/Groupe de recherche en épidémiologie des zoonoses et santé publique (GREZOSP).

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BACKGROUND

Swimming and activities in natural waters can be linked to various human health risks, including infectious diseases, chemical pollutant-related diseases and accidental injuries (WHO 2003). Although all swimmers are vulnerable to developing health problems after swimming, certain groups are at higher risk, such as elderly people, young children and immune-compromised individuals. Gastroenteritis is most commonly associated with swimming, but respiratory illnesses and infections of the ear or skin are also linked to this type of activity (Pruss 1998). Various types of pollution can affect recreational waters, including fecal contamination, algae, cyanobacteria, and chemical pollutants (WHO 2003) Fecal contamination—which can come from a number of sources including farming activities, urban activities and wildlife—can introduce many disease-causing microorganisms in humans.

Currently, monitoring of recreational water quality is primarily based on the detection of microbial indicators of fecal pollution, such as *Escherichia coli* bacteria and fecal coliforms, which can provide a water quality assessment relatively quickly. Although these measures are important and necessary in order to quickly take public health actions, they do not allow for a global assessment of the risk of fecal contamination of natural waters. In addition to water analysis, the World Health Organization (WHO) also recommends assessing and monitoring those sources of contamination and characteristics of the environment (environmental determinants) that may contribute to an increased risk of fecal contamination, such as certain land uses and topography (WHO 2003). The combination of these two monitoring components would provide a basis for an overall assessment and classification of recreational waters based on the risk and current level of fecal pollution. Consequently, there was a need to develop new, efficient and sound methods to describe the land cover close to these waters in order to help identify those environmental characteristics that lead to an increased risk of fecal contamination and thereby identify at-risk beaches as well.

MAIN ILLNESSES ASSOCIATED WITH SWIMMING IN NATURAL WATERS

- Gastroenteritis
- Respiratory infections
- Dermatitis
- Ear infections

Tele-epidemiology involves monitoring and assessing the distribution of animal and human illnesses strongly linked to climatic and environmental variations through the application of spatial technologies, including Earth Observation (EO) imagery from remote sensing satellites (Marechal et al. 2008). Seeing as they can provide detailed information on land use and coverage, EO imagery is among new methods worth exploring for the purpose of assessing the risk of fecal contamination of recreational waters. Therefore, this pilot project is an initial technical assessment of the uses of EO imagery and more specifically the uses of satellite images in assessing this risk.

OBJECTIVES

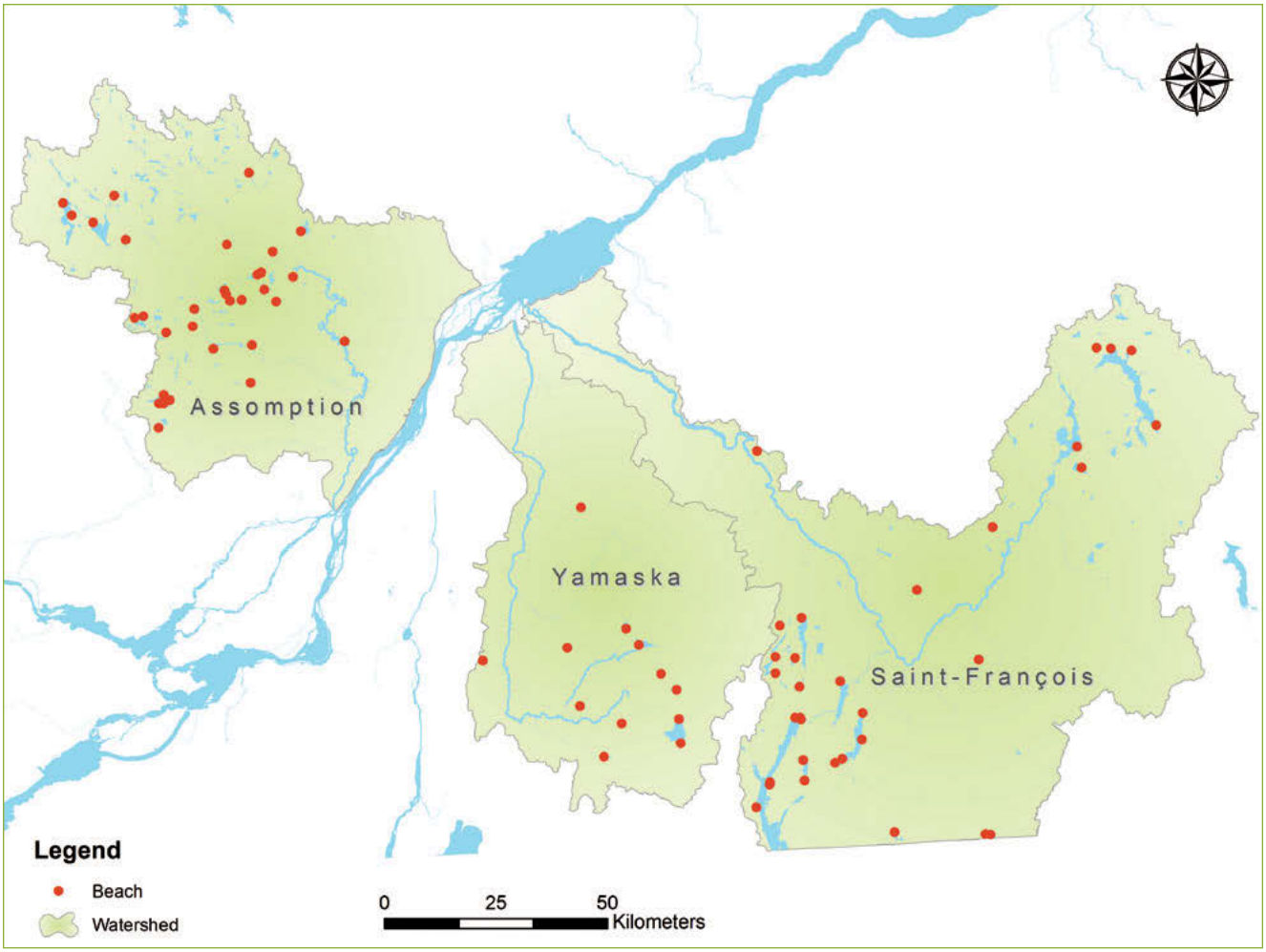
The project aimed to assess the value added and usefulness of satellite data as part of monitoring and managing microbial risks associated with recreational waters. More specifically, this assessment included the development of measures using satellite data and data conceptually related to the recreational waters' microbial risks, as well as the construction and assessment of statistical models comparing the average contamination level of the beaches studied with the measures developed.

METHODOLOGY

BEACHES STUDIED

The beaches studied were part of three southern Quebec watersheds, namely the Yamaska, Saint-François and L'Assomption river watersheds (Figure 1). Only beaches bordering lakes and having participated in the Quebec recreational water monitoring program, Environnement-Plage, for at least three summers between 2004 and 2011 inclusively were chosen for analysis [*n*=78] (MDDEP 2006).

FIGURE 1. Distribution of beaches studied on the three watersheds



FECAL CONTAMINATION MEASURES

The fecal contamination measures used for this project were taken from the Quebec recreational water monitoring program, Environnement-Plage. Through this program, water samples were taken during the months of June, July and August every summer of the period under review (2004 to 2011). For this project, average of the concentration of fecal coliforms (microbial indicator of fecal pollution) from all samples taken during the study period was used as representative measure of the average contamination level for each of the beaches. This measure was intended as a general contamination indicator for a beach relatively unaffected by extreme levels which may arise following special circumstances associated with a specific sampling session, such as heavy rain or a heatwave.

ENVIRONMENTAL DETERMINANTS

This project addressed environmental determinants associated with fecal contamination of recreational waters that remain relatively stable over time, such as land use and topography, which excludes determinants more susceptible to high temporal variation such as particular meteorological conditions. According to a previous study, approximately 40% of the variations in recreational standing water bodies average fecal contamination levels can be attributed to those determinants which tend to remain stable over time (Turgeon et al. 2011). Figure 2 illustrates the determinants that were the focus of this project. The measures representing these determinants and used in the statistical models were primarily based on land use and certain geohydrological characteristics of the beaches studied, including a region's average climatic conditions, land topography, soil drainage capacity, the number of tributaries, and the surface area of the adjacent lake.

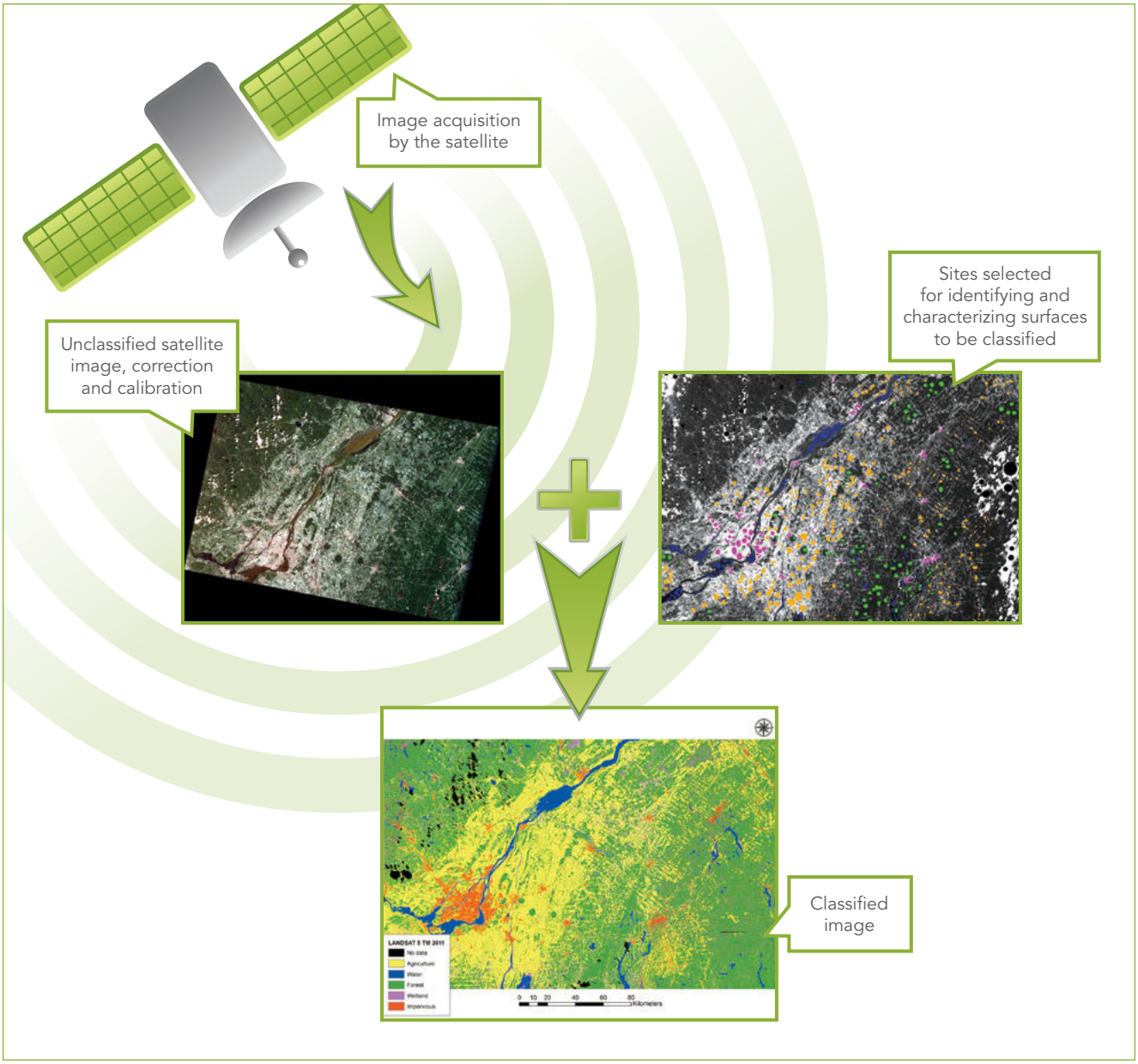
FIGURE 2. Illustration of environmental determinants that could lead to fecal contamination of recreational waters

Geographic areas corresponding to the types of land use studied—specifically agricultural lands, impervious surfaces, forests and wetlands—were extracted from classified satellite images data. Agricultural lands include cultivated areas and pastures. These surfaces can be a source of several fecal microorganisms and can cause surface water contamination in various ways, including direct deposit of fecal matter by animals on pasture and manure spreading. In remote sensing, impermeable surfaces like roads, buildings and parking lots are generally used as indicators of a region's degree of urbanization (Zhang et al. 2010). Urban environments can be sources of fecal microorganisms through various mechanisms such as rainfall runoff containing germs from household garbage, pets, and urban wildlife, in addition to wastewater flowing directing into waterways (Marsalek and Rochfort 2004). Forests have been associated with higher-quality standing water bodies based on their ability to reduce runoff, the amount of nutrients and sediments transported towards watercourses, and their positive influence on increasing infiltration of water toward the water table (Matteo et al. 2006). Wetlands can also positively impact water quality by acting as a filter, due to their retention capacity for area nutrients, sediments and microorganisms, including those of fecal origin (Kao and Wu 2001).

ESTIMATE OF ENVIRONMENTAL DETERMINANTS BY SATELLITE IMAGE CLASSIFICATION

Data from various Earth observation satellite images were used for cartography and monitoring land use. These satellite images show specific features that can be used to describe phenomena occurring to varying degrees. In this study, satellite images were assessed based on the opportunity they offered to estimate and monitor environmental determinants. The main satellite sensors used to extract land use data were: SPOT-5, Landsat 5, Meris FRS 1, MODIS, AVHRR, GeoEye and WorldView. Figure 3 presents a diagram illustrating the general methodology for processing various EO imagery used in the assessment.

FIGURE 3. Diagram of general methodology for processing various EO imagery used in the assessment



STATISTICAL ANALYSES

Statistical analyses were carried out to compare the capacity of the various types of EO imagery to describe environments near beaches being studied, in addition to identifying environmental determinants with the greatest influence on the level of fecal pollution of these beaches.

COMPARISON WITH VARIOUS TYPES OF EARTH OBSERVATION IMAGERY

Different comparison criteria may be taken into account when comparing different types of EO imagery with regard to their capacity for identification of environmental characteristics associated with a higher level of fecal pollution and thereby those recreational waters that may be at higher risk for contamination. Moreover, certain criteria must also be taken into account when this information is gathered for possible use by a recreational water monitoring program. Among these criteria, we note the results of statistical analyses, cost of the images, hours of work, and the expertise and material required to process the images.

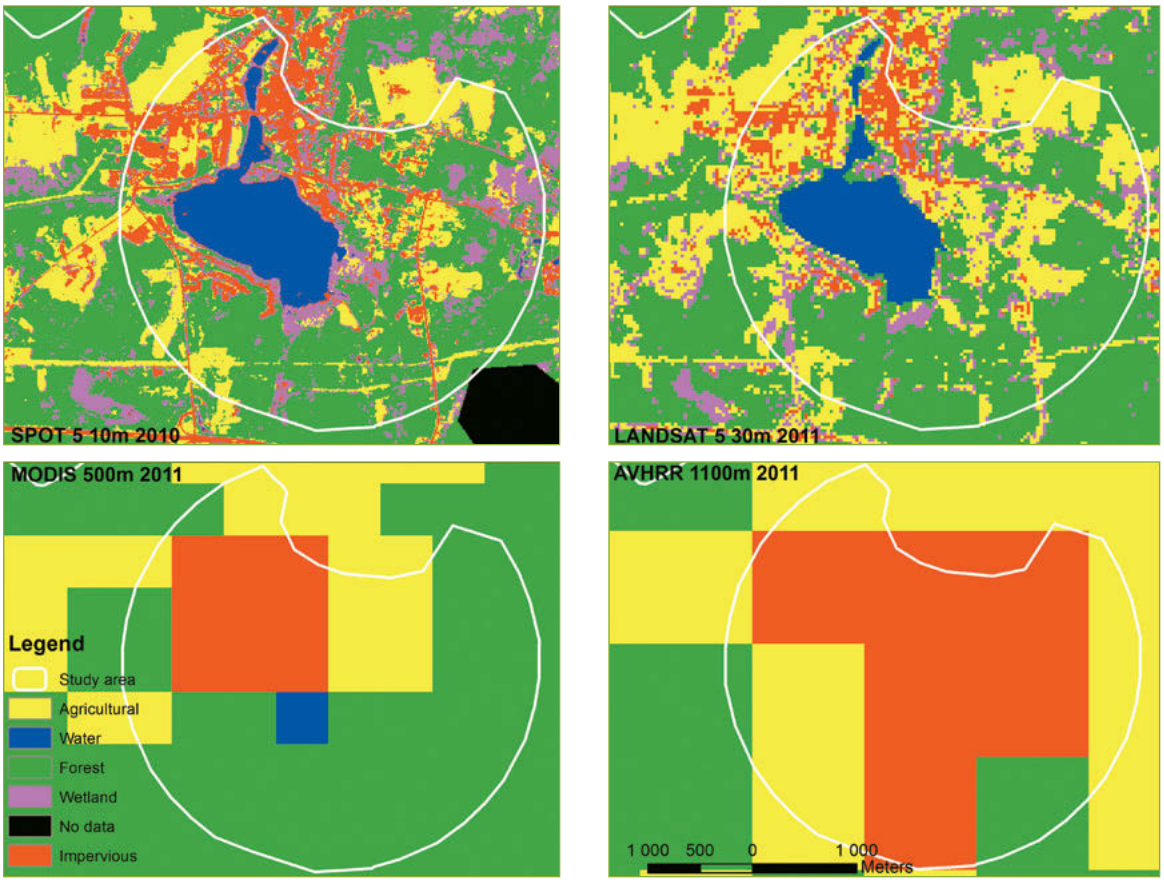
RESULTS AND EVALUATION

PERFORMANCE OF EARTH OBSERVATION IMAGERY IN CHARACTERIZING THE TERRITORY AND ASSESSING THE RISK OF MICROBIAL CONTAMINATION OF RECREATIONAL WATERS

The classification of satellite imagery from the various Earth Observation systems yielded generally good results for the region studied as a whole. Types of land use generally extending over large homogeneous areas, such as standing water bodies and forest cover, were identified with greatest precision using various types of EO imagery.

The assessment of classified images demonstrated that the estimate of surfaces corresponding to the various environmental determinants studied was highly influenced by the type of EO imagery used. EO imagery with the lowest spatial resolution (250 m pixel and higher) masked the heterogeneity of surface types that could normally be observed in environments near the beaches being studied. EO imagery with finer spatial resolution (30 m or less) offered significantly superior surface discrimination (Figure 4). This variability was even more significant when the surface types being studied covered a smaller area such as impermeable and agricultural surfaces. Therefore, there was greater uncertainty in the estimates of smaller surface areas, as opposed to larger surface areas such as forests.

FIGURE 4. Variability of surface types representing the environmental determinants studied in four different types of EO imagery



MAJOR LIMITATIONS ENCOUNTERED WHEN CLASSIFYING SATELLITE IMAGES

- Cloud cover
- Variability of wetlands
- Image acquisition date

Despite the good overall classification results, there were some limitations related to the classification of all EO imagery. First, in several cases, the presence of clouds and their shadows prevented classification of the entirety of the image pixels. To limit these situations, EO imagery was captured on several dates throughout the summer. Second, because they are small geographic areas that change over time, wetlands presented a challenge in terms of classification. These environments were the land use type with the lowest levels of precision with regard to classification. Furthermore, the acquisition date of the EO imagery—primarily of vegetation and wetlands—affected its classification results. In general, distinction between different classes was easier and more precise when images to be classified were taken in late spring or early summer (late May, early June). Concurrent analysis of EO imagery taken on several dates during the summer therefore appeared to be a promising approach for superior land use category discrimination at various levels of detail, based on the targeted environmental determinants.

Following the statistical model assessment, it was possible to highlight certain land uses that lead to an increased risk of recreational water contamination. The finding was that recreational waters located in environments with high proportions of agricultural land and/or impermeable surfaces were subject to a higher level of fecal contamination. Among the satellites providing EO imagery, Landsat 5 performed best in terms of statistical models linking the level of fecal contamination of beaches to the measures developed.

Finally, it was possible to compare the various types of EO imagery according to the previously mentioned criteria. Based on this comparison, MODIS images presented several valuable attributes compared to the others, especially in terms of technical aspects such as the cost of the images, hours of work, and the material and expertise required for image processing. However, the statistical model produced using images from MODIS performed poorly in terms of predicting the average level of fecal contamination, and this limitation may be a major drawback in the context of a program seeking to identify beaches at highest risk for fecal contamination. A compromise between all criteria will therefore be necessary to determine the best type of EO imagery to use. For the time being, by offering the best statistical model performance and providing free images, the Landsat 5 satellite would appear to be the best choice.

LANDSAT 5 OFFERS THE BEST COMPROMISE BETWEEN ALL SENSOR COMPARISON CRITERIA

USEFULNESS OF EARTH OBSERVATION IMAGES IN MONITORING MICROBIAL RISKS ASSOCIATED WITH RECREATIONAL WATERS

This project allowed us to identify two main influences on the microbiological quality of recreational waters, specifically farming and urban activities. The level of classification used did not lend itself to identifying the exact mechanisms involved in this contamination given that we cannot pinpoint the specific farming activities (manure spreading, animals on pasture, manure piles on production sites) and urban activities (density of population, intensity of beach use) with the most significant impact on the beaches' fecal contamination levels. Nonetheless, the information that could be extracted from this level of classification allowed for the targeting of several environmental characteristics that can increase the risk of contamination. This would make it possible to identify beaches at higher risk for fecal contamination which could lead, in turn, to better allocation of resources.

PRIMARY DETERMINANTS INFLUENCING MICROBIOLOGICAL QUALITY OF WATERS STUDIED

- Farming activities
- Urban activities

Data from EO imagery can provide benefits compared to other methods of data collection. First, satellite images can cover a vast territory—a great advantage when studying Quebec and Canada. Moreover, EO imagery data from an individual satellite may be reproducible and constant over a long period of time. In the context of a recreational water monitoring program, these two elements could facilitate regular monitoring of the evolution of the environmental characteristics identified as contributing to an increased risk of microbial contamination. Unlike census data which are grouped together by administrative region, certain EO imagery can be used to map environmental characteristics and land use with considerable precision based on their location relative to water courses, which is a significant advantage.

PRIMARY ADVANTAGES OF SATELLITE IMAGES

- Considerable coverage
- Reproducibility
- Constancy
- Precision

Any implementation of EO imagery as part of a recreational water quality monitoring program should be done while taking into account the significant financial, technical and human resources that may be required for their integration.

CONCLUSION AND FUTURE DIRECTIONS

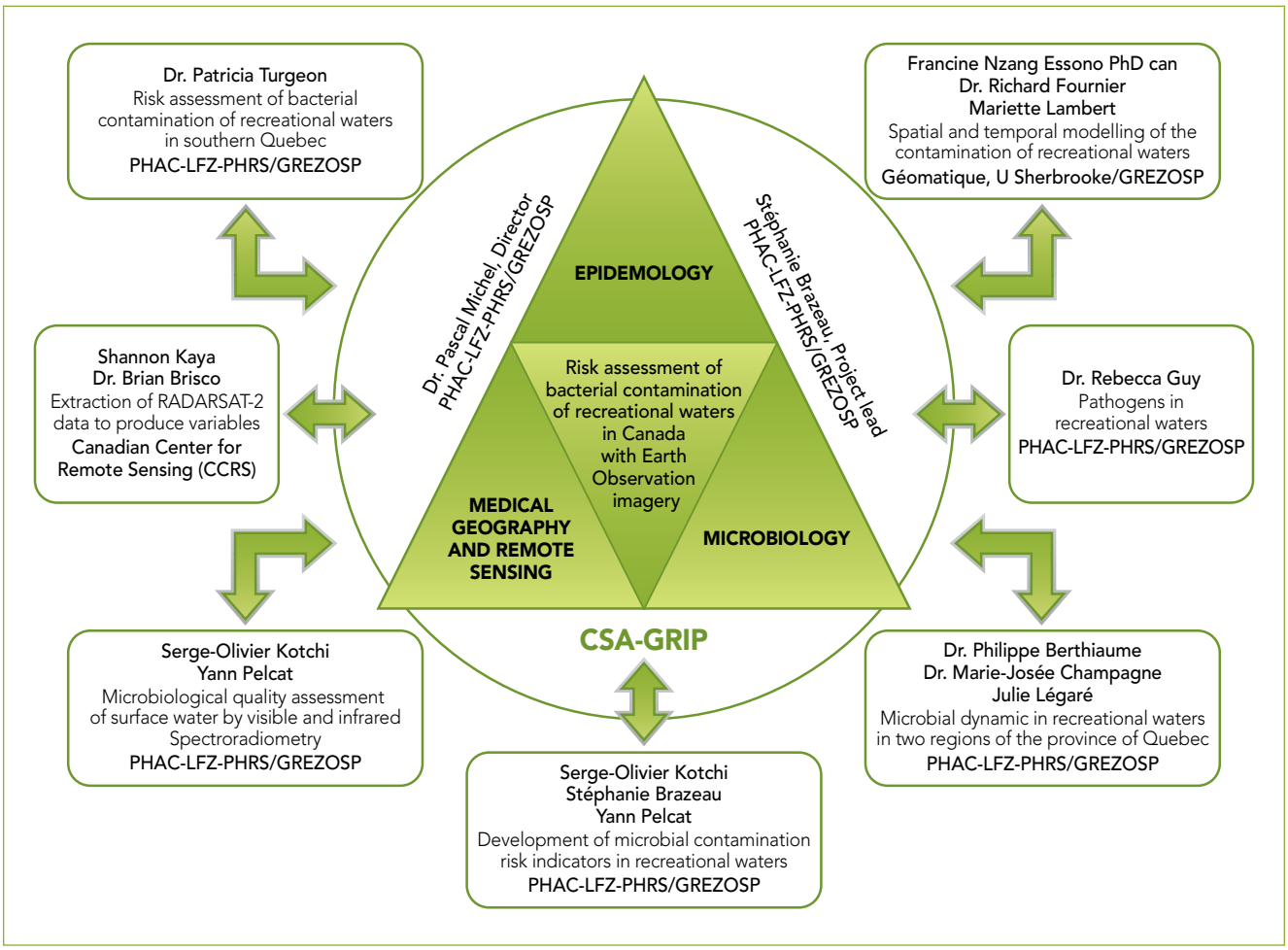
In the coming years, it is expected that surface waters will be subject to significant disturbances. Deterioration in surface water quality, particularly at the microbiological level, is to be expected and could lead to significant public health problems, including the incidence of infectious diseases transmitted through drinking water or recreational water. In terms of managing water quality, the WHO recommends a type of management called a multi-barrier approach. This approach involves control and prevention measures from source to tap, or even from source to the users' exposure. Management would therefore include potential sources of contamination, possible contamination routes, available treatments, consumption activities and foreseeable exposure.

Further to this approach, understanding environmental characteristics contributing to an increased risk of surface water fecal pollution will be essential in order to ensure proper management of this resource and to minimize public health risks. To do so, new assessment methods should be developed in order to describe the environment more effectively and consistently across large territories like Canada. This pilot project was developed and carried out with that in mind. Therefore, this project enabled us to evaluate the usefulness of Earth Observation imagery, and more specifically satellite images, to assess the risk of fecal contamination of recreational waters through the identification, around beaches, of environmental characteristics associated with a higher risk of contamination. Although the use of EO imagery can certainly contribute to this field, other work will be needed before this tool can be added to existing recreational water monitoring programs. This new work could include, among other things, the development of new measures using other satellites like RADARSAT-2, multi-criteria analyses for comparing various types of EO imagery, and cost-benefit analyses.

Understanding microbial contamination of recreational waters remains a complex issue. This contamination comes from various sources affected by the environment and climatic events which have an impact on the movement and survival of bacteria. To better

understand this contamination and the underlying mechanisms, various research projects are underway within the Public Health Risks Sciences (PHRS) Division and in collaboration with partners from Université de Sherbrooke and the Canada Centre for Remote Sensing of Natural Resources Canada. These projects and team members and presented in Figure 5.

FIGURE 5. Current projects on recreational waters



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- Université de Sherbrooke's applied geomatics department and the Centre for research and applications in remote sensing
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- Natural Resources Canada, Canada Centre for Remote Sensing

REFERENCES

- Kao C, Wu M (2001) Control of non-point source pollution by a natural wetlands. Water Sci Technol 43 (5):169–174
- Marechal F, Ribeiro N, Lafaye M, Güell A (2008) Satellite imaging and vector-borne diseases: the approach of the French National Space Agency (CNES). Geospatial health 3 (1):1–5
- Marsalek J, Rochfort Q (2004) Urban wet-weather flows: sources of fecal contamination impacting on recreational waters and threatening drinking-water sources. J Toxicol Environ Health A 67 (20–22): 1765–1777
- Matteo M, Randhir T, Bloniarz D (2006) Watershed-scale impacts of forest buffers on water quality and runoff in urbanizing environment. Journal of Water Resources Planning and Management 132 (3):144–152
- Programme Environnement-Plage (2006) Ministère du Développement Durable, de l'Environnement et des Parcs du Québec. www.mddep.gouv.qc.ca/programmes/env-plage/
- Pruss A (1998) Review of epidemiological studies on health effects from exposure to recreational water. Int J Epidemiol 27 (1):1–9
- Turgeon P, Michel P, Levallois P, Archambault M, Ravel A (2011) Fecal Contamination of Recreational Freshwaters: the Effect of Time-independent Agroenvironmental Factors. Water Qual Expo Health 3 (2):109–118
- WHO (2003) Guidelines for safe recreationnal water environments. Coastal and fresh waters. vol 1. World Health Organization, Geneva, Switzerland
- Zhang Y, Guindon B, Sun K, Sun L. Remote sensing for improving understanding on Canadian urbanization (2010) Canada Centre for Remote Sensing. Natural Resources Canada. www.ccrs.nrcan.gc.ca/optical/curlus_e.php Accessed May, 2011