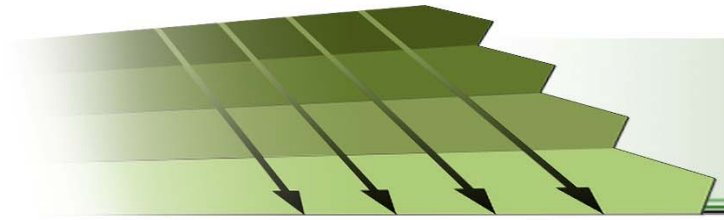

CORE
Public Health Functions for BC

Evidence Review:
Communicable Disease Surveillance

Population Health and Wellness
BC Ministry of Health

September 2006

This is a review of evidence and best practice that should be seen as a guide to understanding the scientific and community-based research, rather than as a formula for achieving success. This review does not necessarily represent ministry policy, and may include practices that are not currently implemented throughout the public health system in BC. This is to be expected as the purpose of the Core Public Health Functions process—consistent with the quality improvement approach widely adopted in private and public sector organizations across Canada—is to put in place a performance improvement process to move the public health system in BC towards evidence-based best practice. Health authorities will develop public performance improvement plans with feasible performance targets and will develop and implement performance improvement strategies that move them towards best practice in the program component areas identified in the Model Program Paper. These strategies, while informed by the evidence in this review, will be tailored to local context.

This Evidence Review should be read in conjunction with the accompanying Model Core Program Paper.

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Evidence Review accepted by:
Population Health and Wellness, Ministry of Health (September 2006)
Core Functions Steering Committee (March 2007)

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EXECUTIVE SUMMARY

Communicable disease surveillance is the ongoing, systematic collection, analysis, interpretation and dissemination of infectious disease data for public health action. It acts as an early warning system for outbreaks and identifies infections that are the most important causes of illness and death, so prevention and control activities can be prioritized.

Many sources of data can be used for monitoring. Some, like reportable diseases, are legally mandated. Others, like health utilization data and school or work absenteeism information, are not. More recently, informal data from public internet sites and media sources have been used. The type of information collected depends on the purpose of the surveillance system.

Information is usually transmitted by telephone, fax or mail. More recently, data transfer has been by electronic means. Advances in information technology have led to automated data extraction and analysis of routinely collected information. Other innovations include integrated public health information networks.

With growing concerns about emerging infections and bio-terrorism, surveillance networks have been developed to share data across different sectors and countries. Examples include the global communicable disease surveillance network and the international surveillance of pathogens in animals.

1.0 OVERVIEW/ SETTING THE CONTEXT

In 2005, the British Columbia Ministry of Health released a policy framework to support the delivery of effective public health services. The *Framework for Core Functions in Public Health* identifies health assessment and disease surveillance as one of the 21 core programs that a health authority provides in a renewed and comprehensive public health system.

The process for developing performance improvement plans for each core program involves completion of an evidence review used to inform the development of a model core program paper. These resources are then utilized by the health authority in their performance improvement planning processes.

This evidence review was developed to identify the current state of the evidence based on the research literature and accepted standards that have proven to be effective, especially at the health authority level. In addition, the evidence review identifies best practices and benchmarks where this information is available.

1.1 An Introduction to This Paper

Surveillance is one of the most important tools used in public health. As early as the 17th century, statistics were compiled about plague in London so appropriate action could be taken to contain the epidemic (Declich & Carter, 1994).

Concepts of public health surveillance have evolved over time. Prior to 1950, surveillance had usually meant "personal surveillance"; i.e., the close observation of persons exposed to a communicable disease to detect early symptoms and institute prompt isolation and control measures (Declich & Carter, 1994). Around 1950, surveillance was broadened to mean "population surveillance" (Langmuir, 1963). By 1968, the World Health Assembly had adopted the concept of population surveillance as an essential function of public health practice (Lucas, 1968). Globally, communicable diseases were the first health events to be put under international monitoring (Declich & Carter, 1994).

Public health surveillance is the ongoing, systematic collection, analysis, interpretation and dissemination of data regarding a health-related event for use in public health action to reduce morbidity and mortality and to improve health (Centers for Disease Control and Prevention [CDC], 2001). Effective communicable disease surveillance provides information about (Weinberg, 2005):

- Infections that are the most important causes of illness, disability and death so priorities can be determined for control and prevention activities.
- Populations most affected or at risk so control and prevention efforts can be focused.
- Outbreaks so that immediate action can be taken to identify and control the source.
- Likely demands on health care services.
- Effectiveness of control and prevention activities.

Surveillance has alerted health officials about epidemics such as the *E. coli* outbreak in Walkerton, Ontario, which affected over 1,300 people and resulted in 27 cases of hemolytic uremic syndrome and 6 deaths (Public Health Agency of Canada [PHAC], 2000). Surveillance has also identified new infections such as new variant Creutzfeldt-Jakob disease (CJD), a disease previously unknown among humans (Will et al., 1996). In 1990, concerns about bovine CJD in the United Kingdom led to human surveillance, which identified 10 cases among young people with an atypical clinical course and neuropathological changes not previously reported.

In recent years, unprecedented social and environmental changes linked to urbanization, mobility and deforestation have created new opportunities for infection. Rapid adaptation of micro-organisms has also facilitated the return of old communicable diseases and the emergence of new ones (Heymann & Rodier, 1998). Concerns about infectious disease threats have grown and this has fostered national and international efforts to bolster surveillance efforts by utilizing new technologies and global telecommunications.

Surveillance underpins all communicable disease efforts and is a public health strategy that has application across all programs. This is highlighted in the Core Functions Framework. The evidence review on health assessment and disease surveillance (Ministry of Health [MOH], Population Health and Wellness [PHW], 2006) should be read in concert with the present document.

This paper reviews communicable disease surveillance from a 21st century perspective. It focuses on surveillance among humans, but related topics such as animal surveillance are discussed. The report is divided into two sections. The first reviews components of surveillance by addressing modern techniques alongside conventional methods. The second presents new developments in surveillance such as syndromic surveillance. Public health actions are not covered since these are discussed by other core program documents.

2.0 METHODOLOGY

The literature search for this paper included the following databases: MEDLINE, OLDMEDLINE, EMBASE, CINAHL. Searches were limited to English-language publications in developed countries, using the following search terms: Communicable/infectious disease surveillance, syndromic surveillance, linked communicable disease databases, antimicrobial resistance surveillance, data dissemination, alerting algorithms, global surveillance, animal surveillance, enteric surveillance and geographic information systems.

Websites of Canadian and United States government agencies as well as the World Health Organization were also searched for relevant information. Titles and abstracts of citations were reviewed and potentially relevant articles were retrieved. Reference lists in retrieved articles were scanned and additional citations were obtained. Consultations were also conducted with officials from the BC Ministry of Health, BC health authorities and the British Columbia Centre for Disease Control (BCCDC).

Evidence uncovered in the literature review included descriptions of specific types of surveillance, evaluations of various surveillance systems, opinions of health officials or academics and guidance documents produced by expert committees. One systematic review was found that evaluated the utility of existing surveillance systems for detecting bio-terrorism-related diseases (Bravata et al., 2004).

The National Health Service (NHS) evidence grading system was used to grade the material. According to the NHS scheme, the type of evidence used in this paper is graded as 3 (case reports) and 4 (expert opinion). The single systematic review is graded as 2++.

Table 1: Evidence of the Efficacy of an Intervention – Did it Work?

Level of Evidence	Type of Evidence
1++	High quality meta-analyses, systematic reviews of RCTs (including cluster RCTs), or RCTs with a very low risk of bias.
1+	Well conducted meta-analyses, systematic reviews of RCTs, or RCTs with a low risk of bias.
1-*	Meta-analyses, systematic reviews of RCTs, or RCTs with a high risk of bias.
2++	High quality systematic reviews of, or individual high quality non-randomised intervention studies (controlled non-randomised trial, controlled before-and-after, interrupted time series), comparative cohort and correlation studies with a very low risk of confounding, bias or chance.
2+	Well conducted, non-randomised intervention studies (controlled non-randomised trial, controlled before-and-after, interrupted time series). Comparative cohort and correlation studies with a low risk of confounding, bias or chance.
2-*	Non-randomised intervention studies (controlled non-randomised trail, controlled before-and-after, interrupted time series), comparative cohort and correlation studies with a high risk of confounding, bias or chance.
3	Non-analytical studies (e.g., case reports, case series).
4	Expert opinion, formal consensus
* Studies with a level of evidence (-) should not be used as basis for making recommendations. Source: Adapted from SIGN (2001).	

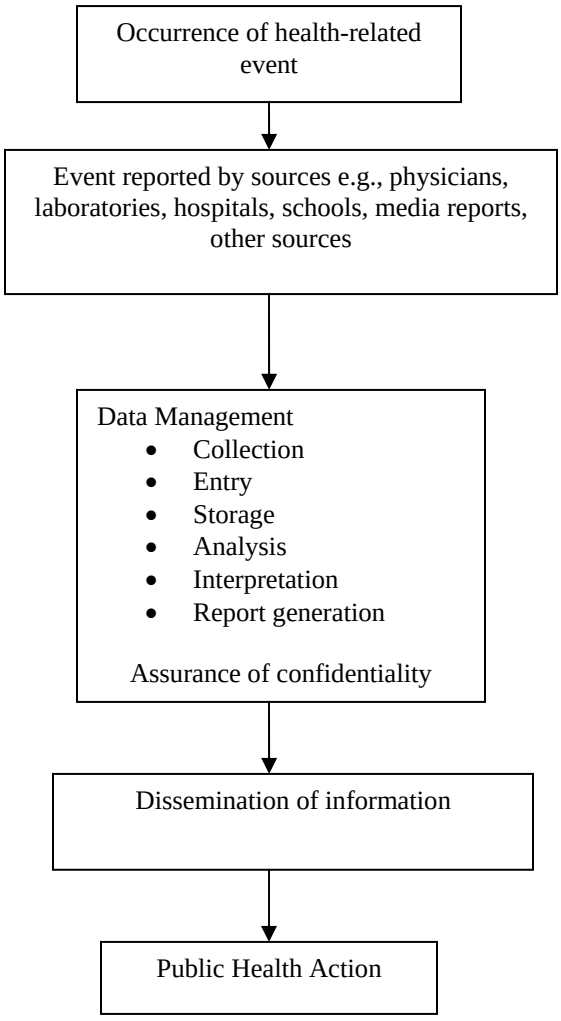
Source: Adapted from Weightman et al., 2005.

3.0 OVERVIEW OF COMMUNICABLE DISEASE SURVEILLANCE

3.1 Components of a Generic Surveillance System

Figure 1 outlines the different components of a public health surveillance system. Each component will be addressed in greater detail in the following pages.

Figure 1: Components of a Public Health Surveillance System



Source: Adapted from CDC, 2001.

3.2 Attributes of Effective Surveillance Systems

The attributes of a useful surveillance system have been delineated. When designing or evaluating a particular surveillance system, the relative importance of each attribute needs to be weighed in light of the objective of the system and the resources available for its implementation (CDC, 2001):[1]

[1] Further information about the evaluation of surveillance systems can be found at CDC, 2001.

- *Data Quality* – The accuracy and completeness of information within the surveillance system. One aspect is the use of standard and specific case definitions. This ensures that information is comparable over time and across jurisdictions.
- *Representativeness* – How well reported events reflect reality.
- *Sensitivity* – The proportion of cases of a disease detected by the surveillance system.
- *Predictive Positive Value (PVP)* – The proportion of reported cases that actually have the health condition under surveillance. When PVP is low, resources are being spent investigating false positive cases.
- *Timeliness* – The speed between steps in the surveillance system. The need for rapidity of response depends on the condition under surveillance.
- *Simplicity* – The ease of operating the surveillance system. Systems should be as simple as possible while still meeting their objectives.
- *Flexibility* – The ability of the system to adapt to changing information needs or operating conditions.
- *Acceptability* – The willingness of individuals and organizations to participate in the surveillance system.
- *Stability* – The ability of the system to collect, manage and provide data when it is needed, without failure.

3.3 Prioritizing Conditions for Surveillance

It is impossible to place all communicable diseases under surveillance; therefore, it is necessary to identify diseases or conditions that are sufficiently important to warrant the time and effort required for monitoring. In 1987, the Advisory Committee on Epidemiology (ACE) established a subcommittee to develop a systematic process to determine which communicable diseases should be under surveillance (Carter & National Advisory Committee on Epidemiology Subcommittee, 1991). The criteria that were adopted at the time were updated in 1997–1998 (Doherty, 2000) and again in 2006 (National Notifiable Diseases Working Group, 2006):

1. Diseases of interest to national/international regulatory and prevention programs.
2. Incidence in Canada.
3. Severity.
4. Potential spread to the general population.
5. Potential for outbreaks.
6. Socioeconomic burden.
7. Preventability.
8. Risk perception.
9. Necessity for public health response.
10. Appearing to increase in incidence or change patterns over the past five years.

Diseases that are internationally reportable are automatically included. For other diseases, a numeric score is given for each criterion based on ranking guidelines; a summary score is then tallied. If a disease's summary score ranks above a particular threshold, it is considered for surveillance.

A similar priority-setting exercise was undertaken by the Public Health Laboratory Service (PHLS) in the United Kingdom. This resulted in the identification of six criteria for choosing diseases for surveillance (Giesecke, 1999):

1. Present burden of ill health.
2. Social and economic impact.
3. Potential threats.
4. Health gain opportunity.
5. Public concern and confidence.
6. PHLS-added value.

Increasingly, the need for early detection of outbreaks has prompted surveillance of pre-disease indicators, such as pharmacy sales and work absenteeism. These will be discussed in greater detail in Section 4.1.

3.4 Data Sources

Many sources of data can be used for communicable disease surveillance. They may be obtained from routinely collected reports, from collections for other purposes and by special efforts on the part of the investigator. Examples include: mortality data, laboratory reports, hospital statistics, animal reservoir and vector distribution studies (Declich & Carter, 1994). A surveillance system would not normally include all data sources described in the sections that follow. Specific sources would depend on the goal of surveillance, available resources and diseases of interest.

3.4.1 Legally Mandated

Communicable disease surveillance has traditionally been based on reportable diseases, a system where laws regulate the reporting of selected diseases to the health department (Advisory Committee on Epidemiology & Laboratory Centre for Disease Control, 2000). In Canada, the reporting of communicable diseases is mandated by provincial legislation, and the list of reportable diseases differs by province and territory. In British Columbia, the reportable disease list exists under the Health Act Communicable Disease Regulation (*Health Act*), Schedule A (reportable from all sources) and Schedule B (reportable by laboratories only).

The BC *Health Act* states that any person, physician, laboratory and hospital should report known or suspected communicable diseases to the medical health officer. The *Health Act* supersedes the *Freedom of Information and Protection of Privacy Act* (FOIPPA) and allows communicable disease reports to be collected by medical health officers or designates. It also states that the medical health officer will forward such reports to the Provincial Health Officer within seven days.

In most instances, only confirmed cases are reported; a combination of clinical, laboratory and epidemiologic criteria is used to classify a confirmed case. Probable cases may be described to assist local public health authorities in conducting outbreak investigation and contact tracing. These officials are responsible for determining that the case meets the surveillance case definition before they officially report the case.

Currently, the pathway of reporting is case-by-case to the medical health officer. This means that for diseases with high incidence, there is a heavy administrative burden at the regional level even if there is no case-by-case follow-up. BCCDC is actively looking at other routes of laboratory reporting, such as automated electronic reporting of laboratory results. Such systems are discussed in Section 3.5.

Surveillance data are commonly aggregated from local, through provincial, to national data sets. Communicable disease data for about 50 diseases are shared by each province with the Public Health Agency of Canada.

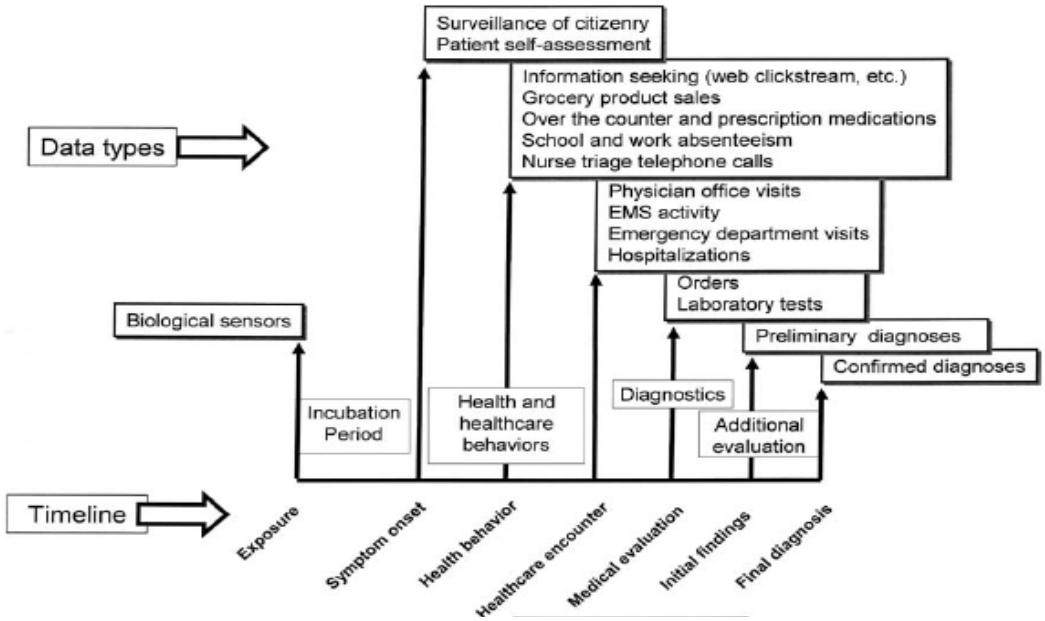
3.4.2 Health-related Data Sources

Some early warning systems for outbreak detection rely on data that signal the presence of disease before it is confirmed in a laboratory. When people become sick, they may purchase over-the-counter remedies, may be absent from work or school, may visit primary care sites, activate emergency 911 services or visit emergency rooms. Data sources can be chosen along this continuum of disease (See Figure 2). Examples of data sources include (Lober, Trigg, & Karras, 2004: Hefferman et al., 2004):

- Emergency department log of chief complaints.
- Real-time emergency department discharge diagnoses.
- Total hospital or intensive care unit admission from emergency department.
- Ambulatory care clinic diagnosis.
- 911 call type.
- Provider hotline (e.g., telehealth volume).
- Poison control centre calls.
- Unexplained deaths.
- Physician billing data.
- Clinical laboratory or radiology ordering volume.
- School or work absenteeism.
- Pharmacare (public drug plan).
- Over-the-counter medication sales.

- Volume of internet-based health inquiries by the public.
- Hospital discharge summaries.

Figure 2: Continuum of Disease and Data Sources.



Source: Mandl et al., 2004.

The BC Ministry of Health is developing the Aggregated Health Information Project (AHIP). Work on the project began in November 2004. This is a data warehouse of all Ministry of Health databases, including data from the Medical Services Plan, Pharmacare (public drug plan) and Pharmanet (all prescriptions filled by BC pharmacies), hospital separation, continuing care, mental health and addictions, as well as all laboratory reports. The personal health number is used to link contacts with the health system. Information access will depend on the legally mandated role of the health provider. AHIP is planning a pilot project that will use an interactive, web-based geographic information system to support surveillance of influenza, pertussis and waterborne enteric diseases (K. Barnard, personal communication, September 5, 2006).

In addition to administrative databases, behaviour risk factor surveillance has been conducted in some jurisdictions. Since 1984, the CDC has operated the Behavioral Risk Factor Surveillance System (CDC, *Behavioral*, n.d.). This monthly, cross-sectional telephone survey is conducted by state health departments using standardized questionnaires in order to determine the distribution of risk factors and health practices among non-institutionalized adults. BRFSS interviewers ask questions related to behaviours that are associated with preventable chronic diseases, injuries, and infectious diseases (CDC, *Behavioral* n.d.). A surveillance system modeled on the BRFSS has been in place in Ontario since 1999 called the Rapid Risk Factor Surveillance System (RRFSS). [2] In March 2006, phase 1 of the BC Health and Wellness Survey (BC-HWS) was launched. This is a telephone survey based on the Ontario RRFSS; it aims to interview 10,400

[2] More information on the Rapid Risk Factor Surveillance System can be found at http://www.rrfss.on.ca.

adults over 18 years of age in specific local health areas (L. Masse, personal communication, August 30, 2006).
Other types of data that have been used in communicable disease surveillance include food and water sampling, as well as animal studies.

3.4.3 Informal Sources

Global expansion of telecommunications, media and public Internet sites permit public health professionals to have access to disease reports previously unavailable. One example is the Global Public Health Intelligence Network (GPHIN), which was developed and maintained by Health Canada. Its powerful search engines actively crawl the World Wide Web looking for reports of communicable diseases and communicable disease syndromes in electronic discussion groups, news wires, etc. (Mykhalovskiy & Weir, 2006).

3.5 Data Collection

Many methods are used to collect information, but they usually fall into one of the following categories:

- Passive surveillance – The data recipient waits for data providers to report conditions of interest.
- Active surveillance – Reports may be obtained by searching for cases or by contacting those who may know about such cases. Because significant resources are required to do this, active surveillance is often limited to specific diseases over a specific period of time (e.g., during an outbreak).
- Sentinel surveillance – Reporting relies on a pre-arranged sample of reporting sources (e.g., general practitioners) who agree to report all cases with a specific diagnosis or condition.

3.5.1 Automated Electronic Laboratory Reporting

Passive surveillance relies on providers to report, but studies have shown that some providers (e.g., physicians) are unaware of this responsibility (Sen & Osborne, 1995). Certain attitudes are also associated with under-reporting. In a survey of 360 primary care physicians in Spain, factors that impeded reporting included the need to confirm a diagnosis before reporting, the time taken to report, not being sure how the information will be used, and the belief that only serious diseases need to be reported (Figueiras et al., 2004). Because conventional methods of reporting via mail, fax or telephone require active participation of staff, *automatic* reporting of reportable diseases is thought to provide more complete and timelier information (Silk & Berkelman, 2005).

Medical laboratories play a very important role in confirming known infections, detecting microbial resistance and identifying new organisms. In Hawaii, the Department of Health has an electronic system that links the three largest commercial laboratories with the public health department. At a predetermined time each day, a dedicated computer automatically connects to the laboratory information system at the facility. This connection launches a data extraction program that scans files for test results posted the previous day. If the test results fulfill the

criteria in the data dictionary, the record is flagged and written to a transfer file that is sent to the health department; authorized staff can then review each record. Comparison of six months' data showed that automatic electronic reporting more than doubled the number of reports received and reduced reporting time by 3.8 days (Effler et al., 1999).

In Pennsylvania, comparison of an automated laboratory reporting system with a paper-based system during an 11-month period showed no significant difference in completeness of reporting, but electronic alerts were received a median of 4 days sooner than paper-based reporting (Panackal et al., 2002). In 2002, an Internet-based reporting system replaced the paper-based reporting system in the Netherlands. Evaluation of electronic reporting in 2005 compared with paper-reporting in 2001, showed that the median delay time was reduced from 10 days to 1 day (Ward et al., 2005).

Automated reporting has some advantages but it also poses challenges. Errors in data abstraction and data transmission can reduce the sensitivity of the reporting system. Extraneous reports (e.g., non-reportable conditions, duplicate reports and unnecessary negative reports) are sometimes included. Technology necessary for electronic reporting, such as standardized coding of data, may not be available in some laboratories (M'ikanatha, Southwell, & Lautenbach, 2003; Jernigan, 2001).

3.5.2 Integrated Public Health Information Networks

There are many information systems that have data relevant to communicable disease surveillance. However, these systems are administered independently, use non-standardized data formats and are often unable to communicate with each other. With increasing concerns about early identification of outbreaks and bioterrorist events, some countries are developing surveillance systems that link different information systems from public health, laboratories and clinical sources (Pezzino, 2001; Snee & McCormick, 2004).

Development of a national Canadian Integrated Public Health Surveillance (CIPHS) system is underway to capture, integrate and transmit data generated by laboratories and public health. The main components of CIPHS are the Public Health Information System (iPHIS) and the Laboratory Data Management System. Originally developed by BCCDC, iPHIS is an automated, client health record and reporting system that tracks immunization, case management and surveillance components using a central information system. The Public Health Agency of Canada (PHAC) has now made iPHIS available to all provincial and territorial jurisdictions. iPHIS adheres to national data standards, which enables data sharing. Therefore, it can function independently or work in conjunction with other complementary systems in a national network of health surveillance (PHAC, 2006).

The Laboratory Data Management System is a laboratory information management system that has the ability to exchange information with public health surveillance. It is currently operating in two Health Canada laboratories: the Laboratory for Foodborne Zoonoses in Guelph, Ontario, and the Enterics Division, National Microbiology Laboratory in Winnipeg, Manitoba (PHAC, 2006). Unfortunately such a system does not exist in BC. The lack of a linked laboratory and public health surveillance system is a major gap in conducting effective and timely communicable disease surveillance in the province.

The need for increased investment in surveillance was identified following the SARS outbreak in 2003. In March 2004, $100 million was provided to Canada Health Infoway to develop a public health surveillance component. This component is dedicated to support the management of infectious diseases and immunization. Canada Health Infoway was established in 2001 by the 14 federal, provincial and territorial Deputy Ministers of Health. Its mission is to develop an electronic health information system with compatible standards and communication technologies across Canada (Beasley, 2006).

Jurisdictional planning about the surveillance component began in 2005, with a goal of full implementation in 2009 (Beasley, 2006). When it is built, iPHIS will be sunsetted. More specifically, Canada Health Infoway has been directed to construct a bilingual pan-Canadian health surveillance system. This system will be consistent with the electronic health record solution architecture of Canada Health Infoway and will address the following issues:

- Infectious disease case management.
- Immunization management.
- Infectious disease outbreak management.
- Health alert network.
- Infectious disease surveillance and reporting.
- Integration with jurisdictional registries and laboratory repositories.

It is anticipated that the Canada Health Infoway solution will improve linkages between public health agencies and laboratories, improve timeliness of information exchange and improve record keeping.

The electronic health record (EHR) is another major priority of Canada Health Infoway. EHR is an individual health record that is accessible online from many separate, interoperable automated systems within an electronic network (Health Canada, n.d.). British Columbia is moving towards EHR. For example, Vancouver Coastal Health Authority has a full EHR for all encounters that occur in the community (P. Daly, personal communication, September 6, 2006). This system assists surveillance activities by reducing the administrative work of data entry and allows more opportunities for analysis based on information within the EHR.

The United States is also developing an integrated public health information system known as the Public Health Information Network (PHIN). One component of PHIN is the National Electronic Disease Surveillance System (NEDSS).[3]

3.5.3 Information System Architecture

When designing information systems to integrate data from diverse sources, various architectural components need to be considered (Lober et al., 2004, Forslund et al., 2004):

[3] More information on the National Electronic Disease Surveillance System can be found at http://www.cdc.gov/nedss.

- Data elements to be included in the extracted data set need to be identified (e.g., age, sex, geographic locator).
- Standard vocabulary usage is required so heterogeneous data sources can be combined (e.g., Logical Observation Identifiers Names and Codes (LOINC) is the vocabulary standard for laboratory reporting).
- Different data extraction methods are used to acquire a data set from the source system (e.g., Message-based systems send a message to the surveillance system whenever something of interest occurs in the source system. These messages are commonly in Health Level 7 (HL7) format).[4]
- Data typically travel through the Internet. Therefore, messages need to be encrypted to protect patients' identities.
- Data arriving from different source systems may be in different formats. Computer programs are needed that can transform the syntax and normalize the semantics to ensure that formats are synchronized among different sources.
- Various techniques can be used to integrate data from heterogeneous sources into a single analysis set (e.g., construct relations between data sources so they appear integrated to the surveillance system user, even though the data remain at their original location, subject to the control of the original owner).

3.6 Data Analysis and Interpretation

Surveillance data are usually analyzed in terms of time, place and person. Simple tabular and graphic techniques are frequently used to display the data. Current data are compared with some "expected" value based on historical information or data from neighbouring areas. The difference between observed and expected values is assessed to determine if it represents a true increase. Further investigation is undertaken to determine if this increase is real or an artifact.

3.6.1 Analytic Methods for Rapid Outbreak Detection

Whatever data are used, the goal is to distinguish an abnormal pattern from a normal one. The challenge is to identify a signal corresponding to a cluster or outbreak amid substantial "background" noise in the data. A variety of aberration-detection methods have been developed (Henning, 2004; Burkom et al., 2005). Pre-determined alarm thresholds are adjusted to increase or decrease the sensitivity of detection.

Different mathematical theories are used as the basis for detection (Wagner et al., 2001). One is signal detection theory, which processes input data (signal) and determines whether an event has occurred. The second is the use of decision theory. This provides methods for estimating the benefits of true alarms and the cost of false alarms in order to identify optimal sensitivity,

[4] HL7 is a recognized standard for electronic data exchange in health care environments. It is a defined set of rules for sending simple text characters in groups that represent patient identifiers, clinician identifiers, laboratory test information, test results and other clinical and administrative data (CDC, 1997).

specificity, and timeliness thresholds of detection. The statistical methods used by detection theories include (Mandl et al., 2004; Thuppal, 2003; Burkom et al., 2005; Buckeridge et al., 2005):

- Cumulative sum method to compare the cumulative differences between observed and expected data in a time window. Because many health care data sets show regular periodicities, the expected number needs to change over time to reflect daily and seasonal periodicities.
- Temporal modeling compares observed patterns with those predicted by a model. This approach requires a robust model of the baseline pattern of syndromes as well as the selection of a threshold to signal an alarm. To establish normal patterns, one or more years of historical data are usually required.
- Spatial and spatiotemporal modeling are also used. The simplest approach is to examine the spatial distribution of observed cases or case counts without respect to time. A variety of statistical methods are available to assess case location and clustering. A more powerful approach is to examine the joint spatial and temporal distribution of case locations or case counts over a fixed time interval.

Many articles that examine statistical methods for rapid outbreak detection have been published. Readers who have an interest in this area can refer to two reviews of statistical methodologies by Buckeridge et al. (2005) and Burkom et al. (2005).

An aberration detection method is being used at BCCDC. This statistical method uses the generalized additive model to compare the fit between daily case counts with a threshold based on historical data. Depending on the fit, daily alert levels are generated for specific communicable diseases. Prior to implementation, threshold levels were developed using randomly generated data sets as well as real data (M. Naus, personal communication, August 30, 2006).

Successful management of infectious disease outbreaks requires rapid event recognition so appropriate control measures can be undertaken. Systematic approaches to outbreak investigations have been published (Gregg, 2002).[5]

Recent concerns about bio-terrorism and emerging infections have led to the development of criteria to differentiate between intentional and unintentional outbreaks (Grunow & Finke, 2002). These criteria assess data collected during an investigation to determine the likelihood of a natural versus intentional source. Data include epidemiological and clinical characteristics; specific pathogen features; political, military and social characteristics of the affected area; and evidence of a biological weapon or proof of release (Rotz & Hughes, 2004; Dembek, Kortepeter, & Pavlin, 2006).[6]

[5] Interested readers can refer to CDC's online outbreak management course: http://www.cdc.gov/excite/classroom/outbreak/steps.htm.
[6] Interested readers can refer to the article by Grunow & Finke (2002).

3.7 Data Dissemination

Data must be disseminated in a timely manner to those who need to know so appropriate public health action can be taken. In an outbreak, information should be disseminated as quickly as possible (Foldy, 2004). Besides telephone, fax and email, the Canadian Network for Public Health Intelligence (CNPHI) is available to registered staff at the local level to access and post information on an electronic bulletin board about enteric and respiratory outbreaks. This network also enables information to be shared at the national level. There is interest in linking CNPHI with Epi-X in the United States for cross-border notifications (D. Patrick, personal communication, August 3, 2006).

The Program for Monitoring Emerging Diseases (ProMED-mail) is an Internet-based global monitoring system for emerging diseases. It is one mechanism by which public health staff in BC can receive as well as post information about diseases of international interest. Founded in 1994, ProMED-mail's goal is to disseminate information about outbreaks of emerging diseases rapidly to a worldwide audience (Madoff, 2004). Reports are simultaneously posted on the ProMED-mail website and distributed to mailing lists of subscribers by email. Subscription is offered free-of-charge to all sources. Anyone with access to ProMED-mail can post an item of interest; however information is only disseminated to subscribers after it is vetted by the editors. The collection and vetting of information in ProMED is not covered here.[7]

Results of analyses should also be shared with those who provide the data. Presently, in the health authorities this is done by personal contact, telephone, fax, email or newsletter. This increased awareness of communicable diseases in the community assists clinicians in diagnosis and stimulates their interest in reporting cases (Silk & Berkelman, 2005). A German study examined what surveillance information primary care physicians were most interested in receiving (Krause, Ropers, & Stark, 2005). Of the 1,320 physicians surveyed, 92 per cent preferred to receive surveillance reports on a regular basis (i.e., quarterly, semi-annually or on special occasions such as during an outbreak) instead of having to actively search for the information on the Internet. The preferred formats were fax (32 per cent), mail (31 per cent) and email (21 per cent). Surveillance topics that were of greatest interest included:

- Outbreaks of infectious diseases (85 per cent).
- Recommendations about preventive measures (65 per cent).
- Reports of imported or travel-related diseases (60 per cent).
- Disease trends (48 per cent).

The CDC has developed a guidance document to assist public health departments in developing and distributing clear and concise health alerts and advisories. It can be found at: http://www.cdc.gov/epo/dphsi/files/Guidance_for_Public_Health_Alerts_Advisories_Updates.doc (CDC, *Guidance*, n.d.).

[7] More information on the collection and vetting of information in ProMED can be found in Madoff (2004) and Madoff and Woodall (2005).

Data should also be shared with policy-makers, administrators and planners. Communication should be tailored to the audience, usually in the form of written reports. Health authority medical health officers usually make reports to the health authority board on a regular basis and have the opportunity to keep the board apprised of any unusual communicable disease occurrences in the community.

Information can be made available on public websites for those who wish to access it. The Public Health Agency of Canada has developed a Disease Surveillance On-Line website that provides mapping and other services for reportable diseases.[8] In Sweden, county and national communicable disease surveillance data are available to the public from the Swedish Institute for Infectious Disease Control website. Web statistics contain information from 1997 to the present and are stored in a relational database. The user can view the data by tabulated format, by interactive maps or in graphical form (Rolfhamre, Grabowska, & Ekdahl, 2004).

[8] The Disease Surveillance On-Line website can be found at http://www.phac-aspc.gc.ca/dsol-smed.

4.0 NEW DEVELOPMENTS IN COMMUNICABLE DISEASE SURVEILLANCE

4.1 Syndromic Surveillance

Syndromic surveillance refers to methods that rely on detection of clinical case features that are discernable before confirmed diagnoses are made (Mandl, 2004). The ability to reliably detect an outbreak at the earliest possible stage is the major purpose of syndromic surveillance.

Most diseases are reported when they are confirmed; however some diseases (e.g., measles) need to be reported when the disease is suspected (Nordin et al., 2004) because control measures must be instituted as quickly as possible. This type of "syndromic surveillance" has been in operation for many years.

In recent years, concerns about bio-terrorism and emerging infections have been greatly heightened, following the terrorist attack in New York in 2001, the anthrax threats of 2001 and the SARS outbreak of 2003. Military and government officials soon realized that bio-terrorism preparedness requires sophisticated surveillance systems. This in turn led to significant resources being spent on research and development in this area (Bravata et al., 2004). Unlike measles-like illness monitoring, which was described earlier, these new systems utilize sophisticated information technology to gather and analyze data from many different sources.

4.1.1 Examples of Syndromic Surveillance Systems

Many syndromic surveillance systems have been described in the literature (Das et al., 2005; Besculides et al., 2005; Paladini, 2004; Fleischauer et al., 2004; Steiner-Sichel et al., 2004; Lewis et al., 2002; Muscatello et al., 2005; Terry, Ostrowsky, & Huang, 2004; Dembek et al., 2004) but evaluations have shown varying success.

One operated by the New York City Department of Health conducts daily monitoring of ambulance dispatch calls, emergency department visits, over-the-counter pharmacy sales and worker absenteeism (Hefferman et al., 2004, Besculides et al., 2005, Das et al., 2005. Evaluation of its emergency department-based data found that syndromic surveillance was able to detect seasonal disease such as influenza (Steiner-Sichel et al., 2004). An assessment of syndromic surveillance using over-the-counter medication sales in New Hampshire showed that the system detected a large-scale gastrointestinal disease outbreak four days earlier than traditional surveillance and a major influenza outbreak ten days earlier (Zhang, Fiedler, & Popovich, 2004). However, an evaluation of a syndromic surveillance system in Westchester County, New York found no incidents of public health significance despite investigating 59 aberrant signals (Terry et al., 2004).

While most systems for syndromic surveillance are continuously collecting, analyzing and reporting data, some systems are designed for short-term use at mass gatherings such as the Olympic Games, where there is a potentially increased risk of infectious disease transmission and bioterrorist attack (Meehan et al., 1998, Thackway et al., 2000). At the Athens Olympics in 2004, a syndromic surveillance system was developed that relied on data from emergency room

visits. Public health staff visited participating sites daily to review chief complaints and preliminary diagnoses. Information was collected about 12 public health syndromes of interest. Data were faxed to the Hellenic Centre for Infectious Diseases and an analysis report was produced daily. Public health staff conducted further investigations when required (Dafni et al., 2003).

Criteria for evaluating the usefulness of syndromic surveillance systems have been published by the CDC (the reference can be found in the bibliography by Buehler [2004]).

4.1.2 Systematic Review of Surveillance Systems to Detect Bio-terrorism-related Diseases

The San Francisco-Stanford Evidence-based Practice Center has conducted a systematic review of the ability of available information technologies to detect bio-terrorism-related diseases (Bravata et al., 2004). These diseases have been designated by the CDC, and include influenza-like illness, acute respiratory distress, gastrointestinal symptoms, febrile hemorrhagic syndromes and febrile illnesses with dermatologic or neurologic findings. The researchers reviewed over 17,500 citations of peer-reviewed articles and over 8,000 websites to identify 192 reports of 115 surveillance systems that met their inclusion criteria. Of these, 29 systems were designed specifically for detecting bio-terrorism-related diseases and 86 were designed for naturally occurring diseases with elements that were relevant for bio-terrorism surveillance.

The researchers found that electronic collection and reporting of surveillance data improved timeliness of detection, compared to manual methods. However, many health departments did not have adequate resources to manage, analyze and interpret such large data sets. They only found three studies that had evaluated a surveillance system's sensitivity and specificity. No study was found that had evaluated the best methods for analyzing and presenting surveillance data to facilitate public health decision-making. The reviewers concluded that there were critical scientific gaps about the utility of existing surveillance systems to detect bio-terrorism-related diseases.

4.2 Global Surveillance of Communicable Diseases

Expansion of international travel and trade means that diseases in one part of the world can quickly spread to another country. Rapid and comprehensive data collection is critical to contain global health threats. In 2001, the World Health Organization (WHO) formalized an infrastructure called the Global Outbreak Alert and Response Network (GOARN) for early detection of outbreaks. The network interlinks in real time with over 100 existing networks, including national institutes of public health, WHO regional and national offices, non-governmental organizations, newspapers, television and radio (Heymann et al., 2001). Other information providers are Internet- and electronic mail-based discussion group such as ProMed. The WHO also utilizes the Global Public Health Intelligence Network (GPHIN) to look for reports of communicable diseases in electronic discussion groups, news wires and elsewhere (Heymann & Rodier, 1998; Grein et al., 2000).

4.2.3 Infectious Disease Global Surveillance Framework: A Network of Networks

The WHO has also revised the International Health Regulations (IHR) to strengthen the legal requirement of Member States to report disease to the WHO. The revised IHR was adopted in May 2005 and enters into force on June 15, 2007. The IHR requires States to notify the WHO of all events that may constitute a public health emergency of international concern; it also sets out the basic public health capacities a Member State must develop in order to detect, report and respond to public health risks and emergencies.[9]

Information about communicable diseases are processed and analyzed at the WHO headquarters and subsequently shared through the weekly WHO Outbreak Verification List, which consists of over 900 institutions and public health professionals. At the same time, a process has begun to verify reported outbreaks. Upon confirmation, information is distributed through the WHO website and the Weekly Epidemiological Record (WHO, 2000; Grein et al., 2000).

4.3 Antibiotic Resistance Surveillance Systems

Antibiotic resistance has developed predominantly in the last 50 years. Widespread use of antibiotics provides the selective pressure favouring propagation of the resistant organisms. Typically, it arises as a result of genetic mutation, expression of a latent resistance gene or acquisition of genes with resistance determinants. These three mechanisms may co-exist within a given bacterium (Conly, 2002).

The basic objectives of antibiotic resistance surveillance are (Fluit et al., 2006):

- To identify and predict trends in resistance.
- To detect the emergence of new resistance mechanisms.
- To monitor the impact of antibiotic prescribing.
- To guide patient therapy and maximize appropriate prescription of antimicrobial agents.
- To study how resistance develops, persists and spreads.
- To monitor the impact of interventions (e.g., infection control).

The Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) monitors trends in antimicrobial use and the development of resistance in selected bacterial organisms from humans, animals and animal-derived food sources across Canada (PHAC, 2004). Agrifood surveillance includes abbatoir surveillance and retail surveillance. Abbatoir surveillance collects and analyzes isolates of generic *E. coli* and *Salmonella* from the intestinal contents of healthy animals at slaughter. Retail surveillance analyzes isolates of generic *Campylobacter*, *E. coli*, *Enterococcus* and *Salmonella* from retail meats for antimicrobial resistance.

CIPARS also includes passive surveillance of antimicrobial resistance in *Salmonella* from human and diseased animal specimens collected from laboratories across Canada. Provincial public health laboratories forward a representative sample of *Salmonella* isolates with

[9] More information on the International Health Regulations can be found at http://www.who.int/csr/ihr/en/.

accompanying data to the National Microbiology Laboratory for phagetyping and susceptibility testing. Through an agreement with IMS HEALTH Canada and its CompuScript database, complete human antimicrobial prescription data on all classes of oral antimicrobials is also incorporated into CIPARS (Conly, 2002).

There are many national and international antibiotic resistance surveillance systems in existence. Readers can find a list of websites of major antimicrobial resistance networks in the article by Falagas & Karveli (2006).

4.4 Active Sentinel Surveillance of Enteric Diseases

Enteric disease refers to gastrointestinal illnesses that result from ingesting bacteria, virus or other parasite that can be traced back to food, water, animals or an infected person (PHAC, n.d.). It is estimated that only 5 per cent of bacterial foodborne illness is reported through the passive surveillance system (Angulo et al., 1998). Most cases are not identified or reported because ill persons are not sick enough to seek medical care. Even if they do seek care, physicians may not order a laboratory test.

In 1996, the CDC, the United States Department of Agriculture, and the Food and Drug Administration established an active sentinel surveillance system for foodborne diseases called FoodNet. The project consists of active surveillance for foodborne diseases. Related epidemiologic studies are also conducted to help public health officials better understand the epidemiology of foodborne diseases in the United States.

Active surveillance is conducted at nine sites for seven bacterial diseases (*Campylobacter, E. coli O157, Listeria monocytogenes, Salmonella, Shigella, Vibrio* and *Yersinia Enterocolitica*) and two parasitic diseases (*Cryptosporidium* and *Cyclospora*). Public health officials contact microbiology laboratories on a regular basis to collect information on all culture-confirmed cases. Because most foodborne infections cause diarrheal illness, FoodNet also focuses its studies on persons with this condition. Surveys of care-seeking behaviour, surveys of clinicians regarding their clinical practices and surveys of laboratories about testing methodologies have been performed (Allos et al., 2004). By so doing, it has been determined that 38.6 cases of *Salmonella* infection occur for each culture-confirmed case reported (Voetsch et al., 2004).

Canada is developing the C-EnterNet model based on FoodNet. However, its scientific mandate is broadened to include in-depth investigation of foodborne and waterborne diseases and exposures. It will focus on the pathogens known to have the greatest potential of causing enteric diseases in Canada. These organisms are listed on its website, at: http://www.phac-aspc.goc.ca/c-enternet/source_e.html.

Each sentinel site would include a working network that includes the local public health unit, local water, agriculture and retail food sectors, as well as provincial and federal institutions. A pilot site has been established in the Region of Waterloo, Ontario, and four other sentinel sites are planned across Canada (PHAC, n.d.).

4.5 Pathogen Surveillance in Animals

Surveillance of animals is increasingly important in the control of infectious diseases among humans (Jebara, 2004). With an estimated 70 per cent of all emerging infections arising from animal sources (Kuiken et al., 2005), attention has turned to developing surveillance in animals for zoonotic pathogens.

One example of animal surveillance is the West Nile virus surveillance program among birds, mosquitoes and horses in Canada. Surveillance is conducted to detect the presence of the virus as early as possible, so communities can take steps to reduce their risk. Dead birds are tested for West Nile virus from late April until the first hard frost. Mosquito surveillance focuses on establishing the count of mosquito species in a given area through mosquito collection and testing. Mosquito surveillance helps to identify how different species spread the virus to birds, animals and people, and determines the best intervention to reduce the risk of infection. West Nile virus in horses is also monitored (Shuai et al., 2006).

In 1997, the Canadian Animal Health Network was founded to act as an early warning system for animal disease threats to the food supply, food safety and public health. It is described as a "network of networks", linking animal disease surveillance partners in Canada such as representatives from federal, provincial and territorial veterinary services, diagnostic laboratories, veterinary colleges, veterinary practitioners, producer organizations and wildlife interest groups.[10]

Internationally, a list of pathogens that affect international trade, including many important zoonoses, are reported to the World Organization for Animal Health (OIE) by member countries. Monthly information is collected on fifteen diseases that have the potential for very rapid spread, while annual information is collected on more than a hundred animal diseases, including zoonoses (Jebara, 2004). Other international organizations involved in pathogen surveillance of animals include the United Nations Food and Agriculture Organization (FAO) and the WHO. The inter-relatedness of animal and human health has drawn these organizations to work together as never before. These three organizations have developed a Global Early Warning System (GLEWS) to track diseases among the three sister organizations. Another planned component is the development of a coordinated response coupled with an international contingency plan (Kuiken et al., 2005, Jebara, 2004; ProMED-mail July 27, 2006).

4.6 Climate-based Monitoring Systems

The temporal and spatial distribution of pathogens, vectors and zoonotic reservoirs and their interactions with humans are influenced by environmental factors such as landscape structure, rainfall, temperature, etc. Projections of international global climate-change scenarios suggest that under conditions of global warming, parts of Canada may experience excess precipitation, floods and higher temperatures, which could increase the risk of waterborne infections (Charron et al., 2004).

[10] More information on the Canadian Animal Health Network can be found at http://www.cahnet.org/general.htm.

Many remote sensing systems such as aerial photographs and satellite sensors are able to measure changes in these environmental factors. In addition, geographic information systems (GIS) have allowed the integration and analysis of spatially referenced data (Pinzon, Wilson, & Tucker, 2005). Scientists now use remote sensing data and GIS to model environmental conditions conducive to vector populations (Cromley, 2003). The application of this type of tool to communicable disease surveillance is being explored. For example, CDC has partnered with NASA to determine how weather, climate and other key environmental factors correlate with the occurrence of infectious diseases. Once verified, validated and benchmarked, the plan is to include these relationships into surveillance systems.[11]

[11] More information on the CDC/NASA initiative can be obtained at www.cdc.gov/nceh/tracking/nasa.htm.

5.0 CONCLUSION

Concerns about communicable disease threats are best addressed by strong surveillance systems and committed public health action. Advances in informatics and telecommunications have allowed integration of diverse databases in real-time. Novel data sources, automatic data retrieval and aberrant signal detection methods have improved the timeliness of early warning systems. However, technological advances in and of themselves are insufficient to improve surveillance unless key system attributes are addressed, skilled personnel are in place and adequate resources are allocated for capacity building and infrastructure support. Scientific evaluations are essential to determine how well new technologies are contributing to surveillance under real-world conditions.

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