# A real-time Road Weather Information Network (RWIN)

# Spatial Data Management and Information Delivery architecture

Awtar Koonar, P. Eng., PMP, Paul Delannoy, Brian Scarlett

## ABSTRACT

A Road Weather Information System Canada (RWISC), a Canada wide integrated network of Environmental Sensor Stations (ESS) and instrument vehicles is being designed and implemented in order to make Canada stronger economically by offering a safer, sustainable, and more efficient highway system to Canadians. Provincial Territories Canada (PTC) servers acquire data from fixed and mobile stations in real-time. A central system, Road Weather Information Network (RWIN), will acquire ESS data from these servers, provide Quality Assurance and Quality Control services, alert PTC partners, in real time, of errors or deterioration or outages of any station or its components, and make the data available in real-time to clients and partners. RWIN features will ensure that the RWISC and other spatial and imagery datasets can be spatially browsed, viewed in a map form and transferred for the whole PTC area or for a specified area of interest. The RWIN architecture is scalable and is capable of handling text, snap shots, video, image, GIS and raster data sets and delivering spatial information in an interactive and batch mode using various web services. The web services deliver information to clients in GML using SOAP web services and ArcIMS OGC connectors and in SVG format through XSLT processor. The plug and play, and reusable software components architecture provides the flexibility of adding new applications or new data sources easily.

A Canada wide integrated network of Environmental Sensor Stations (ESS) and instrument vehicles, called Road Weather Information System Canada (RWISC), is being designed and implemented in order to make Canada stronger economically by offering a safer, sustainable, and more efficient highway system to Canadians from coast to coast to coast (Pacific, Atlantic and Arctic Oceans). Provinces and Territories of Canada (PTC) are acquiring and installing sufficient stations within their jurisdictional boundaries to support the National Highway System (NHS) segments within their own jurisdiction. It is anticipated that within the next three years, approximately 400 ESS will be installed nationally. The PTC are planning to use common ESS sensors conforming to Intelligent Transportation Systems (ITS) architecture for Canada which is compatible with the US architecture. The data from the fixed and mobile stations will be acquired in real-time by the PTC servers. A central system, called Road Weather Information Network (RWIN), will acquire data from these PTC servers. RWIN is being developed to acquire ESS sensor data, provide Quality Assurance and Quality Control services for acquired data, alert PTC transportation agencies and/or their suppliers, in real time, of errors or deterioration or outages of any station or component sensing systems, store raw and QA data, and finally make the ESS - QA data available in real-time to each PTC road administration and/or agency designated by them. RWIN features will ensure that the RWISC data can be spatially browsed, viewed in a map form and transferred for the whole PTC area or for a specified area of interest. Additionally, PTC will be able to browse and access other meteorological data sets such as Numerical Weather Prediction (NWP) grid-format outputs, terrestrial radar and satellite imagery in an integrated fashion.

RWIN relies on geo-spatial and information management technologies for real-time data acquisition, quality assurance and control, spatial data storage and real-time delivery of quality assured data to clients. The RWIN is based on a client/server, distributed computing architecture and makes use of the GIS, spatial data browsing and visualization, and spatial data management technologies. The RWIN data architecture is scalable and is capable of handling text, snap shots, video, image, GIS and raster data sets. The web dissemination architecture supports spatial data browsing, data views in a map form, and data exchange in an interactive and batch mode using various web services. A Metadata catalogue for ESS and for non-ESS datasets enables a user to view data spatially and temporally and to view an ESS performance, status and maintenance history. The plug and play, and reusable software components architecture provides the flexibility of adding new applications or new data sources easily.

RWIN is built using technologies such as ESRI ArcIMS, Oracle Relational Database, and Lintel platforms. The application software is being developed using object oriented methodology, spatial objects, and Java programming language. RWIN project follows the Project Management Body of Knowledge (PMBoK) project management approach. The final RWIN product will be implemented and documented to satisfy ISO 9001 Standards certification requirements.

## 1.0 Introduction

Canada's National Highway System (NHS) has over 24,000 km of paved highways and adjacent roads [1], (over 1 million kilometres of paved roads in Canada), with the provinces of Ontario, Quebec and British Columbia accounting for over 50% of that total. The World Health Organization has announced that the theme for the 2004 World Health Day will be Road Safety. Environment Canada is actively participating in this effort to address Canadian's interest in safer roads by working with Transport Canada and provincial and territorial governments to implement road weather observational networks, including establishing and maintaining common national standards and protocols.

The RWIN is being designed to meet the following requirements;

a) Acquire real-time data from a PTC management or data collection centre. The PTC management centre acquires data from Environmental Sensor Stations in its jurisdiction.
b) Provide Data Quality Control and Quality Assurance (QA) service for ESS data. The QA data means data that has been thoroughly checked and cross-checked both spatially and temporally to ensure that it meets the minimum standards of accuracy and precision.
c) Alert, in real-time, PTC transportation agencies and/or their suppliers about ESS data quality, errors, deterioration or outages of any ESS platforms and/or instruments.
d) Establish and maintain a complex RWISC database.
e) Make the RWISC QA raw data, for a PTC area or a sub-set of it, available in real-time to each PTC road administration and/ or agency designated by them.
f) Provide PTC and/ or private sector maintainer, meteorological or ITS firms retained by them, access to meteorological data sets such as NWP grid outputs, satellite data, Radar data, etc.
g) Provide performance statistics on the operation and quality of NHS ESS sites and provide station performance and maintenance reports in real-time.
h) Provide data access security to ensure denial of access to the RWISC data base by third parties not authorized by PTC.

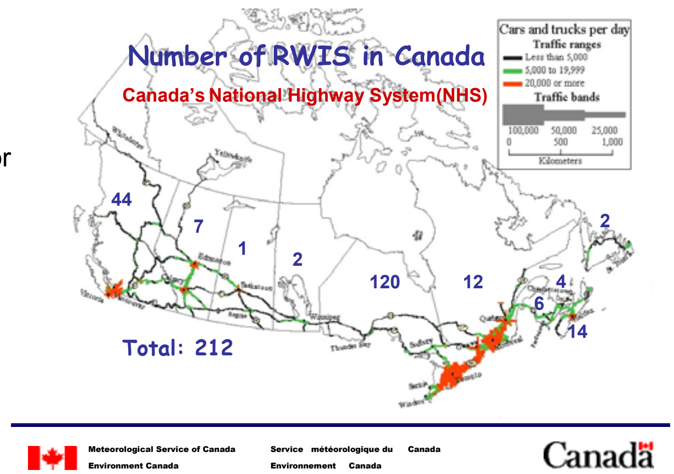
The system must be "fit-to-use" by PTC and end-users. "Fit-to-use" includes system usability, reliability, availability, maintainability, and performance. RWIN must be reliable and efficient in a production environment yet flexible and scalable enough to adapt to new data sources, products, platforms and evolving business requirements. The RWIN production environment is critical to support road maintenance decisions. Interactive spatial data browsing and delivery, and automated web-based data delivery will be introduced in the future to allow clients and partners the ability to select and deliver limited data sets for targeted geographical area.

### 1.1 Environment Sensor Station (ESS)

An ESS is a single specialized automatic road weather information reporting station (RWIS) permanently installed along a road segment or adjacent or connecting roadway and incorporating sensors embedded in and sunk below the road surface. The National Highway System (NHS) is a network of ground transportation links making up the national network of major highways across Canada including alternate links across most provinces and territories and major links to the United States. The sensors are deployed for the purposes of assessing and predicting road weather and surface conditions along NHS segments. The ESS is compliant with the North American NTCIP-ESS standard. NTCIP-ESS is the National Transportation Communications for ITS (Intelligent Transport System) Protocol for communications specifically and strictly from an ESS to the data collection agency or a PTC management centre.

[2]Sample ESS are shown in the opposite diagrams. An ESS is equipped with a number of common core and optional atmospheric and pavement sensors. Atmospheric sensors provide information regarding air temperature, relative humidity, wind speed and gust and wind direction, pressure, precipitation occurrence, and optionally, snow depth, visibility, present weather, and total radiation (solar and Infrared). The pavement sensors provide information about pavement surface and sub-surface, with other options including temperature, moisture, freeze point, residual chemical factor and even traffic volume/ speed. An ESS can also be equipped with a video Camera to provide visual images. Some ESS stations can be configured to trigger a spray system to automatically spray the roadway the instant it ices up. Sensor packages can be installed on patrol or maintenance vehicles and may include a Global Positioning System (GPS) to provide vehicle location, an ABS Friction sensor, and various sensors for providing road temperature, air temperature, relative humidity and pavement freeze point.

[2]Many provinces and municipalities in Canada have begun experimenting with or installed ESS as a decision aid tool for their winter safer roads planning and road maintenance during winter road conditions. The opposite figure shows Road Weather Information System (RWIS) or ESS installation base in




### 1.2 Intelligent Transport Systems (ITS) Applications

The ITS architecture for Canada includes road weather data feeds into a number of key user services such as Advanced Traffic Management System (ATMS), Advanced Traveller Information Systems (ATIS), salt management, dynamic route optimization, etc. ATMS use a network of traffic loops and central processors to optimize traffic flow through the control of traffic signals. Road weather information (e.g. road slipperiness information) can be used to increase traffic signal cycle lengths for example. ATIS can combine road weather data and forecasts with road condition reports and traffic flow data to provide travellers with improved route and trip planning information. Road salt applications from maintenance vehicles can be managed remotely to deliver just the precise amount of salt required over each section of the road according to current and forecast temperature and precipitation automatically. Dynamic route optimization for taxies, commercial transport fleets or maintenance vehicles can be provided based on weather and traffic conditions. The RWISC road weather data and the road weather and condition forecast generated from it will form an extremely rich data set for numerous ITS applications and research and development work by universities or by the private sector.

## 2.0 RWIN Architecture

The architecture must support existing and future requirements. Keeping this in mind, RWIN can be viewed as being comprised of six sub-systems, as shown in figure 3.0, each providing the following functions [3]:

**a)** **Data Acquisition and Processing** automatically receives data from different sources, formats ESS data to a common NTCIP format, imports imagery to a common projection using Canadian Geodesic datum, and converts model outputs to the required grid spacing, and inserts all results into a central data repository. Load balancing through clustering and distributed databases are necessary for this sub-system to meet the requirements dictated by strict data delivery deadlines.

**b)** **Quality Assurance and Quality Control** automatically performs quality assurance of acquired data based on defined QA/QC rules for ESS atmospheric and pavement data, inserts the QA/QC controlled as well as rejected data in a central data repository. This subsystem maintains status of each ESS platform and instrument and also generates alerts based on defined rules. This sub-system is based on Meteorological Service of Canada (MSC) Data Management Framework (DMF). The data auditing or data profiling provide statistics about the content of data fields such as counts, frequencies, missing values, and extreme values.

**c)** **Alert Manager Sub-System** is used to generate both internal and external notifications. The sub-system can send warnings or error messages in a variety of formats (e.g. email, paging, internet broadcasts, etc). All errors ranging from a lack of system resources (e.g. out of disk space) to data quality problems are handled. The Alert Manager maintains a small library of contact profiles (e.g. email addresses, pager numbers) and a comprehensive list of all possible alert codes. Other RWIN sub-systems provide the Alert Manager with the details of the problem along with an alert code. The severity of the problem can then be dynamically evaluated based on the alert code and the type of data. The functionality of the Alert Manager sub-system is kept focused allowing for rapid notification when problems are encountered.

**d)** **RWIN Data Manager Sub-System** consists of two components; a repository and an application programming interface to encapsulate the repository. This sub-system is also based on DMF.

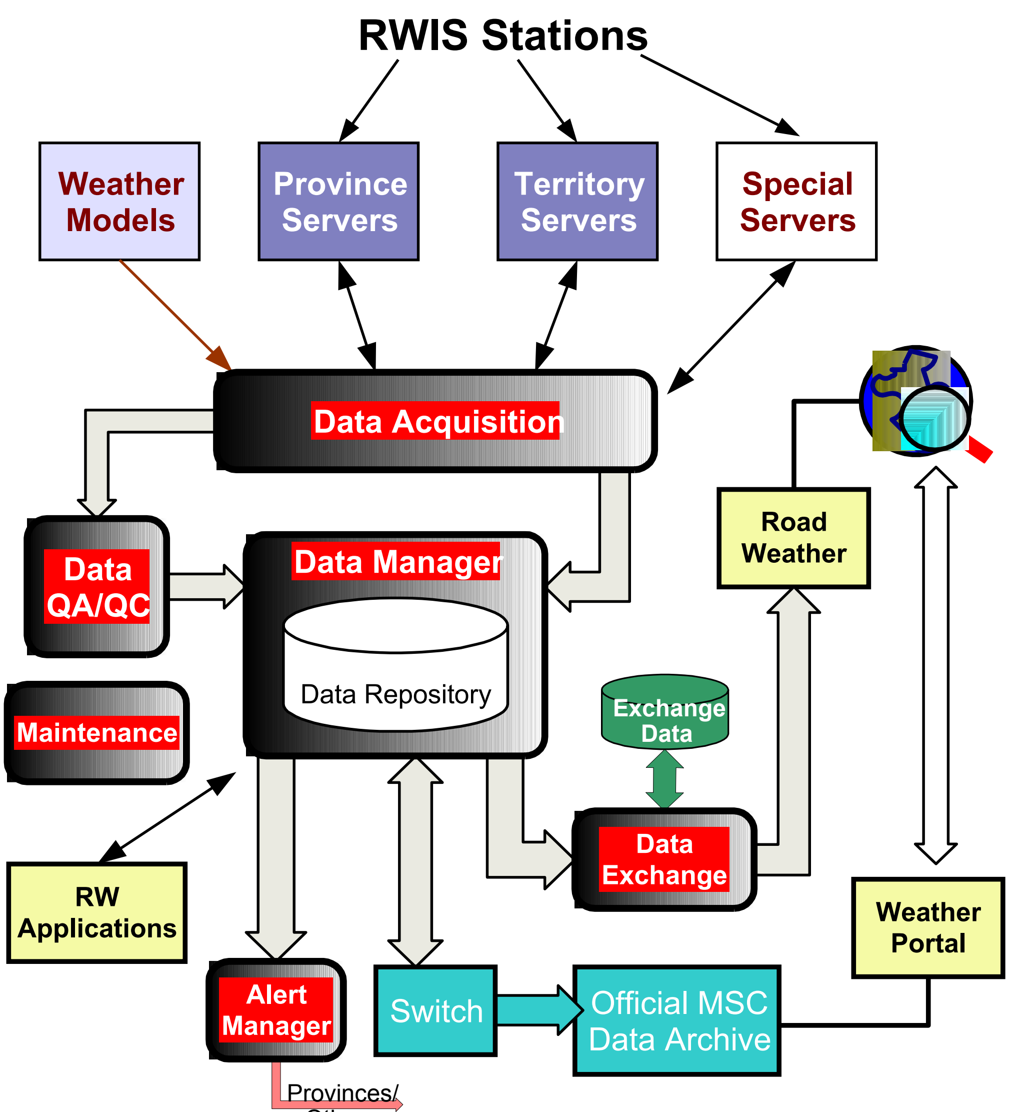



*Figure 3.0: RWIN High-level Architecture*

**RWIN Application Interface (1st Component)** of the Data Manager is a small set of reusable, data-level software components which can be used to assemble more sophisticated applications. This interface is used by all other RWIN sub-systems to add, modify and delete data objects in the repository. The application interface ensures the integrity of the repository since access to the data objects is controlled and constraints are strictly enforced

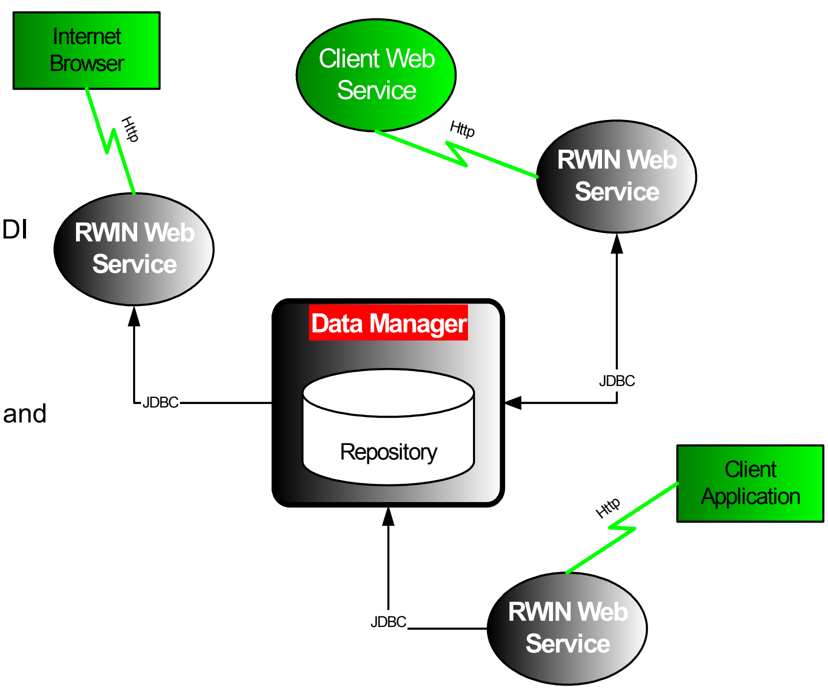
**RWIN Repository (2nd component)** can be further divided into a Relational Database Management System (RDBMS) and a Metadata Catalogue [4].

**(i) RDBMS** provides automatic indexing and low-level data security and stores the majority of data objects such as the instrument observations in RDBMS tables. For those data objects which do not fit efficiently within RDBMS tables, (e.g. satellite or terrestrial imagery), file storage will be used instead. The mechanism for locating the associated data object is accomplished with a Uniform Resource Locator (URL). The URL is the unique address of the data object, allowing the metadata and data to be stored in completely different infrastructures and locations. Along with the location, the URL defines the access protocol to assist in the transfer of the data object for either remote data or local data. RWIN will use Oracle database and its spatial capabilities which support Open GIS Consortium (OGC) simple features.

**(ii) Metadata Catalogue** is intended as a resource that provides access to metadata records in a consistent fashion that can be searched efficiently and extensively. The Catalogue ensures the integrity of the metadata since access to the records is controlled and constraints are strictly enforced. All data objects in the RWIN repository, whether they are stored within the RDBMS or as files have a corresponding entry in the Metadata Catalogue. The metadata required for the RWIN Repository is geospatial. “Geospatial” indicates that a spatial reference (e.g. latitude and longitude co-ordinates) is a primary means of storing and accessing information in the database. Geospatial metadata allows the “footprint” of the data to be superimposed on reference layers allowing the user to see the geographic extent of the data object and thereby helping to present more effectively the context of the data. The ESRI shapefile specification, which has been published and is the de facto industry standard for handling simple geospatial features, is proposed as the method of implementing metadata footprints.

The consistency of digital objects is the core of interoperability among diverse systems used by MSC and PTC. If the digital objects and associated metadata are compliant with the standards, then these can be used in broader range than the specific electronic resource for which they were created.

**e) Data Exchange Sub-System** is used for the dissemination of RWIN data to other systems. The Data Exchange Sub-System is fundamentally based upon the concept of a Web Service. Web services describe a standardized way of integrating Web-based applications using the Extensible Mark-up Language (XML), Graphical Mark-up Language (GML), Simple Object Access Protocol (SOAP), Web Service Description Language (WSDL) and Universal Description Discovery and Integration (UDDI) open standards over an Internet backbone. XML is used to structure the data, SOAP is used to transfer the data, WSDL is used for describing the services available and UDDI is used for listing what services are available. Web services allow organizations to communicate data without knowledge of the IT systems behind the firewall.
Web services share business logic, data and processes through a programmatic network interface allowing remote applications to interface. Web services allow different applications from different sources to communicate with each other without time-consuming custom coding, and because all communication is in XML, Web services are not tied to a specific



operating system or programming language.

In the case of RWIN, multiple Web services will be the access method to the RWIN repository for clients and partners. This allows user-driven requests via a standard Web browser and scheduled application requests from clients to be satisfied. RWIN web services are tailored for exact user requirements such as providing data in specific formats (e.g. NTCIP) and at the same time, provide very controlled access to the holdings within the RWIN Repository. Web services are relatively light-weight processes allowing many services to be run on a single server. With clustering at the operating system level, the number of Web services can be multiplied very effectively allowing for excellent system scalability. The user driven requests are handled by Internet Management System (ArcIMS) and the scheduled or bulk data transfer requests are handled by a Web service.

The clients and partners can transfer the data using File Transfer Protocol (FTP) from designated mailboxes or they can use out of a box Geo-Spatial Metadata Browser to visualize metadata from RWIN data repository using temporal and spatial filters to assist in rapid data discovery and transfer. The RWIN users can generate and view performance graphs or trend analysis for a single or a group of ESS stations. They can use standard geospatial tools such as MapPoint by Microsoft or Batik from open source Apache group or ArcExplorer from ESRI to display vector data. Map Point fully supports the Scalable Vector Display (SVG). ArcExplorer supports many ESRI vector formats including Shapefiles. Batik provides opensource Java tools for viewing and manipulating SVG. Geography mark-up language (GML) provides a standard way of sharing intelligent spatial information (features and pixels with attributes) through encoding geospatial data in XML. GML and its supporting OpenGIS standards provide a standard, vendor-neutral way of encoding virtually any kind of geospatial data as well as virtually any method for processing and displaying such data.

**f)** **Maintenance Sub-system** is the primary method of administering all of the other RWIN sub-systems. This sub-system will use one or more web services to provide a wide range of functionality and user interfaces. These interfaces are intended to be intuitive. This subsystem will provide functions for managing and monitoring all subsystems of RWIN, viewing any ESS station log file and history, managing and maintaining data acquisition or data exchange profile, an ESS station or an environmental sensor attributes. This sub-system will also be used to generate standard and ad-hoc reports and maps. The reports and maps may include station performance, quality or other reports and trend analysis.

## 4.0 Leveraging Standards and Open Interfaces

RWIN utilizes standards and open interfaces to facilitate the reality that information is disparate by nature. Thus by leveraging standards RWIN will be able to tie together disparate information types and facilitate information transfer between various agencies to support their needs. RWIN makes extensive use of internationally accepted standards which are established and proven. As well as providing general flexibility and ease of maintenance, emphasis on industry standards minimizes development efforts and encourages interaction with other decision support systems. The RWIN will use the following standards:

### 4.1 National Transportation Communications for ITS Protocol (NTCIP) [5]

for Intelligent Transportation Systems Protocol (NTCIP) is a family of standards designed to meet the communication needs of modern roadside devices and their associated data transfer traffic control systems. These standards provide the rules for communication (i.e. protocols) and the vocabulary (i.e. objects) required for electronic communication. Simple point-to-point protocols for command/response are defined as well as sophisticated system-to-system messaging. The NTCIP family of standards focuses on two fundamental aspects of communication; interoperability and interchangeability. *Interoperability* is the seamless integration of devices which perform different tasks but which are connected to a common infrastructure for data exchange. Communication with a management centre is therefore shared rather than being implemented as a discrete channel for each type of device. *Interchangeability* is the seamless integration of a device type from different manufacturers. This allows devices performing a specific task to be combined from a variety of manufacturers yet still be fully functional within the system. The Joint Committee on the NTCIP describes this as a "Mix and Match" approach which has benefit for both the producers and the users of the equipment. NTCIP provides standards for two different type of communication; Centre to Field (C2F) and Centre to Centre (C2C).

**NTCIP C2F** is the first type of communication protocol supported by NTCIP. This protocol supports communication between a management centre and all the devices which are monitored or controlled by that centre. This is known as Centre to Field (C2F) communication and it typically involves a group of roadside devices sharing a communications channel with a remote management computer.
**NTCIP C2C** the second type of communication protocol by NTCIP supports communication between multiple management centres. This is known as Centre to Centre (C2C) communication and it can involve centres which are separated geographically as well as those which are hosted within the same building. An example of C2C would be the interaction of multiple traffic signal management systems to coordinate all traffic signals for a large urban area. Similarly, the interaction between a highway management system and a system to broadcast dynamic messages at the roadside (e.g. in the case of an accident or detour) is another example of C2C.

**4.2 Extensible Mark-up Language (XML)** is a standard for describing electronic documents. A mark-up language defines a set of annotations and their usage. These annotations take the form of embedded tags. XML does not define page or screen appearance but identifies document elements and the relationships between those elements. Unlike HTML, XML explicitly separates information content from how it's presented. Presentation of an XML file is left to the client device. If the client device is a Web browser, then it will know how to display document-type XML files. XML files can be received and interpreted by non-browser devices, such as client software applications and XML-enabled devices and systems. There is a Road Weather Mark-up Language (RWML) developed by Japan and it essentially defines specifically the schema for the encoding and transfer of road weather data. [7]The Digital Weather Mark-up Language (DWML) is developed by National Weather Services (NWS) in US. It is a National Digital Forecast Database (NDFD) Extensible Mark-up Language, a service providing the public, government agencies and commercial enterprises with user selected components for point locations of the NWS data embedded in XML elements.

**4.3 Geography Mark-up Language (GML)** is an adopted specification [6] within the OpenGIS Consortium (OGC) which provides an XML-based encoding of geo-spatial data. GML encoding is intended for the modeling, transport, and storage of geographic information. Considered a dialect of XML, GML provides a framework for distributing geographic information which is both open and non-proprietary. As it is based on XML, the principle is to separate content from presentation such that GML does not address the actual visualization of encoded data. A styling mechanism is required allowing the same geographic data to be displayed in a variety of applications. GML is extensible, cab be easily linked to non-spatial XML data and can be displayed as a map on a Web browser with minimum effort. Oracle and Environmental Systems Research Institute (ESRI) both actively support the current GML specification (GML 3.0).

**4.4 ISO Geographic Metadata Standard (ISO 19115:2003)** defines the schema for describing geographic information and services. It provides information about the identification, extent, quality, spatial and temporal schema, spatial reference, and distribution of digital geographic data. This standard is applicable to both geographic datasets and individual geographic features**.**

**4.5 Scalable Vector Graphics (SVG)** is an open W3 standard and is based on XML. SVG drawings can be interactive and dynamic. Animations can be defined and triggered either declaratively (i.e., by embedding SVG animation elements in SVG document) or via scripting. Sophisticated client-side applications of SVG are made possible by use of a browser-based scripting language such as JavaScript, which accesses the SVG Document Object Model (DOM).

The SVG DOM provides complete access to all elements, attributes and properties of the SVG document, after it is loaded into the browser. Once a map rendered in SVG is downloaded to the browser all types of manipulation are possible. SVG files can be read and modified by a range of tools. Unlike bitmapped GIF and JPEG formats, SVG is a vector format and is scalable. A user can pan, zoom, theme a map, select objects and manipulate layers on a SVG image. SVG can be applied to GIS projects, using entirely open source tools. There are several viewers available to view SVG images such as Microsoft MapPoint, Adobe's SVG Zone, Apache Batik, Map2SVG for MapInfo Professional, SVGMapper for ESRI ArcView.

**4.6 Unified Modelling Language (UML)** is a standard for creating diagrams and supporting text which are used in system development. The UML is used to model and document the details of the system design. The concepts and notation of the language are derived from several existing object-oriented design and analysis methodologies. A modelling language such as UML is the translation of the natural language describing the problem into the specific technology language which articulates the solution. For this reason, UML is often called the tool to "bridge the chasm between the requirements and the system".

**4.7 Web Services** are a set of standards which have been developed to provide programmatic access to the application logic of the web. This application logic is accessible to clients on every platform, and in every programming language. With Web services, the Internet is used to present a wide array of services which are self-contained modules of business function that can be discovered and used on demand. The entire Web services approach is based on a set of standard protocols and technologies, so that all participating components understand how to communicate. For example, service discovery in a UDDI registry, as well as requests for the service, use a standard messaging protocol called SOAP. Service definitions follow a description standard called WSDL**. Universal Description Discovery and Integration (UDDI)** is a method for defining business registry standards, including specifications for publishing and discovering information about Web services. UDDI can be viewed as the "Yellow Pages" for Web services. A UDDI registry provides simple information for describing as service, locating a service and contacting a service**.** SOAP is also programming language and is platform independent. SOAP is generally implemented using HTTP as a mechanism for file transfer and as a result it leverages security features such as SSL (Secure Sockets Layer). **Simple Object Access Protocol (SOAP)** allows messages to be transmitted as XML documents and invokes the capabilities of Web Services. The Simple Object Access Protocol defines both a message format and a message exchange model that allows distributed systems to communicate. Other remote procedure call systems such as Common Object Request Broker Architecture (CORBA) are in wide-spread use already, but SOAP combines the ubiquity of HTTP with the openness of XML. **Web Service Description Language (WSDL)** is an XML-based language for describing a Web service. WSDL is an integral part of UDDI as it is the language that UDDI requires. As examples, UDDI provides details about which Web service methods are available, which parameters are required for each request and what to expect in a response.

**OGC Web Services** - The OpenGIS Consortium and ISO have recently defined content encoding standards and service interface specifications for geospatial data. XML is used for the collaborative discovery, exchange and display of geospatial data. These standards include the Web Map Service and the Web Feature Service interface specifications. Using the OGC Web Map Service (WMS), a generic Web Browser can submit a request to a Web service for a geo-referenced map. The actual content of the results is dependent upon how the request was made. For example, the request can specify that a map be returned as an image in JPEG, GIF, TIFF or PNG format. The request can also specify that the service should reply by describing its capabilities (e.g. the format of map that can be produced and which spatial reference systems are supported). Using OGC Web Feature Service (WFS), a generic Web Browser can also submit a request to a Web service for a geo-referenced map. However, the results are returned in a vector form allowing individual map elements to be manipulated. Features are encoded using GML. As with WMS, a WFS request can specify that the service should reply by describing its capabilities (e.g. describe the features that are available and the supported operations on them).

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**4.8 ESS METADATA -** The minimum proposed metadata information to be collected for each site includes: Latitude & longitude, elevation referenced to the Geodetic Datum of Canada, site physical description & soil type, sensors installed along with make and date, dates of commissioning, maintenance, inspections, and instrument calibrations, road construction (asphalt/concrete, asphalt over concrete thickness, fill or cut, insulated or not), vegetation in area (for each side of the roadway to include: type, height, and proximity), effective times of overcoming by shadows (week by week) during the winter months, owner and operator/maintainer contact information, and digital photographs of the view in each cardinal compass direction are highly recommended.

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Awtar Koonar, P.Eng., PMP, IM/IT Project Manager (RWIN Project Manager)
Services Clients and Partners Directorate, Meteorological Service of Canada
Awtar.Koonar@ec.gc.ca

Paul Delannoy, Director, Natural Resource Sector Services Branch
Services Clients and Partners Directorate, Meteorological Service of Canada
Delannoy.Paul@ec.gc.ca

Brian Scarlett, GIS Consultant