Modernizing SDI

Enabling Data Interoperability for Regional Assessments and Cumulative Effects CDS

Publication Date: 2021-05-27

Approval Date: 2021-03-30

Submission Date: 2021-03-05

Reference number of this document: OGC 21-013

Reference URL for this document: http://www.opengis.net/doc/PER/Mod-SDI-CDS

Category: OGC Public Engineering Report

Editor: Robert Thomas, Josh Lieberman

Title: Modernizing SDI: Enabling Data Interoperability for Regional Assessments and Cumulative Effects CDS

OGC Public Engineering Report

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Chapter 1. Abstract

Report: Modernizing SDI: Enabling Data Interoperability for Regional Assessments and Cumulative Effects

OGC Modernizing SDI Concept Development Study (CDS)

by OGC

This engineering report (ER) presents the results of a Concept Development Study (CDS) on Modernizing Spatial Data Infrastructure (SDI), sponsored by Natural Resources Canada, executed by the Open Geospatial Consortium (OGC). The focus of this study was to understand how to best support the modernization of SDI(s) by enabling increased data interoperability for Regional Assessments (RA) and Cumulative Effects (CE), to advance the understanding of stakeholder issues, and serve stakeholders' needs in these contexts. The study was completed through stakeholder engagements including an open Request for Information (RFI) that gathered external international positions and opinions on the optimal setup and design of a modernized SDI. In addition, a stakeholder Modernizing SDI Workshop was also employed providing in depth information on requirements and issues related to stakeholders, architecture, data, and standards of current and future SDI.

The RFI and workshop also gathered information and provided insight on the current state of SDIs to better support governments, agencies, non-governmental organizations and citizens, unlocking the full societal and economic potential of the wealth of data at national, regional and/or local levels.

The ER presents an analysis of the RFI and Modernizing SDI Workshop responses and interactions, providing in-depth information on requirements and issues related to stakeholders, architecture, data, standards of current and possible future SDI modernization. All RFI and workshop responses will contribute to SDI modernization efforts moving forward and help to assess interoperability, availability and usability of geospatial Web services and tools across different types of spatial data uses. In addition, the report identifies gaps, and defines core components of a possible future SDI.

The outflow of this report may be used to help define reference use-cases and scenarios for possible future research and follow-on OGC Innovation Program activities.

Chapter 2. Executive Summary

Multiple jurisdictions across expansive regions are spending increasing time and resources to assist communities and citizens to analyze environmental data and their associated cumulative effects.

Cumulative Effects (CE) are defined as changes to the environment, health, social and economic factors caused by multiple interactions between human activities and natural processes that accumulate across space and time. The analysis of CE has become increasingly necessary to predict and possibly mitigate effects of climate change and natural or human-induced disasters.

In Canada, approval of major development projects now requires an impact assessment that analyzes all possible CE that could impact the environment and the people who live and work in it, both over time and in combination with other existing or future projects.

The current objective is to determine what can be done to modernize current spatial data infrastructure (SDI) to better serve stakeholders involved in CE analysis.

This concept development study (CDS) seeks to specifically identify emerging standards-based solutions and overall recommendations that can better enable an SDI to provide increased data interoperability of key environmental data. The CDS evaluates the current state of spatial data infrastructures, assesses the availability and interoperability of geospatial data across various regions and explores practical means to achieve an improved SDI with efficient geospatial data interoperability.

Business Value

The establishment of a modernized SDI is expected to offer the following benefits when implemented:

- Users will have easy access to relevant and updated geographic and thematic information covering the entire region of interest;
- Improved information management practices through the adoption of commonly accepted policies and technical standards;
- Improved accessibility of SDI across borders, thereby allowing for cross-border solutions to be established to solve shared regional problems;
- A distributed infrastructure consisting of interlinked servers offering high quality geospatial data.

To realize these benefits, it is necessary to maintain an understanding of the users, their needs and their roles in the overall picture of relevant stakeholders.

This engineering report is important because it advances understanding of the use cases and architecture from which the aforementioned benefits will be derived.

2.1. Concept Development Study Overview

This CDS seeks to specifically identify standards-based solutions for SDIs that enable data interoperability of key environmental data, from multiple jurisdictions, using emerging Internet-based technology like machine-learning/reasoning, data fabrics, data lakes, cloud services, OpenAPIs, and other evolving standards, technologies and tools. This was accomplished through the use of:

- A Request for Information (RFI) that was widely distributed to the geospatial community.
- An intensive Modernizing SDI Workshop that collected input from subject matter experts. A stakeholder workshop summary is included as Appendix A.
- Secondary research of other recent, relevant material.

2.1.1. Scope:

The scope of this CDS includes:

- Characterizing the current state of SDIs and their use of current or emerging standards and advanced technology to enable data interoperability, and understanding current gaps and challenges;
- Assessing the availability and interoperability of geospatial data across various regions or jurisdictions, specifically those needed for regional environmental assessments or CE analysis, as well as the technologies and services currently leveraged;
- Exploring and articulating practical means to achieve modernized, intelligent, inferential, machine-driven solutions that support and enable improved, efficient geospatial data interoperability.

2.2. The Issue and Objective

In CE analysis, data is sourced from a range of jurisdictions, governments, sectors, domains, over time, and social/community contexts. The primary question or issue for a modernized SDI in this context is:

> How can an ocean of environmental, foundational/framework, biological, socio economic and other data, from multiple different sources, collected over time, and with varying levels of standardization, be readily consumed and integrated by scientists and citizens alike?
>
> — Natural Resources Canada, Government of Canada

The overall objective of this CDS is to consult the community and inform federal, provincial, territorial and First Nations/Indigenous stakeholders, concerned with cumulative effects and regional assessments, how best to establish consensus and implement common, open standards-based, approaches that leverage emerging technological capabilities, leading to new levels of digital geospatial data interoperability. Consultation outcomes will provide insight into what is required to implement a modern SDI to best meet stakeholder needs in the CE context.

2.3. Key Conclusions and Recommendations

In addition to secondary research, an RFI, and a Modernizing SDI Workshop were used to collect the views of the SDI community to provide for future SDI modernization with a focus on CE, governance and future directions.

These key conclusions and recommendations are summarized below. A more comprehensive description and list is presented in Chapter 10, Conclusions and Recommendations.

- For any modernization of an SDI to be considered successful, “FAIR” guiding principles should be adopted (i.e., Findable, Accessible, Interoperable, Reusable).
- Coordination of SDI modernization related activities, and collaboration among the various organizations involved, is a critical success factor for an SDI modernization effort.
- An SDI modernization should be community-driven, fostering links across existing data initiatives, and gaining commitment and support from local, regional, Indigenous, national and international governments and umbrella organizations.
- From the CDS needs analysis, five high level, overarching requirements can be applied to any SDI modernization. A modernized SDI should:
    1. Foster data integrity and provide stakeholders with security-based, appropriate access to the spatial data they need. Getting the right information to the right person at the right time.
    2. Allow access of data on a variety of devices and platforms including mobile, e.g., smartphones and tablets.
    3. Allow different stakeholders, at different locations, to access the SDI.
    4. Allow for data exchange in an interoperable, appropriate, efficient and secure way that respects the rights of data owners (e.g., the First Nations principles of OCAP® (Ownership, Control, Access, and Possession)).
    5. Require the continued and increasing use of OGC and other open standards to achieve the four requirements listed previously.
- The modernized SDI Reference Architecture must find the right balance between being prescriptive while remaining agile to allow for easy integration of upcoming technologies.
- The increased use of OGC Application Programming Interface (API) Standards is recommended for any SDI modernization effort. The OGC API family of standards makes it easy for organizations to provide geospatial data to the web. This may aid in more effective discovery and distribution of geospatial information.
- Machine Learning and Cloud Services may be leveraged against data mined from web services, Open APIs, and other sources, to provide valuable solutions in resolving interoperability challenges.
- Improved Geospatial/Health integration maybe possible using improved analytics to bring together digital health records and health trends with geospatial data (e.g. clusters, hot spots, etc.).
- Outreach and awareness activities will help attract new stakeholders and raise awareness of the importance of modernizing an SDI among stakeholders already involved or at least aware of the relevance of an SDI modernization.

These conclusions and recommendations listed here may provide a focus for a future modernized SDI and a possible pilot initiative following the CDS. Additional conclusions and recommendations and analysis are presented in Chapter 10.

2.3.1. Future Work

Building on this CDS and the conclusions and recommendations for future SDI development, e.g., pilot actions, the OGC will produce a strategy to achieve this goal. As an ongoing activity, the OGC will seek the support from potential sponsors and the community by building a communications strategy to inform SDI modernization developments. The conclusions and recommendations should not be regarded as a definitive list. Instead, these conclusions may provide a focus for a future modernized SDI and a possible pilot initiative following the CDS.

2.4. Document Contributor Contact Points

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2.5. Foreword

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

Chapter 3. Acknowledgements

The OGC expresses its gratefulness to the sponsor of this Concept Development Study: Natural Resources Canada.

The OGC further wishes to express its gratitude to all workshop panelists and participants (Appendix A) and to the following companies and organizations that provided excellent contributions in responding to the formal Request for Information that provide key content for this OGC Engineering Report.[1]

Table 1. Organizations and companies contributing to this report

Organization/Company
Natural Resources Canada (Sponsor)
Arctic Institute of North America
Arctic SDI
CRIM, Computer Research Institute of Montreal (Canada)
CubeWerx (Canada)
Cyient Limited (India)
DFO – Flood Observatory, at the University of Colorado (USA)
Ecere (Canada)
Canadian Wildlife Service (Environment and Climate Change Canada)
DataCove.eu (INSPIRE)
Esri Canada (Canada)
Fisheries and Oceans Canada (Canada)
GeoCat (Netherlands)
Government of Alberta (Canada)
Government of Saskatchewan: Saskatchewan Ministry of Environment
Cumulative Impacts and Science (Canada)
Geomatys (France)
Health Solutions Research (HSR) (USA)
JRC (European Commission)
KU Leuven Be: Public Governance Institute (Belgium)
Meteorological Service of Canada (Environment and Climate Change Canada)
Natural Resources Canada (GeoConnections)
Netherlands’ Kadaster Land Registry and Mapping Agency (Netherlands)
Nunatsiavut Government (Canada)
PatternedScience (Canada)

Organization/Company

SensorUp (Canada)

Skymantics Europe, SL (Spain)

United Kingdom Hydrographic Office

United States Geological Survey

[1] To avoid an overload with references, in particular as paragraphs often include parts provided by different companies or organizations, this report does not include local references other than for images.

Chapter 4. Overview

This report presents the results of a concept development study on modernizing Spatial Data Infrastructures (SDI) that enables data interoperability for Cumulative Effects (CE), sponsored by Natural Resources Canada, and executed by the Open Geospatial Consortium. The focus of this study was to understand how to best support the modernization of an SDI as related to CE analysis and how to make existing SDI implementations better serve stakeholders’ needs.

The study included an open Request for Information (RFI) and a Stakeholder Modernizing SDI Workshop (Appendix A) that gathered external positions and opinions on:

- the current state of SDIs,
- the availability and interoperability of geospatial data, and
- solutions that support and enable improved, efficient geospatial data interoperability.

A complete list of questions contained in the RFI are included as Appendix B.

The report begins with a background (Chapter 5) on the Canadian Geospatial Data Infrastructure (CGDI) and continues with a description of the Federal Geospatial Platform, the Open Science and Data Platform for Cumulative Effects, Data Interoperability and Environmental Data. Responses to this RFI and workshop (Appendix A) have been integrated into this report and are examined in more detail (Chapter 6). This report discusses the various classes and types of stakeholders of an SDI examining their specific needs (Chapter 7) and then looks into currently used and emerging standards within current SDIs (Chapter 8). The report then discusses possible SDI architecture models, data, standards and interoperability leading to an interoperability reference architecture based on RFI responses and workshop (Chapter 9). The report concludes with conclusions and recommendations (Chapter 10).

Organization managing the CDS

The Open Geospatial Consortium (OGC) is an international consortium of more than 500 companies, government agencies, research organizations, and universities participating in a consensus process to develop publicly available geospatial standards. OGC standards support interoperable solutions that "geo-enable" the Web, wireless and location-based services, and mainstream IT. OGC standards empower technology developers to make geospatial information and services accessible and useful with any application that needs to be geospatially enabled.

Sponsor

Natural Resources Canada (NRCan) seeks to enhance the responsible development and use of Canada’s natural resources and the competitiveness of Canada’s natural resources products. NRCan is an established leader in science and technology in the fields of energy, forests, and minerals and metals and use our expertise in earth sciences to build and maintain an up-to-date knowledge base of our landmass. NRCan develops policies and programs that enhance the contribution of the natural resources sector to the economy and improve the quality of life for all Canadians.

Chapter 5. Background

This Engineering Report (ER) is a component of an OGC Concept Development Study (CDS) and a possible Interoperability Pilot with the goal of assembling ideas, technologies, and practices that may enable federal, provincial, territorial and First Nations/Indigenous partners concerned with cumulative effects and regional assessments to establish inter-jurisdictional consensus and implement common, open standards-based approaches that leverage emerging technological capabilities, leading to new levels of digital data interoperability.

To fully understand the scope and components of interest of this study, and its Canadian context, background and definitions are provided in the following sections.

5.1. The Canadian Geospatial Data Infrastructure (CGDI)

Canada's SDI, referred to as the CGDI, is the relevant base collection of standards, policies, applications, and governance that facilitate the access, use, integration, and preservation of spatial data.

GeoConnections is a national program with the mandate and responsibility to lead the CGDI through a baseline of consensus-based, internationally accepted standards-based technologies and operational policies for data sharing and integration.

5.2. The Federal Geospatial Platform

The Federal Geospatial Platform (FGP) is an initiative of the Government of Canada's Federal Committee on Geomatics and Earth Observations (FCGEO), a committee of senior executives from 21 federal departments and agencies that are producers, consumers or stakeholders in activities, requirements and infrastructure related to geomatics. In 2017, the FCGEO community acted on an opportunity for federal departments and agencies to manage geospatial information assets in a more efficient and coordinated way by using a common "platform" of technical infrastructure, policies, standards and governance. The FGP fully leverages the standards, standards-based technologies and operational policies endorsed by the CGDI.

The FGP's primary mission is to "Geo-enable the Canadian Federal Government". The FGP intranet site provides a collaborative online environment where federal government employees can easily share, find, view and analyze the Government of Canada's authoritative geospatial data holdings to support informed and insightful decisions and policy-making, and ultimately provide better service for Canadians. Overall, the FGP provides an enabling infrastructure to the public service and to Canadians, for access, visualization and analysis of trusted geospatial data, services and applications.

Under the basic premise, "build it once, use it many times," the FGP leverages coordination efforts and utilizes best practices, new technologies, and open standards to provide more accessible data and services while realizing efficiencies through shared, cloud-enabled infrastructure and economies of scale. This approach allows FGP to supply its data and services to other government initiatives. The FGP makes all federal open geospatial metadata and web services available to

Canada's Open Government Portal - Open Maps. The FGP will also underpin the Open Science and Data Platform for Cumulative Effects.

5.3. The Open Science and Data Platform for Cumulative Effects

NRCan and Environment and Climate Change Canada have co-developed and launched the Open Science and Data Platform (OSDP) for Cumulative Effects. The FGP is a primary delivery partner for the OSDP initiative, with responsibility for making geospatial technologies, federal, provincial and territorial geospatial data and web services needed for CE analysis available to the OSDP.

The OSDP provides Canadians a single point of access to environmental data and scientific information that can be used to understand the CE of human activities. By looking at science, environmental data and information about development activities across the country, we can learn about potential impacts to support better decisions in the future. The scope of data and information planned for release through the OSDP highlights a critical need to collaborate with all partners towards greater data interoperability.

Figure 1 shows how the OSDP and its companions FGP and Open Maps integrate into and leverage the CGDI.

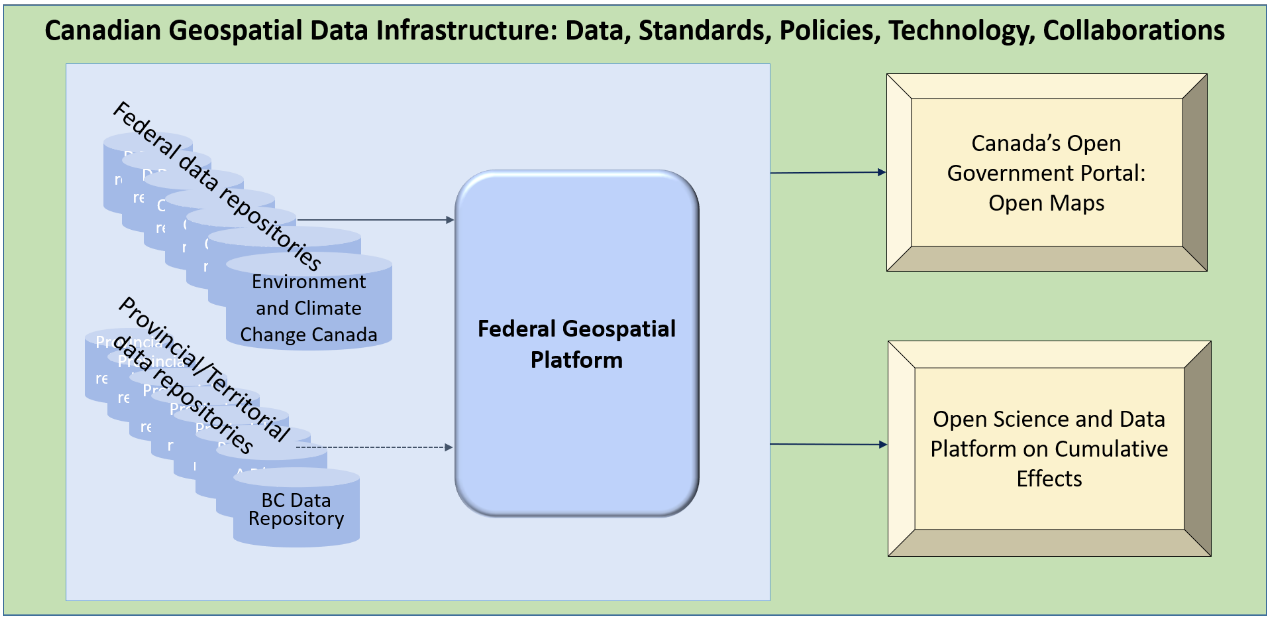

Figure 1. Relationships between the OSDP, FGP, Open Maps, and the CGDI (Source: Natural Resources Canada)

5.4. Data Interoperability

Data interoperability is generally defined as the ability for data held in one system to be compatible with other data products or systems and thus able to be integrated with other datasets across a number of different systems or analytical products. Data interoperability can be achieved by optimizing both the usability and reusability of data through the use of open standards.

5.5. Focus on Environmental Data

This CDS will focus research and discussion on the use case of geospatial data typically required for environmental Regional Assessments (RA) and/or CE analyses. NRCan’s current commitment to providing essential geospatial data via the FGP, to support initiatives such as the OSDP, is driving this context.

Additionally, the broad scope of geospatial data requirements for RA/CE, as well as climate change studies and science, make this use case particularly and widely applicable to many stakeholders.

The scope of data needed for RA or CE analysis confirms a critical need to collaborate with all partners towards greater data interoperability. An example of the wide variety and quantity of data required for a RA and CE analysis is demonstrated by the recently completed “Regional Assessment of Offshore Oil and Gas Exploratory Drilling East of Newfoundland and Labrador”. This assessment included the following data categories:

- Boundaries and Basemaps - National/International boundaries, offshore areas, leases, etc.
- Physical Environment - Bathymetry, Atmospheric Light
- Biological Environment - Fish and Fish Habitat, Marine Birds, Marine Mammals and Sea Turtles, Special Areas
- Socioeconomic Environment - Marine Fisheries including Domestic and International Commercial Fish Landings and Locations, Aquaculture Facilities, Indigenous Communities and Lands, Petroleum-related Activity, Shipwrecks and Legacy Sites, Other Marine Infrastructure (cables, etc.)

Other geospatial data commonly used in Regional Assessments and Cumulative Effects processes can include:

- Data related to development activities,
- Data on valued environmental components (VEC’s),
- Data that describe environmental management frameworks,
- Data drawn from Indigenous or traditional knowledge

A more comprehensive list is shown in Figure 2.

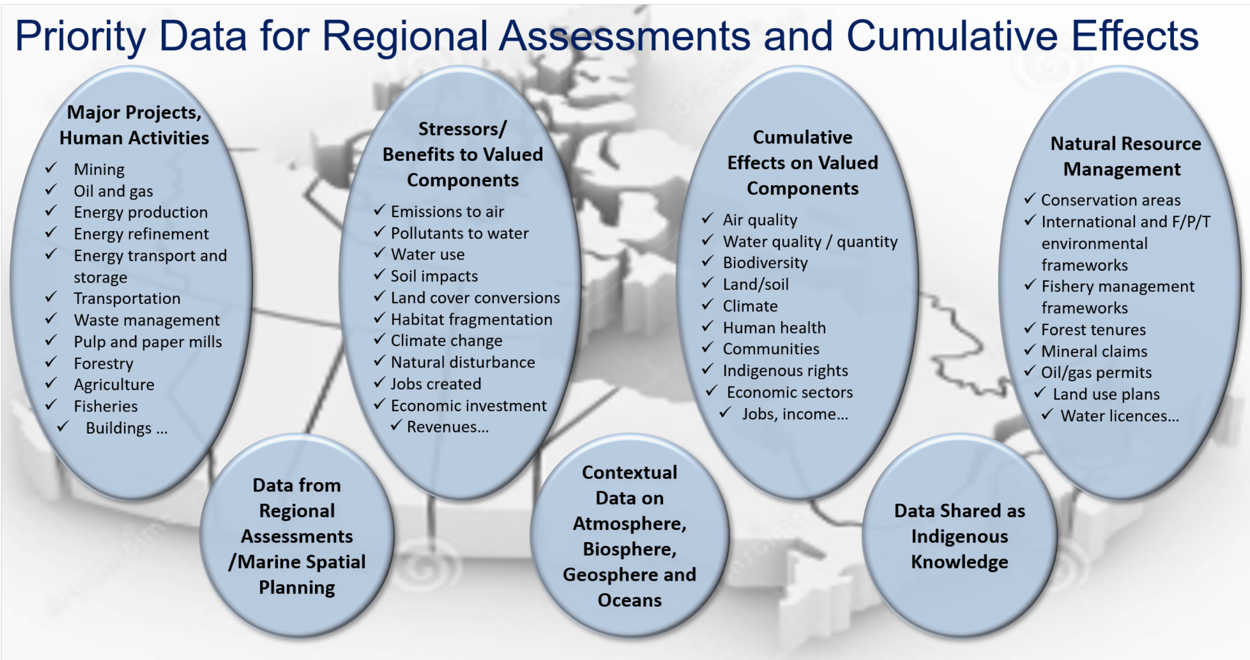

Figure 2. Priority Data for Regional Assessments and Cumulative Effects (Source: Natural Resources Canada)

Chapter 6. RFI Respondent Characteristics

The following chapter presents some of the characteristics of the Modernizing SDI RFI respondents. The RFI included forty questions that helped provide a comprehensive response on the many aspects of SDIs.

These questions were divided into eight categories deemed important to the direction of a modernized SDI. These included:

1. Stakeholders
2. SDIs and Data Architectures
3. Data for Regional Assessments/Cumulative Effects Analysis
4. Technology and Applications
5. Requirements
6. Usage Scenarios
7. Operation and Organization
8. Other Factors

Respondents were invited to answer any or all questions and take as much space as they felt required to provide a thorough response. The responses to these questions have been summarized and/or analyzed and included in the corresponding areas of this report. A complete list of questions contained in the RFI are included as Appendix B.

6.1. Profile of Respondents

A total of 22 responses to the RFI were received representing contributions from 8 different countries. Figure 3 shows the geographic breakdown of respondents.

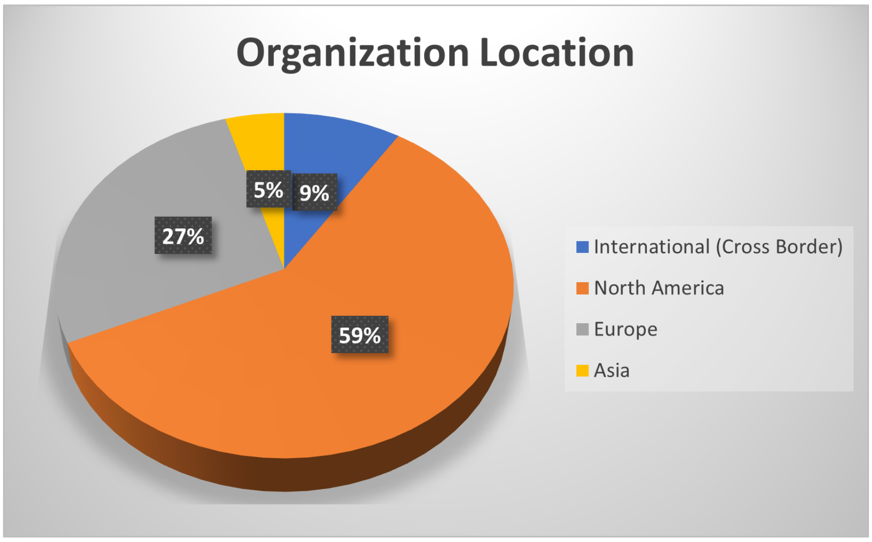

Figure 3. Location of RFI Respondents (Source: OGC)

The locations of the respondents represented a cross section of the global SDI community including responses from North America, Europe, Asia and International representation.

As Figure 4 shows, almost half (45%) of the responses were from the private sector; 23% from Federal/National Governments and 14% from Academic institutions. The remaining 18% of responders are represented by Provincial, Territorial or State Governments, NGOs and Indigenous communities. Again, this is a representative cross section of organization types.

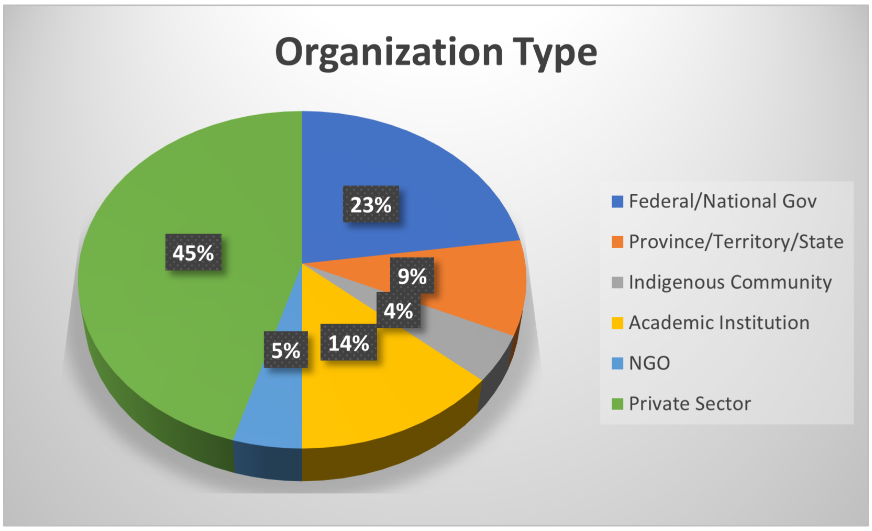

Figure 4. Organization type for RFI Respondents (Source: OGC)

The variety of organization types and wide geographic distribution of respondents indicates that the CDS has a wide variety of stakeholder representation, increasing the validity of the study.

6.2. Role of RFI Respondents

The RFI included a question on the role of the respondent within their organization. This question determined whether the respondent was a data provider and/or data owner, a data user (scientist/researcher or other data user), a solutions provider (e.g., a data enabler, helps provide access to the data, software company, data standards organization, app developer, etc), a policy analyst or other role.

As shown in Figure 5, there was equal representation between data providers, data users (combining scientist and data user responses) and data enablers (solutions providers).

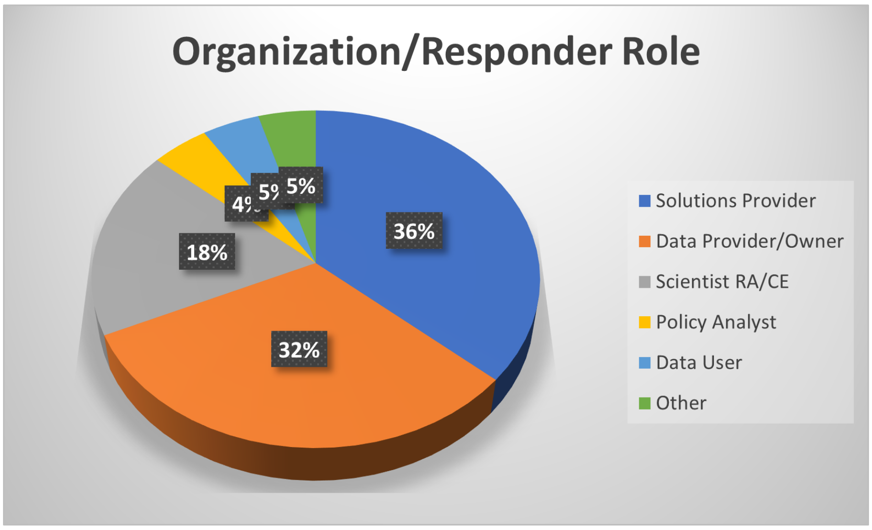

Figure 5. The RFI respondents' role within the organization (Source: OGC)

These results indicate that these three key stakeholders have been well represented in the study.

Chapter 7. SDI Definition and Stakeholders

7.1. What is a Spatial Data Infrastructure?

There is no single definition of the term Spatial Data Infrastructure. However, for the purposes of this study, the following definition is appropriate:

> The relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data. The SDI provides a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, the commercial sector, the non-profit sector, academia and by citizens in general.
>
> — SDI CookBook, Global Spatial Data Infrastructure (GSDI) Association

Key components of an SDI include governance, technology, organization, and data. These components do not exist in isolation. Each component must be aware of "User Needs" and overall "Socio-economic Value". An SDI is about spatial data, but it is also about infrastructure. “Infrastructure” suggests a reliable supporting environment, in which common technologies, and policies exist. SDI supports applications using geographically-related data through a minimum set of practices, protocols, and specifications (GSDI 2012). Spatial infrastructure must provide access to spatial data in a reliable, consistent, and well-defined manner so that it can support functions addressing end-user needs.

The four key components of an SDI are shown in Figure 6:

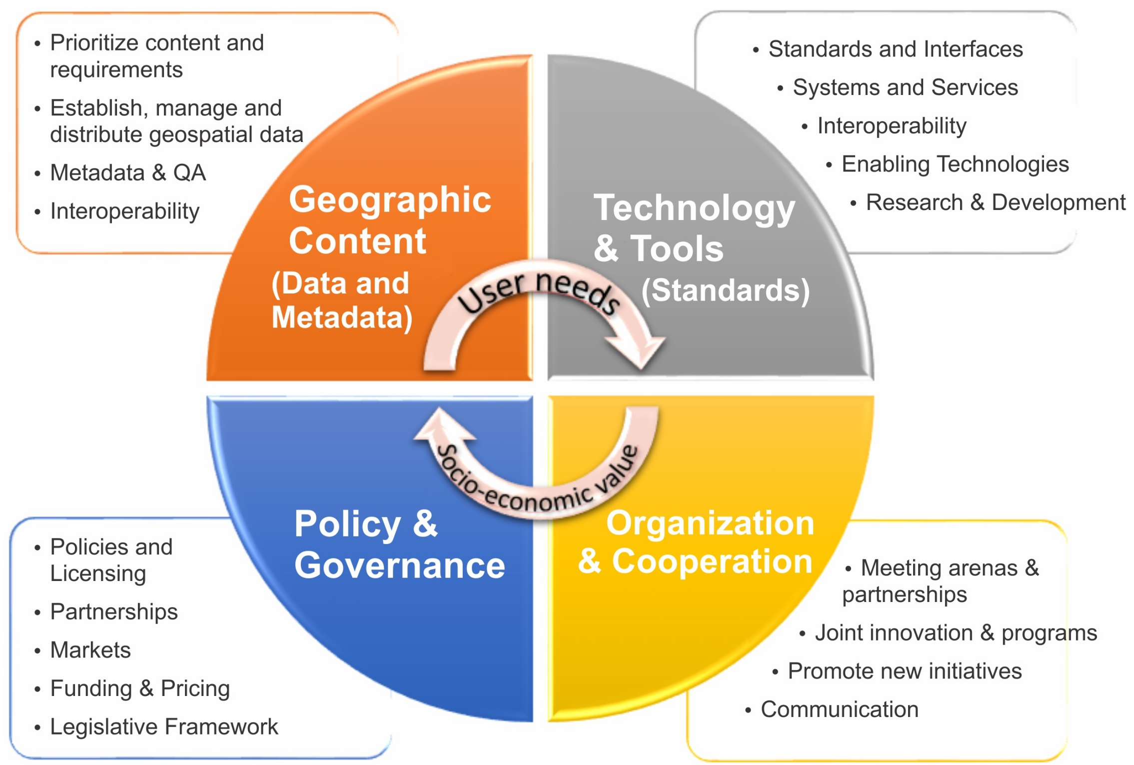

Figure 6. Key Components of an SDI (Source: Spatial Data Infrastructures: “Cookbook” - modified)

These components are defined as follows:

1. **Geographic Content (Data and Metadata)** - comprise the data and information to be made accessible
2. **Technology and Tools** - encompasses the technologies (hardware, software and systems) required for the SDI to exist. It emphasizes the harmonization and interoperability of standards essential for “unlocking” geospatial data and producing a coherent SDI. This is achieved through the employment of rigorous standards, ensuring seamless interoperability.
3. **Organization and Cooperation** - which fosters an environment of joint innovation and partnerships through communication, meeting arenas and promoting new initiatives and programs.
4. **Policy and Governance** - which dictate the management of spatial data via the legal and administrative requirements such as defining data security, licensing, liability, intellectual property and privacy. This includes the structural relationships of all those involved.

In addition, an SDI includes all aspects related to spatial information including the structure of the data and all the interfaces to the systems that disseminate or present the information. At a more granular level, these fundamental components can include:

- Data structure/schema (Application Schema)
- Data description/semantics (Feature Catalogue)
- Metadata
- Data and metadata capture operations
- Data (the data elements)
- Data management
- Discovery
- Access
- Transformation

The advantages of a modernized SDI include the reduction of data duplication, preservation of data, ease of access to multiple data sources, integration of data for use in disparate tools, facilitates database maintenance, promotes institutional cooperation and general promotion of awareness of spatial data.

7.2. SDI Stakeholders

The number and types of stakeholders is changing with the changing environment. The ever-expanding sea of data, among other things, are causing these changes. Due to increasing issues surrounding climate change, the chances of disasters and emergencies also increases. This demonstrates the cross-cutting nature of various stakeholder groups.

The responses from the RFI have differentiated the range of stakeholders into five levels or classes. The stakeholders summarized under each level often have some level of influence on each other, illustrated by the circular arrows (Figure 7).

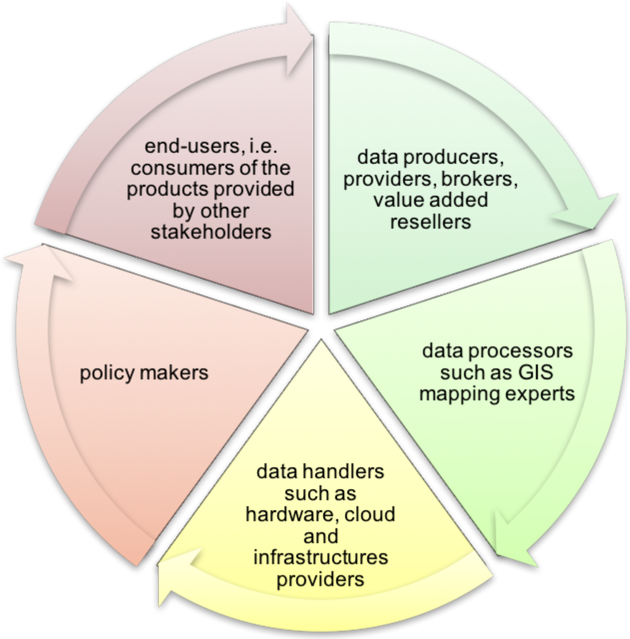

Figure 7. Levels/Classes of Stakeholders

Using Figure 7 and beginning in the upper left, the wide class of end-users includes all consumers of products provided by the other classes, e.g., data and services, products in the form of reports and statistics, policies and regulations, etc. Following the arrows clockwise, the next class aggregates all data producers or creators, data providers, data brokers, and value-added resellers. This large group is of particular relevance, as it is responsible for one of the main products of the SDI, the data. The third class covers data processors such as GIS professionals, data scientists, data modelers, mapping experts, or others in the high-end supercomputing environment who are addressing the complexity of near or real-time analytics/forecasting geospatial products. These experts create products such as analyses, reports, statistics, or maps using data provided by the previous group. The fourth class, data handlers, somewhat intersects the previous three, and includes the hardware, storage and computing service providers that provide the necessary infrastructure for data exchange and processing. The last class, policy (decision) makers, tends to intersect the classes described before. It lays out the necessary rules and guidelines for a successful operation and governance of modernized SDIs.

Identified stakeholders from RFI responses and workshop attendees were classified in one or many of these five levels and come from a wide range of organizations. An already long, though still non-exhaustive, list is provided in Table 2.

Table 2. Abbreviated List of SDI Stakeholders

Stakeholders
Data Producers, Providers, Brokers, Value-added Resellers
Federal, Indigenous, state, provincial, local, or territorial governments
GIS and Information Technology: 311 System, Internet and Social Media
Federal, Indigenous, state, provincial, local, or territorial government agencies
Military Organizations
Utility companies/organizations: Oil & Gas, Power

Stakeholders

Academic and educational institutions

Commercial data/analytic providers

Insurance companies

The General Public (Crowd Sourced)

Data Processors

Commercial data/analytic providers

Federal, Indigenous, state, provincial, local, or territorial government agencies

Software developers

Mapping and GIS experts

Military Organizations

Transportation

Insurance companies

Academic and educational institutions

Data Handlers, Infrastructure Providers

Federal, Indigenous, state, provincial, local, or territorial government agencies

Local Government Agencies

Internet and Social Media Providers

Military Organizations

Academic and educational institutions

Policy Makers

Federal, Indigenous, state, provincial, local, or territorial government agencies

Environmental Protection Agencies

Public Authorities

Local Government Agencies

Military Organizations

Public Works

Standards Developing Organizations

Diplomatic and national security officials

Insurance companies

International and Regional Intergovernmental Organizations

End Users

Federal, Indigenous, state, provincial, local, or territorial government agencies

Stakeholders

Search and rescue officials

Transportation

Military Organizations

Authorities: Transportation Authority, others

Public Works

Utility companies/organizations: Oil & Gas, Power

Mining companies

Researchers from various fields such as climate, conservation

Archaeology, ecology, and geological science

Academic and educational institutions

Insurance companies

NGO Service Providers

Academic and educational institutions

Diplomatic and national security officials

International and Regional Intergovernmental Organizations

The General Public

Many of the organizations included in this list have been emphasized as particularly relevant by respondents to the Modernizing SDI CDS RFI. The editors of the ER continue to welcome the involvement and contributions of anyone involved in data management willing to support the goals and objectives of a possible future pilot.

7.3. Needs of Stakeholders

Though the stakeholders vary considerably, there is substantial overlap in terms of needs. Generally speaking, needs for the data consumers or end users include the aspects of easy discovery, access, download and analysis of spatial data. For the data producer, provider and processor, needs include the ability to publish, integrate, aggregate and analyze geospatial data and related non-geospatial data. Focus should be on ease-of-use and effectiveness. Integrated systems, possibly in a system-of-systems or network-of-networks approach, with the ability to harvest data from existing solutions in a secure, reliable manner, should be supported.

In addition, there is a need for further requirements on real-time or archived availability, data and system Intellectual Property Rights (IPR), reuse and indemnification rules and regulations, security and privacy settings, as well as financial costs. A modernized SDI also needs to consider how to enable and respect the rights of Indigenous nations. An example are the First Nations principles of OCAP® (Ownership, Control, Access, and Possession) which assert the rights of First Nations to control data ownership and access, including how their data can be used.

On the system side, it is essential that systems are operational and reliable with clear life cycle costs to providers and users. Stakeholders require robust, but intuitive, easy-to-use tools, to access, visualize and contribute data in a manner that allows for ingestion into organizations supporting policy development and decision making. The underlying systems have to cater to various types of consumer capacities. While some of the stakeholders may have very limited internal geospatial capacity or solutions, others are far more advanced.

From an analysis of the RFI responses and workshop input, the stakeholder needs relevant to an SDI can be distilled and summarized as follows.

1. The modernized SDI should foster data integrity and provide stakeholders with security-based, appropriate access to the spatial data they need. These data can be static as well as dynamic.
2. The modernized SDI should allow access of data on a variety of devices and platforms including mobile, e.g., smartphones and tablets.
3. The modernized SDI should allow different stakeholders, at different locations, to access the SDI.
4. The modernized SDI should allow for data exchange, especially the dynamic data, in an interoperable, appropriate, efficient and secure way that respects the rights of data owners (e.g. the First Nations principles of OCAP®)

These four overarching needs are a simplification of the wide variety of needs facing stakeholders. However, keeping these four requirements top-of-mind during modernization will lead to a more effective, sustainable, useful and dynamic SDI for all stakeholders.

The challenge is to manage both the data/analytic contributions, and the data/analytical needs of the many stakeholders, during the present period, when an overload of new data is pouring into the community on a regular basis. Preparedness and planning phases are critical to make management and ease of access to the data a reality. The Information and Communications Technology (ICT) infrastructure must be designed to scale up in order to handle the ever-increasing demands for data and its analysis.

The engagement of stakeholders and the awareness raising of an SDI among potential stakeholders are key goals of the Modernizing SDI CDS. First and foremost, the best way to get stakeholders involved and well served is to meet their needs. This requires making data easy to find, use, and understand. It can be best summarized by the **FAIR** principals:

- **Findable** - Can an individual or organization find data and information they are looking for (highly metadata dependent)? The better the metadata usually the easier it is to discover data that meets user requirements.
- **Accessible** - Once discovered, can data actually be accessed or retrieved? Are there ways to easily download or access data?
- **Interoperable** – Is data in a format that can be used and/or exchanged with minimal effort?
- **Reusable** - Is data released with a clear and accessible data usage license, associated with their provenance, and meet domain-relevant community standards?

For any modernization of an SDI to be considered successful, the “FAIR” guiding principles should be adopted. The more we dive into these principles the more complex things tend to get. It must also be kept in mind that a particular SDI does not have to provide everything to everyone.

This report reflects guidelines and experiences from a significant number of data management experts to identify the best way to achieve these essential requirements. In addition, ease of use, reliability, and completeness, are further dimensions that can be actively pursued. The following subsection identifies aspects that need to be addressed in order to improve the participation and integration of stakeholders with a modernized SDI.

7.3.1. Integration and Presentation

Another aspect that needs to be investigated is the integration of SDI modernization with existing regional and national SDIs, such as the CGDI. Further attention should be given to the integration of data and apps (applications that use the data) into widely deployed and used platforms. This is in addition to any stand-alone SDI Portals. Simply put, some stakeholders are better served by integrating data and apps into the tools they use. For geospatial scientists, it means being tightly integrated into their GIS; for policy stakeholders, it would mean simple story maps, creating dashboards using statistical and geospatial data tied to policy questions; and for scientists, it would mean integration of datasets with analytical tools. Additionally, stand-alone Portals must be designed for ease of use, must be interoperable with each other, and be both reliably available and secure. To achieve this level of integration, standards defining generic data containers or Web service interfaces for easy data access are of overall importance.

7.4. Coordination and Communications

Coordination of SDI modernization activities and collaboration among the various organizations involved is a critical success factor for a modernized SDI. A successfully shared modernization effort would be a stepping stone to other collaboration activities that could focus on increased data collection, introduction of robust monitoring programs, and ideally reduced duplication of effort. Additional coordinating activities include fostering early coordination and planning, encouraging transparency within the public sector so that collection priorities and data requirements are clearly stated and that the most efficient approach can be applied to ensure end user needs are met. In particular, the following aspects shall be considered:

- Work closely with organizations that supports the development of SDI modernization and aims to identify and promote national and regional best practices, assess existing and new standards in the provision of components of spatial data infrastructures, promotes SDI training and education, and facilitates (external) SDI communication.
- Involve Government Agencies at all levels, including Indigenous nations through a nation-to-nation approach.
- Integrate multiple technologies during data collection to speed the pace of acquisition, increase safety, and benefit multiple stakeholders with a variety of datasets meeting a varied level of needs.

7.4.1. Outreach and Awareness

Outreach and awareness activities help attract new stakeholders and raise awareness of the importance of modernizing an SDI among stakeholders already involved or at least aware of the relevance of an SDI modernization. Combined with early coordination activities, outreach and awareness activities across stakeholders help to maximize efficiency and transparency, which are crucial components leading to acceptance and eventual success of a modernized SDI. From the RFI responses and workshop input, the following activities and mechanisms are suggested:

- Outreach, including the utilization of social media, story maps, press releases, conference presentations, websites, online and in-classroom training classes, books, etc. All of the above are important for a successful SDI modernization effort to thrive.
- Consider developing a Strategy Document for review and comment at ministerial and senior management levels across all stakeholders.
- Publicize SDI modernization projects to help make stakeholders care more about the modernized SDI and its global impact.
- Improve collaboration between the public and private sectors to share lessons learned, establish best practices, and keep abreast of technology advancements.
- Participate in stakeholder relevant trade shows, symposiums, and conferences.
- Share case studies to demonstrate the wide range of uses of a modernized SDI.

Technology ease of use, coupled with reliability, greatly impacts stakeholder adoption rates as well as ensuring users are successful. Thus, the best outreach is probably achieved by word of mouth, triggered by an excellent implementation of an SDI modernization serving all stakeholders needs. Another approach to improve outreach is to implement it embedded in the exchange technologies. In this case, outreach material is shipped with software or directly part of Web portals. Further on, outreach embedded in technology can provide a base set of data in tools out-of-the-box without requiring substantial download of data at start-up time; an approach that simplifies the usage of software components.

It is a goal of a possible future pilot to demonstrate the value of a modernized SDI to stakeholders through the use of multiple case studies that would demonstrate the new capabilities of the SDI. This case study demonstration would overcome the currently existing paradox: potential stakeholders are not aware of the capabilities of an updated SDI and therefore not using it; meanwhile, the data providers are not able to adapt to the users’ needs, as they are neither formulated nor expressed.

Chapter 8. Currently Used and Emerging Standards

The value of standards is clearly demonstrable and is one of the key pillars of all SDIs and will continue to be a key component to SDI Modernization. The OGC defines an open standard as one that:

1. Is created in an open, international, participatory industry process . The standard is thus non-proprietary, that is, owned in common. It will continue to be revised in that open process, in which any company, agency or organization can participate.
2. Has free rights of distribution: An "open" license shall not restrict any party from selling or giving away the specification as part of a software distribution. The "open" license shall not require a royalty or other fee.
3. Has open specification access: An "open" environment must include free, public, and open access to all interface specifications. Developers are allowed to distribute the specifications.
4. Does not discriminate against persons or groups: "Open" specification licenses must not discriminate against any person or group of persons.
5. Ensures that the specification and the license must be technology neutral: No provision of the license may be predicated on any individual technology or style of interface.

Open standards are key for the quality and development of interoperable geographic information and geospatial software during the entire life cycle of any data set. Standards define how data is created, archived, used, discovered and exchanged between components within a system. They address different aspects of interoperability such as syntax, semantics, services, profiles, or cultural and organizational interoperability. There are excellent publications which discuss the value of standards and the role of standards in geospatial information management [1] or the usage of standards within SDIs [2]. A good starting point to learn more about existing standards relevant to SDI modernization is the website of the International Organization for Standardization (ISO), the Open Geospatial Consortium (OGC) and the World Wide Web Consortium (W3C).

An approach often used by various SDI cookbooks that exist for the development and operation of an SDI [3, 2] appears to be quite suitable here. This approach classifies standards, in the context of an SDI, into three categories:

- Data Content Standards - For understanding the contents of different data themes by providing a data model of spatial features, attributes, relationships, and a data dictionary.
- Data Management Standards - For handling spatial data involving actions such as discovery of data through metadata, spatial referencing of data, collection of data from the field, submission of data by contractors to stakeholders, and tiling of image-based maps.
- Data Portrayal Standards - For structured visual portrayal of spatial data.

The following sections will briefly discuss more details on the various categories to ensure a robust baseline for the development of a possible modernized SDI reference architecture as discussed in Chapter 9.

8.1. Existing Standards and Organizations

The RFI responses and workshop responses described three primary standards bodies, the ISO, the OGC and the W3C. It should be noted that these organizations do not work in isolation and significant efforts are underway to better integrate standards activities within these three organizations.

Standards and Interoperability address mechanisms and agreements to ensure that components which are part of, or that are loosely connected to, an SDI can communicate with each other. The following underlying principles govern the implementation of standards within any SDI.

- Interoperability of SDI components across platforms is of overall importance
- Data shall be served at standardized Web interfaces using standardized encodings.
- Standards-based Web GIS integrates and leverages all the investments that have already been made in GIS standards, data, and technologies. Any SDI should benefit from these investments and should be based on Web GIS patterns.
- Detailed compliance tests shall be available to ensure interoperability across components.

8.1.1. International Organization for Standardization (ISO)

The ISO Technical Committee on Geographic Information TC211 has developed a large repertoire of standards to describe many aspects of geographic information. A number of its standards are abstract high level reference models and abstract schemas. The ISO standards are intended to be guides upon which other groups, such as the International Hydrographic Organization (IHO) or national bodies or industry would develop more specific profiles and product specifications.

The ISO standards are widely adopted and many of the standards are of great importance such as the general feature model, metadata, spatial referencing, spatial schema, coverage geometry and register standards. They already form the basis of the IHO S-100 standard.

The ISO standards also support services and define encodings that are used in a Web Service. The “neutral” encoding defined in ISO is XML and the namespace for geographic information in XML is the Geography Markup Language (GML) an XML grammar defined by the OGC. GML has also been defined in ISO as standard ISO 19136 Geographic information — Geography Markup Language (GML). Both ISO and OGC also define standards for other aspects of Web Services.

The ISO standards are mature and support the modernization of an SDI; but to use them, updated profiles and product specifications may need to be developed.

8.1.2. The Open Geospatial Consortium (OGC)

The OGC is an international consortium of more than 500 businesses, government agencies, research organizations, and universities driven to make geospatial (location) information and services FAIR - Findable, Accessible, Interoperable, and Reusable.

OGC’s member-driven consensus process creates royalty free, publicly available, open geospatial standards. OGC actively analyzes and anticipates emerging tech trends, and runs an agile, collaborative Research and Development (R&D) lab that builds and tests innovative prototype solutions for diverse use cases.

OGC has defined a set of services and compliance tests that essentially make-up the interface to an SDI. This is a hierarchical structure.

OGC standards are in place and sufficient to implement a full suite of Web Services and APIs, however, the standards are actively maintained and are in active development. A Web Service is not something one just builds and lets stand. It needs active maintenance and evolution.

8.1.3. World Wide Web Consortium (W3C)

The World Wide Web Consortium (W3C) is an international community where Member organizations, a full-time staff, and the public work together to develop Web standards. The W3C's mission is to lead the Web to its full potential.

W3C standards define an Open Web Platform for application development that has the unprecedented potential to enable developers to build rich interactive experiences, powered by vast data stores, that are available on any device.

W3C develops these technical specifications and guidelines through a process designed to maximize consensus about the content of a technical report, to ensure high technical and editorial quality, and to earn endorsement by W3C and the broader community.

8.1.4. Current Widely Employed Standards Used in SDIs

This section will describe the different standards that appear to be in wide use across respondents' SDIs.

As Figure 8 shows, almost 50% of respondents currently employ OGC Web Services and APIs and overall demonstrate a high adoption of geospatial standards. This indicates that interoperability has a significant role in SDIs.

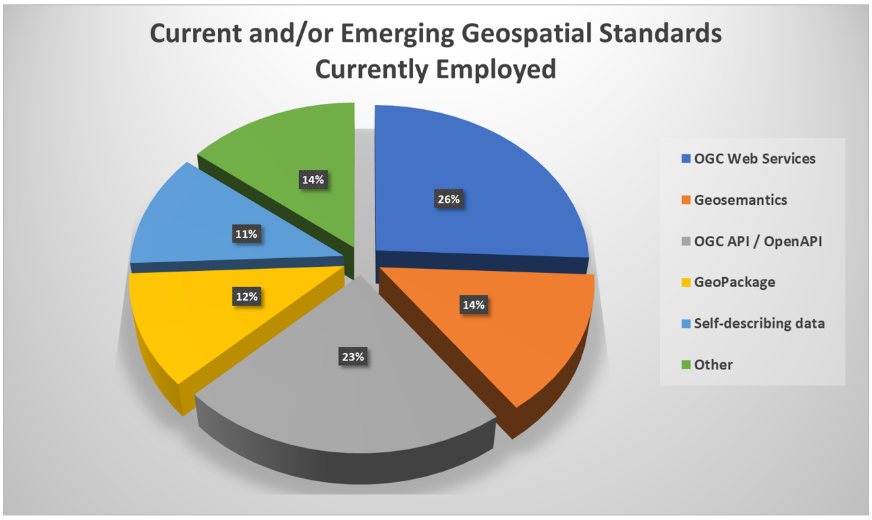

Figure 8. Geospatial Standards Currently Employed by Organizations (Source: OGC)

The use of OGC standards included web services, Geosemantics, OpenAPI-enabled OGC APIs, GeoPackage, self-describing data and others. The major challenge in developing increased usage of the OGC approach will be in community building, adequate support (e.g. cookbooks and, easily deployed stacks), and a clear value proposition.

Although not presented individually in Figure 8, current OGC Web Services Standards used in SDIs include the following.

- Web Map Service (WMS) - Provides a simple Hypertext Transfer Protocol (HTTP) interface for requesting geo-registered map images from one or more distributed geospatial databases.
- Web Feature Service (WFS) - Provides an interface allowing requests for geographical features across the web using platform-independent calls.
- Web Coverage Service (WCS) - Defines Web-based retrieval of multi-dimensional coverages – that is, digital geospatial information representing space/time-varying phenomena.
- Catalogue Service - Supports the ability to publish and search collections of descriptive information (metadata) for data, services, and related information objects and present results for evaluation and further processing by both humans and software.
- OGC Sensor Web Enablement (SWE) - Enables developers to make all types of sensors, transducers and sensor data repositories discoverable, accessible and usable via the Web.

8.2. Emerging Relevant Technology and Standards

Many in the environmental analysis community have adopted OGC standards. However, there were organizations responding to the RFI that were continuing to use proprietary systems. Most of the respondents, nearly 90%, noted the use of open geospatial standards in their organization to make data and maps available for inclusion in external sites and applications. Additionally, many organizations have been instructed to use OGC standards when available and develop best practices for implementation of the standards.

RFI and workshop responses described new or emerging OGC and other community technologies, standards and protocols that may be used within a modernized SDI. Figure 9 shows a percentage breakdown of these technologies.

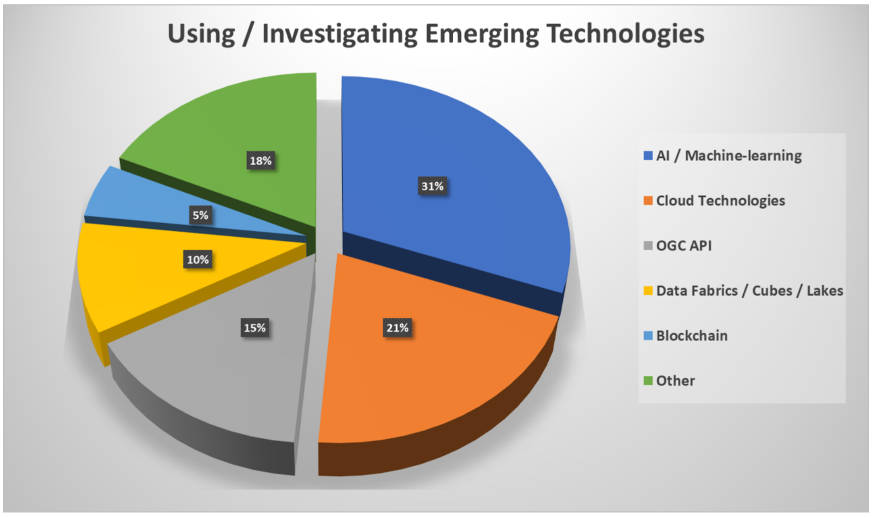

Figure 9. Emerging Technologies Organizations are Using or Investigating (Source: OGC)

The following sections will explore some of these emerging technologies.

8.2.1. AI/Machine Learning

Machine Learning (ML) is an application of Artificial Intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed. ML focuses on the development of computer programs that can access data and use it to learn for themselves.

The process of learning begins with observations or data, such as examples, direct experience, or instruction, in order to look for patterns in data and make better decisions in the future based on the examples that we provide. The primary aim is to allow computers to learn automatically without human intervention or assistance and adjust actions accordingly.

In recent years several groups have been working on integrating ML tools into OGC Web Services (OWS). These best practices include guidance on the use of workflows, service interaction patterns and application schemas, as well as exploratory topics such as tiling and gridding. There is ongoing work for the creation or extension of OGC standards to support ML and AI for geospatial applications.

Over 50% of RFI respondents are using or investigating ML and Cloud Technologies to help meet some of their challenges.

The following are benefits of using ML provided by RFI respondents:

- AI/ML leveraged against data mined from web services, Open APIs, and other sources, may provide valuable solutions in resolving interoperability challenges
- With SDI modernization, there maybe an opportunity for a more prominent role of data intermediaries that, with the use of AI/ML, will help bridge the gap between the provider, and user, of data.
- Geospatial/Health integration may be possible using AI/ML analytics to bring together digital health records and health trends with geospatial data (e.g. clusters, hot spots, etc.)
- Discovery of existing geospatial data and services can be improved by using AI/ML analysis of data/service to improve metadata information.

8.2.2. Cloud Technologies

Current data-driven and computing intensive CE analysis on climate-change, ecosystem modeling, and environmental and natural resources monitoring is based on the collection, management, analysis, and dissemination of geospatial data.

Currently, the acquisition and analysis of Earth Observation (EO) data is most often executed through traditional, computational, and data analysis approaches, which require users to download data to their desktops to perform any analysis. As the volume of EO data continues to grow, new analytical possibilities arise requiring new approaches to data management and processing. The traditional approach to acquire and process satellite EO data sets cannot address this new potential and quickly becomes unsustainable due to the volume of EO data to be analyzed.

Cloud computing systems can help overcome issues with traditional approaches to EO data analytics. Fully integrated systems that are built on top of cloud-based storage and computational systems remove the need to download EO data in order to conduct visualization and analysis of large EO datasets in a scalable, performant manner.

Moving analysis to the Cloud will help achieve the following:

- Bring the user to the data – to achieve high performance geospatial data analytics, it’s critical to bring the user to the data and avoid downloading wherever possible.
- Cloud native – Cloud geospatial involves more than simply migrating desktop apps to the cloud. The platform is built from the ground-up to leverage the power of cloud computing.
- Infrastructure vendor agnostic – a cloud-based platform can be utilized on a wide variety of cloud computing providers.
- Part of an ecosystem of open architected systems – a cloud-based platform is a starting point towards an open architected, distributed ecosystem approach to EO data analytics. Data and processing resources can be distributed to exploit pre-existing distributed data stores.

8.2.3. OpenAPI/OGC API

OpenAPI Defined

The OpenAPI Specification (OAS) defines a standard, language-agnostic interface to RESTful APIs which allows both humans and computers to discover and understand the capabilities of the service without access to source code, documentation, or through network traffic inspection. When properly defined, a consumer can understand and interact with the remote service with a minimal amount of implementation logic.

OGC API

Using the guidance from the OAS, the OGC API family of standards are being developed to make it easy for anyone to provide geospatial data on the web. These standards build upon the legacy of the OGC Web Service standards (WMS, WFS, WCS, WPS, etc.), but define resource-centric APIs that take advantage of modern web development practices.

These standards are being constructed as "building blocks" that can be used to assemble novel APIs for web access to geospatial content. The building blocks are defined not only by the requirements of the specific standards, but also through interoperability prototyping and testing in OGC’s Innovation Program.

To learn more about using the OGC APIs please view our guidelines here.

The OGC API Roadmap highlights current and planned standards efforts as well as related extensions to those standards. Innovation Program activities and other projects influencing and refining the process of standardization are also highlighted.

8.2.4. 3D Standards

3D data standards are emerging as an important interoperability technology. The ability to discover, access and share these datasets has increased in importance in recent years. These 3D Data Standards support activities such as inundation and storm surge modeling, hydrodynamic modeling, shoreline mapping, emergency response, infrastructure inspection, hydrographic surveying, and environmental vulnerability analysis.

The following are a few of the standards that are currently being used by RFI respondents:

- 3D Portrayal Service (3DPS) - The 3DPS standard describes how a client and service negotiate what is to be delivered and in which manner, to enable interoperable 3D portrayal. It provides the ability to view, analyze and combine 3D geoinformation from diverse sources in a single view. This is a joint standard between the OGC and the W3C consortium.
- Indexed 3D Scene Layer (I3S) - I3S is an open 3D content delivery format used to rapidly stream and distribute large volumes of 3D GIS data to mobile, web and desktop clients. I3S content can be shared across enterprise systems using both physical and cloud servers. Developed by Esri, along with numerous endorsing organizations, I3S is an OGC Community standard.
- LAS File Format - The LAS file format is a public file format for the interchange of 3-dimensional point cloud data between data users. The LAS file is intended to contain lidar (or other) point cloud data records. The data is used to derive images and 3D surface models. The American Society for Photogrammetry & Remote Sensing (ASPRS) is the owner of the LAS Specification and was recognized by the OGC as an OGC Community standard.

8.2.5. GeoSemantics/Ontology and Linked Data

Geosemantic interoperability is fundamental for applications using web-based geospatial data and services. Yet, it is often perceived as an abstract concept difficult to materialize.

Geosemantic interoperability is the ability of systems using geospatial data and services to cooperate (inter-operate) at the semantic and geometric levels. Geospatial interoperability allows for the exchange and semantically-compatible use of geometric and non-geometric data and services over the Web. It automatically interprets the semantics of geometric data as well as the type of geometric primitives to produce useful and accurate results. Geosemantic interoperability is the richest form of interoperability for geospatial data and services.

The idea of the Semantic Web has been around for well over 15 years, and more recently principles of Linked Data have been gaining a lot of momentum. The Semantic Web involves data elements and connections between them being published on the Web in order to provide concrete opportunities for experimentation in semantic applications.

Due to the universality of location and time, geospatial (and temporal) semantics particularly have potential for advancing integration of both geospatial and non-geospatial data. At the same time, ontologies are increasingly a part of formal information specifications and models.

Linked Data is a concept related to the semantic web. From W3C, “The Semantic Web isn’t just about putting data on the web. It is about making links, so that a person or machine can explore the web of data. With linked data, when you have some of it, you can find other, related, data.”

Wikipedia defines Linked Data as "a term used to describe a recommended best practice for exposing, sharing, and connecting pieces of data, information, and knowledge on the Semantic Web using Uniform Resource Identifiers (URIs) and Resource Description Framework (RDF)."

GeoSPARQL is a standard specifically relevant here as it supports representing and querying geospatial data on the Semantic Web. GeoSPARQL defines a vocabulary for representing geospatial data in RDF, and it defines an extension to the SPARQL query language for processing geospatial data. In addition, GeoSPARQL is designed to accommodate systems based on qualitative spatial reasoning and systems based on quantitative spatial computations. It can be viewed as a global database that can be queried using SPARQL, a query language used to express queries across diverse RDF data sources and GeoSPARQL, a geographic query language for RDF data (Open Geospatial Consortium, 2012).

8.2.6. GeoPackage with embedded metadata

GeoPackage represents an open, standards-based, platform-independent, portable, self-describing, compact format for transferring geospatial information. This describes GeoPackage. The GeoPackage Encoding Standard describes a set of conventions for storing the following within an SQLite database: vector features; tile matrix sets of imagery and raster maps at various scales; attributes (non-spatial data); and extensions. Since a GeoPackage is a database, it supports direct use, meaning that its data can be accessed and updated in a "native" storage format without intermediate format translations. GeoPackages are interoperable across all enterprise and personal computing environments and are particularly useful on mobile devices like cell phones and tablets in communications environments with limited connectivity and bandwidth.

8.2.7. Linking to IoT Technologies

There are currently several activities in the Internet of Things (IoT) community that may be considered as complementary enhancements of the established Sensor Web architectures, specifically:

- Applicability of IoT protocols (e.g. MQTT, AMQP, COAP, LoRaWAN, etc.) to applications: the complexity of this topic may require dedicated work items/work packages as part of new research projects.
- OGC SensorThings API provides an open, geospatial-enabled, unified and simple way to interconnect IoT devices, sensors, data, and applications over the Web. It provides a standard way to manage and retrieve observations and metadata from heterogeneous sensor systems.
- W3C Web of Things is intended to enable interoperability across IoT platforms and application domains. Overall, the goal of the WoT is to preserve and complement existing IoT standards and solutions (https://www.w3.org/WoT/).

8.2.8. Push based communication flows

Push technology, or server push, is a style of Internet-based communication where the request for a given transaction is initiated by the publisher or central server as opposed to pull/get, where the request for the transmission of information is initiated by the receiver or client such as the SOS protocol used in IoT projects. The following Push based communication characteristics are identified as being important for a modernized SDI.

- A profile for the OGC Publish/Subscribe standard that is tailored to the needs of Sensor Web applications.
- Push based communication patterns through bandwidth constrained links.
- Event stream processing tools for CE application scenarios and develop exemplary

implementations for selected use cases.

- Publish/Subscribe extensions for existing OGC SOS servers.

Chapter 9. Interoperability Reference Architecture

The architecture of an SDI is a multi-dimensional concept, including software, hardware, deployments, networks, operations, federations and many others.

One of the best approaches to demonstrate value and increase stakeholder adoption rates is a careful and well planned implementation of a modernized SDI serving all stakeholder needs.

The following sections discuss architecture requirements, perspectives, and concentrates on a number of key aspects to support the possible future development of a modernized SDI Interoperability Reference Architecture.

9.1. Architectural Observations of RFI Respondents

There were several significant questions from the RFI that indicated SDI usage and value to respondents. As shown in Figure 10 over 80% of respondents contributed to SDIs. This indicates a broad use of SDIs for this group. In addition, close to 90% of RFI respondents noted the use of open geospatial standards in their organization representing a very high adoption of standards and emphasizing their importance.

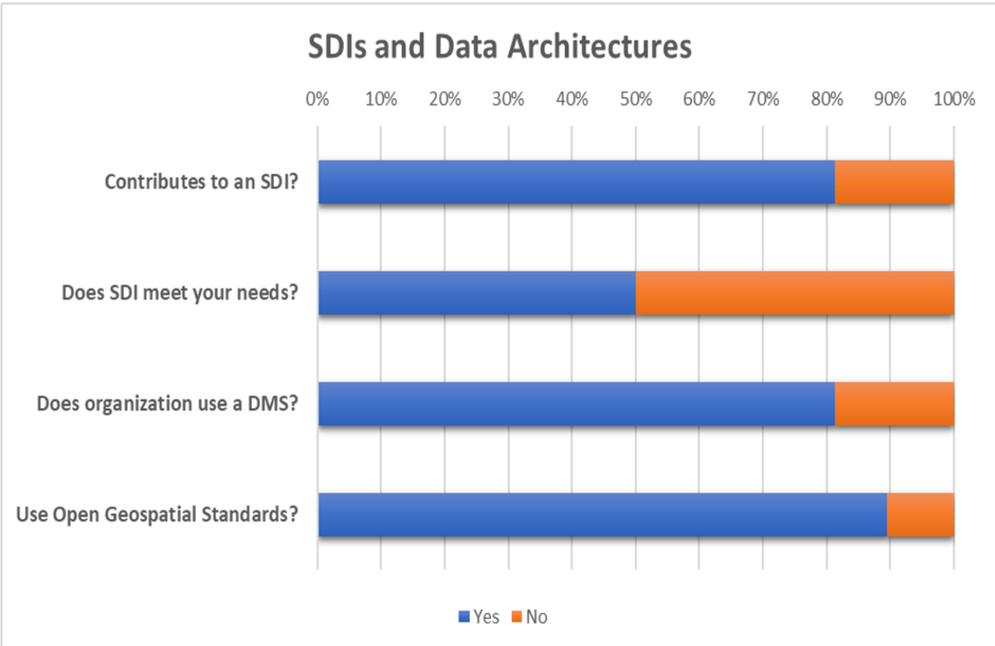

Figure 10. SDI and Data Architecture usage by RFI respondents (Source: OGC)

However, when answering a question on if the SDIs meet their needs, less than 50% said that they did. Given the resources that have been employed in developing SDIs around the globe it is surprising that this number is this low. This result may be explained by examining stakeholder needs in Chapter 7.3.

Additional research into the causes of this result should be undertaken.

Data access and availability for cumulative effects and regional assessment analysis was questioned in the RFI. As shown in Figure 11, almost 70% of those creating data products released standards compliant data. This again indicates the importance of using standards in this community.

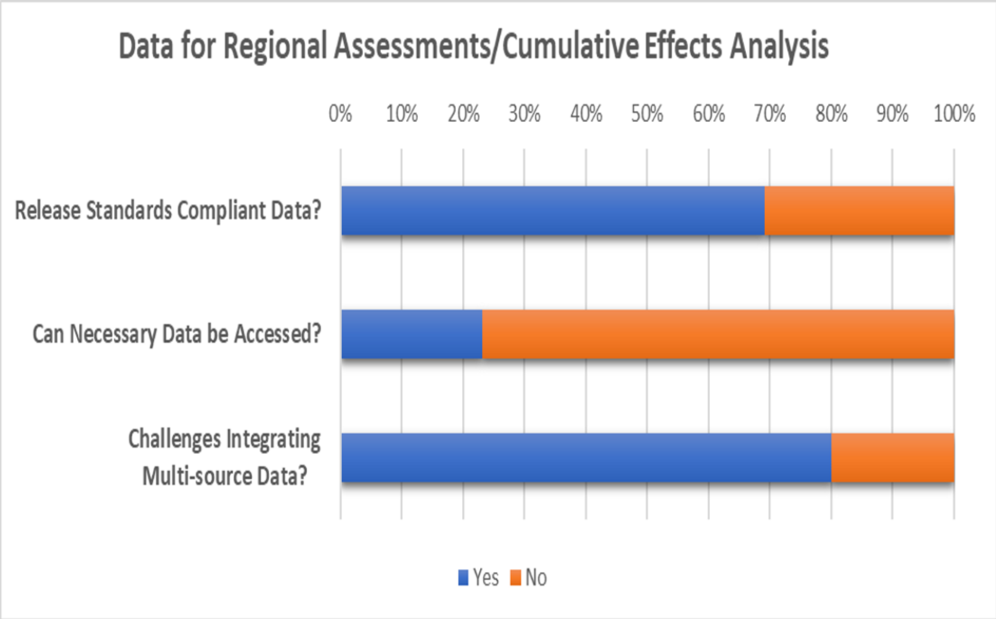

Figure 11. RFI responders data access and availability for CE/RA analysis (Source: OGC)

However, most respondents, almost 80%, encounter challenges when trying to integrate disparate data (different sources, times, etc.). These challenges were further explored in Chapter 9.2.

A surprising result of the respondents was the low response to the question about accessing the necessary data required. Less than 25% of RFI respondents can access the data required for their work, indicating over 75% cannot access the data they need. Obviously, any SDI modernization will have to look closely at the reasons behind this unsatisfactory result and concentrate efforts on improving the delivery of data stakeholders need.

9.2. SDI Challenges

After analyzing RFI responses and workshop input, the following challenges were described:

- Integration of mass quantities and diverse types of information from multiple provincial/state/municipal/territorial stakeholders to create national-level products.
- Data Discovery and Access - existing geospatial services can be difficult to easily discover and access.
- Significant limitations and restrictions on sharing/integrating health data.
- Traditional Knowledge and Scientific Data - western stakeholders understanding of Indigenous geospatial concepts may be limited.
- Standards usage generally remains limited to experts with strong technical knowledge.
- Accessing training datasets to support machine learning applications.
- Geometry/ Attribute/Projection Incompatibility.
- Data Preprocessing Required before use.
- Language and licensing issues.

- Making data available for a SDI can be expensive, time-consuming, and is a lower priority for many organizations.

Addressing these challenges within any SDI modernization will improve the usefulness of data used by stakeholders.

9.3. Requirements

The stakeholder needs discussed in Chapter 7.3 and results from questions answered in the previous sections 9.1 and 9.2, result in a number of requirements and constraints on a modernized SDI that will be expanded upon in this chapter. Requirements and constraints will be explored in terms of data sharing, standards and interoperability, funding and investment, integration with existing systems, agility and adaptability, and security, privacy and safety. Figure 12 illustrates these categories.

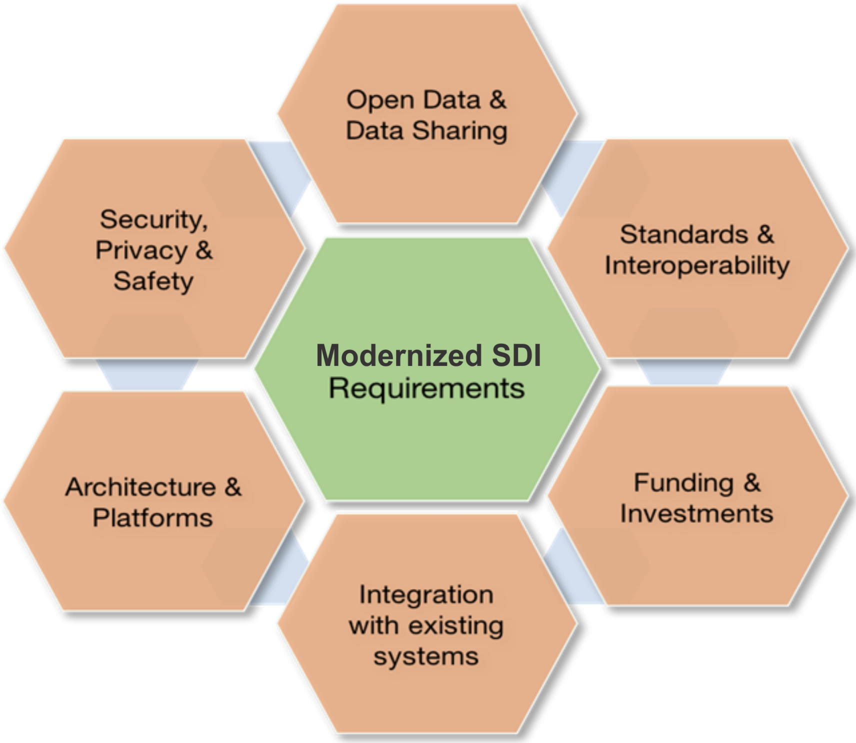

Figure 12. High level modernized SDI requirement categories (Source: Spatial Data Infrastructures: “Cookbook” - modified)

The following sections will briefly discuss more details on the various categories to ensure a robust baseline for the development of a modernized SDI architecture.

9.3.1. Open Data & Data Sharing

Open Data & Data sharing addresses both legal as well as technical aspects such as how to enable data sharing among disparate and heterogeneous endpoints and systems using common data models and schemas. Open data is the idea that some data should be freely available to everyone to use and republish as they wish, without restrictions from copyright, patents or other mechanisms of control. Open Data & Data Sharing further addresses organizational aspects such as how to encourage data sharing with social or economic incentives and enforcement of rules.

- Any modernized SDI shall broker both the delivery of government and non-governmental information or data.
- Integration of near real-time observations from both satellites and in-situ sensors is key. Traditionally, this has not been easily achieved due to the proprietary nature of the sensor interfaces. Current standards technologies such as SensorThings API shall be implemented. Also, auto-registry of sensors is a key requirement.
- The architecture shall support creation and exchange of research-oriented synthesized data sets (i.e. simulation model outputs).
- All data shall be accompanied by metadata. As this requirement may be difficult to implement, new ways shall be explored to minimize the need for manually generated metadata using machine learning techniques.
- Support of Open Data and Data Sharing shall be balanced with the rights of Indigenous nations to control their information. For example, the First Nations principles of OCAP® assert the rights of First Nations to control data ownership and access, including how their data can be used. Canada has undertaken initial work to determine how/if OCAP® principles and open data policies can be reconciled.

9.3.2. Standards and Interoperability

Standards and Interoperability addresses mechanisms and agreements to ensure that components being part of, or that are loosely connected to, a modernized SDI can communicate with each other.

- Interoperability of SDI components across platforms is of overall importance.
- Data in open, standardized formats should be served by Web interfaces using standardized encodings. This should be facilitated through the use of the new OGC APIs.
- Standards-based Web GIS integrates and leverages all the investments that have already been made in GIS standards, data, and technologies. Any modernized SDI should benefit from these investments and should be based on these standards.
- Detailed compliance tests shall be available to ensure interoperability across components.
- Unstructured data feeds should be analyzed to determine the best format to enable sharing with other users for further process in the cumulative effects workflow.

9.3.3. Funding and Investments

The operation and maintenance of a successful SDI modernization generates substantial costs that need to be covered by funding agencies or invested by companies with the goal to generate proportionate profit in the future. In terms of business needs, the following aspects need to be considered:

- Adequate funding from the various participating public sector organizations.
- Funding issues may arise if the benefits to be gained from a modernized SDI are not sufficiently understood by funding bodies within the cumulative effects domain and beyond.
- Recognition of geospatial data as an investment rather than a cost, which is possible through geospatial consortia making the data interoperable between different users to be utilized in an

interoperable manner.

- Development of relevant applications in the private sector, especially intermediary applications, to generate desirable return on investment.
- Any modernized SDI shall consider, not only one-time costs associated with implementing the solution, but the ongoing requirements to support, maintain and enhance the solution over its lifecycle to ensure it continues to deliver value and meet stakeholder needs.
- Individual management objectives, priorities, planning cycles and investment capacity are all constraints that will affect an organization's ability to participate in the development of SDI modernization.
- Cost efficiency is key and any modernized SDI should be implemented, as much as possible, out-of-the-box - meaning using existing cloud hosting and server based geospatial solutions and without the added expense of in-house software development and IT management.

9.3.4. Integration with Existing Systems

Integration with existing systems is a critical aspect to ensure neat integration of data hosted in external systems and the protection of investments in other SDIs or platforms that shall be conserved. Therefore, a modernized SDI must:

- Coordinate with National Mapping authorities that provide data;
- Coordinate with international, national and regional SDIs.
- Integrate with national and regional SDIs without replicating already available resources.
- Integrate with and support widely deployed geographic information systems.
- Not be perceived as a competitor to local, regional, or national SDIs;
- Integrate data platforms operated by national space agencies or other organizations providing satellite-derived data products; and
- Connect (as practical) with any possible environmental data provider (industry, academia, research entities).
- Ensure that any coordination with Indigenous systems is accomplished in a way that respects Indigenous rights (e.g., the First Nations principles of OCAP®).

9.3.5. Architecture and Platforms

Architecture and Platform aspects play a key role in distributed spatial data collection, exploration, and processing environments. They need to ensure that the targeted modernized SDI can keep pace with changing technologies and Internet trends. The following high-level requirements have been identified.

- Development efforts for a modernized SDI could be constrained by how prescriptive the architectural design is at the outset. To benefit from rapidly improving technology, a modernized SDI needs to remain agile. Architectural decisions affect costs to the participants and the ability to benefit as technology changes. Early architectural decisions can translate into constraints if they are too rigid in their approach. Therefore, the following questions must be addressed:

- Will the modernized SDI be a closely architected approach where the platform itself consists of the infrastructure, the content, any number of APIs and Software Development Kits (SDKs), and application and content management tools? or
- Will the modernized SDI be highly architected and all data, apps and services be available as hosted/re-hosted services (cloud and/or on-premise)?, or
- Will the modernized SDI be some combination of the two approaches?

- Multi-linguism and technical language requirements must be considered
- Technical knowledge and availability of skills is often a limiting factor in stakeholders adopting technical solutions, or in continuing efforts to maintain solutions already in place. The modernized SDI architecture has to cater for greatly varying paces at which organizations adapt new technology and will have to bridge a wide variety of technical solutions of differing ages and platforms.
- A modernized SDI shall be very dynamic and flexible because change is occurring at a very high rate. New data sets are continually added, and a huge number of data sets are updated constantly.
- A modernized SDI should consider low-bandwidth and offline capabilities for where Internet connectivity is limited or non-existent (e.g., users operating in the Arctic). SDI designers must decide if they will provide infrastructure as well as data and apps. Examples of using data appliances that are loaded with data, software, and apps, such as GeoPackage, shall be explored.
- Intuitively designed, custom user interfaces through standardized APIs, such as OGC APIs, that can provide structure/navigation best practices allowing lower barrier to entry and provide ease of access to a modernized SDI.
- Efficient search functionality and fast or flexible download rates.
- Preservation of the national language, support for multilingualism, and Indigenous requirements should be taken into account.
- The architecture shall allow for future extensions and allow the integration of upcoming new patterns to handle e.g., Machine Learning and semantic annotation.

9.3.6. Security, Privacy and Safety

Security, Privacy and Safety includes aspects such as vulnerability to attacks, acceptance and assurance of privacy concerns, secure and reliable access, protection of intellectual and Indigenous property rights, and assurance of system availability in critical situations, e.g. emergency responses or major crises. Additionally, Data Integrity is crucial in secure infrastructures where the maintenance and the assurance of the accuracy and consistency of data persists over its entire life-cycle (Boritz, 2004). Users need to identify the source of the data and to be sure that the data was not modified in the process. Additional items mentioned in RFI responses and workshop include the following.

- Many data sets are access-protected for good reasons (e.g. security implications or commercial or government interests). Though these reasons are fully acknowledged, SDI design should provide for obtaining information about how to access datasets that are not open but may be accessed through other means. For example, industrial stakeholders who procure their own data collection programs often are protective of the data set but are willing to share them under certain circumstances. The necessary brokering has to be addressed.

- Foundational data shall be provided as license-free data (public sector) for ease of reuse during crisis support.
- Individual logins, firewall protection and a secure server connections capable of transferring and storing highly sensitive data need to be available.
- Indigenous rights shall be enabled and respected (e.g., the First Nations principles of OCAP®).

9.4. SDI Technology Approaches

When it comes to SDI design reflected in the RFI responses, two important approaches must be differentiated. They are not mutually exclusive and a chosen approach can still be complemented by the other. In fact, both approaches represent the two extremes of a given continuum, with most implementations featuring some level of middle course. Nevertheless, the architecture design differs depending on the preferred approach. The first approach focuses on a closely architected infrastructure that provides data and apps as services. Thus, the defined architecture caters for a defined set of services (includes rehosted services) that are operated and maintained by a SDI control board, i.e., a group with control over the individual components. The second approach focuses on infrastructures, platforms, and geoportals as they currently exist and emphasizes their integration into a federation of systems. Here, emphasis is on discoverability and integration based on open standards. The first approach puts more control into the hands of the control board, whereas the second approach provides more flexibility and distributed responsibilities. Key to both approaches is the strong adherence to standards to avoid vendor lock-in with limited flexibility and extensibility. It should be emphasized that both approaches can complement each other, i.e., they do not necessarily act in isolation, but support interfaces to allow mutual usage.

9.4.1. Closely Architected Approach

The first, closely architected approach is illustrated in Figure 13. The platform itself consists of the infrastructure, the content, any number of APIs and SDKs, and application and content management tools. The actual applications are usually provided as external components or as web-based thin clients. The key here is the fact that the entire system focuses on the single platform concept, which means that the individual layers and implemented aspects are not particular characteristics of the closely architected approach. It is the way they are implemented and linked with each other.

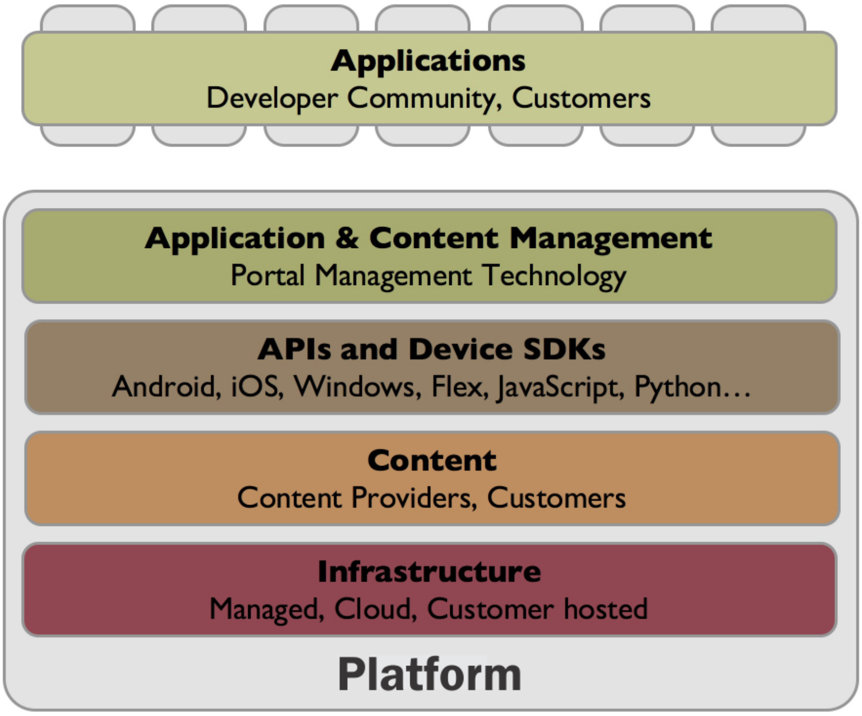

Figure 13. Closely Architected Approach, (Source: Esri - modified)

The infrastructure includes the hardware and software needed in a modernized SDI. The infrastructure design will need to take into consideration the different user scenarios, data sources (either managed by the SDI or coming from third party sources), appropriateness of cloud technologies, current and future IT policies, and existing hosting capacity. The SDI will need to account for offline or restricted bandwidth situations. To mitigate these, the modernized SDI could consider using data appliances and container formats such as GeoPackage.

The content aspect of the modernized SDI can be broken down into the following.

- Geospatial data management - this includes the technologies and workflows for managing vector and raster data that will be managed and used in the SDI. Following the best practices defined by the Infrastructure for Spatial Information in the European Community (INSPIRE) and/or the Federal Geographic Data Committee (FGDC) for the National Spatial Data Infrastructure (NSDI), a modernized SDI would define the key spatial and nonspatial data layers that support the needs of the CE use cases. For these data layers, data management and portfolio management policies and procedures need to be defined. This includes, but is not limited to, data models, data update frequencies, conflation of multi-source data, data quality assurance, and availability assurances.
- Real-time data management - this includes the technologies and workflows for ingesting and using real-time data feeds such as sensor feeds and feeds from other systems relevant for the modernized SDI.
- Data integration with 3rd-party systems - this allows the feeding (push) or consuming (pull) data from the SDI. For this, a Web services approach using common service interface specifications that build on international standards from the W3C and the OGC and others are recommended.

API’s and SDK’s

If data is the fuel of an SDI, APIs and SDKs form the engine that powers the applications and integration with 3rd-party components. Whatever platform is selected, it needs to offer an effective way to create and manage geospatial applications to developers. The offered OGC APIs offer a standards-based approach that supports building web, mobile, and desktop apps that incorporate mapping, visualization, analysis, and more.

Application and Content Management

This component provides the tools and concepts that allow for organizing the content in the modernized SDI in logical and easy to understand groups of thematic or organizational structures. Content Management is typically done through portals.

Applications

The entire platform may be accessed through a number of applications that are tailored to the specific user audiences of the SDI. The applications may vary from templates that are used to tell stories around specific issues of environmental CE analysis to advanced desktop GIS that connects to the metadata catalog and discovers web services and other content to consume. The important realization is that not all users will engage with an SDI for cumulative effects through the portal or through the applications managed as part of the SDI.

9.4.2. Federated Approach

The second approach is illustrated in Figure 14. This approach, shown here with focus on service interfaces and encodings, identifies four main components, visualized using different background colors. The dark components at the bottom represent data sources such as geospatial feature data, geospatial raster data, map, sensor, and other data. This data is served by a number of services that belong to different classes, such as data access services, processing services, sensor web services, discovery services, or other services. These services make use of standardized data models and encodings. Visualization and decision support tools and applications make use of the data provided by the various services in standardized formats.

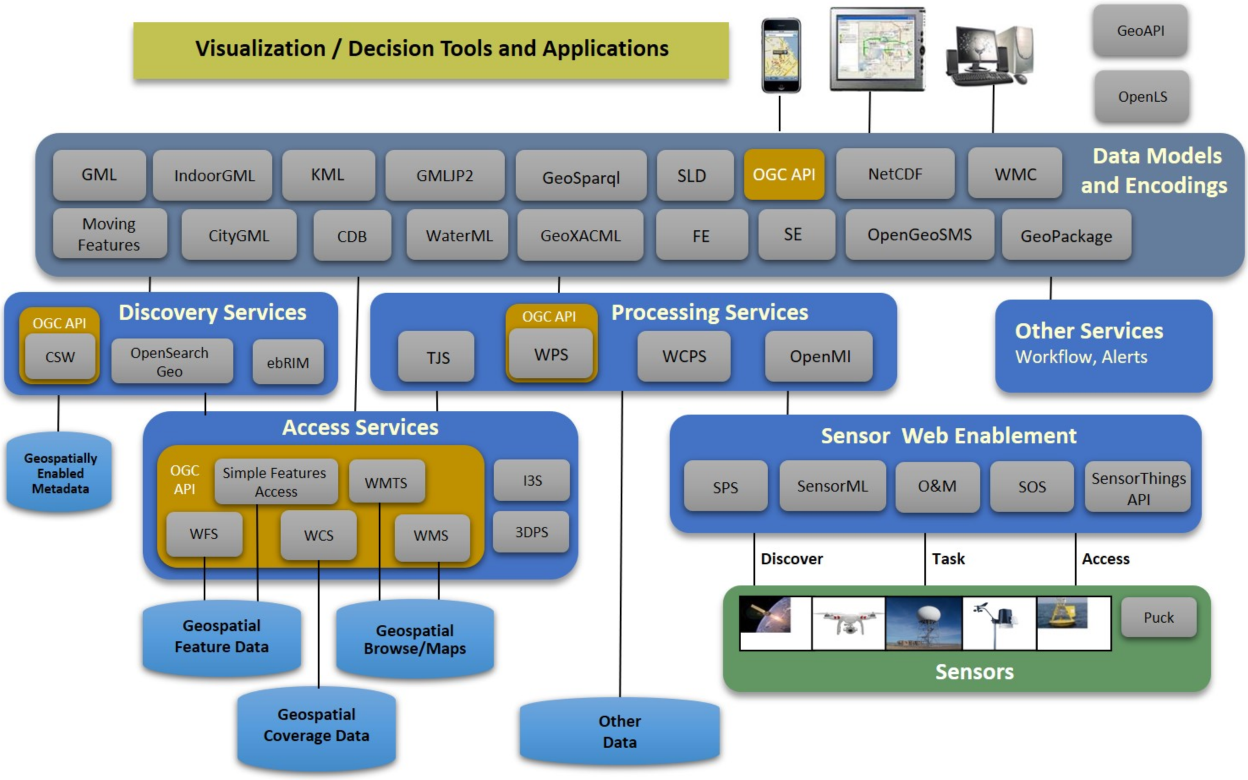

Figure 14. Federated Approach, (Source: OGC)

This approach concentrates on service interfaces and encodings. It allows an entirely decoupled and loosely federated infrastructure with minimized, necessary, scientific knowledge required to interact with the various components. This approach leaves aspects such as maintenance, service configuration etc. to the service operators, i.e., this functionality is not part of the architecture view, as it is irrelevant for the actual SDI. This contrasts with the closely architected SDI concept, where management tools and content tools allow control over more than a single SDI component. The environment illustrated here needs to be enriched with Security Consideration settings, which usually require some sort of higher level organization if features such as single-sign on shall be supported (otherwise service consumers would need to register with every service, which works in principle, but is not very practical).

9.5. Modernized SDI Reference Architecture for CE/RA

The Reference Architecture must find the right balance between being prescriptive while remaining agile to allow for easy integration of upcoming technologies. This requires the modernized SDI to be implemented as a loose federation of portals and platforms, a federated system of systems, discoverable by open specifications and standards rather than being a highly architected infrastructure with data and applications being available as hosted/re-hosted services.

Independent of the chosen approach, a number of additional aspects have been repeatedly identified by RFI respondents and workshop panelists and attendees as being relevant for a successful SDI. These aspects are usually complemented with the standing request for openness as illustrated in Figure 15. Openness usually refers to a number of aspects that describe an element that is openly (in the sense of publicly and royalty free) available and reusable, developed in an open process, and accessible at minimum costs (in terms of data pure reproduction costs or even no costs).

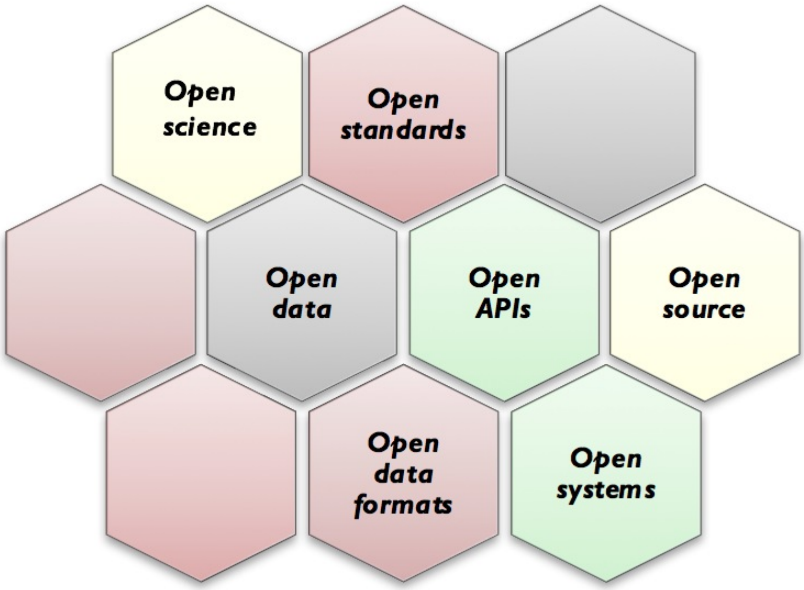

Figure 15. Aspects of openness

Open science is the movement to make scientific research, data and dissemination accessible to all levels of an inquiring society, amateur or professional. Open systems include open source work and GitHub resources, choices in hardware, operating systems, Cloud, databases, developer tools, direct links to non-GIS systems such as CAD and BIM, etc. Open standards include standards as provided by OGC, IHO, CGSB, FGDC, OASIS, W3C, ASPRS, etc.) and open specifications (widely used but not yet adopted by Standards Developing Organizations (SDOs) and openly published technology such as GeoJSON, Geoservices REST API, etc.)

In addition to these general 'Open' requirements, many individual modernized SDI architectural requirements were described in the RFI responses and workshop. From this valuable input, an ideal modernized SDI architecture shall be designed to provide for the following:

- **Registry and Discovery**
  - Rapidly discover and access information, products and data.
  - Architecture shall support search mechanisms that go beyond metadata based keyword search, as metadata is almost never complete and often hard to maintain.
  - Auto-registry system for sensors (both remote and in-situ).
  - Improved search engine capabilities for finding and browsing data, services, and metadata. These should be adaptable to allow for a range of search types from basic quick searches through detailed searches using multiple criteria including: geography, time, organization, physical parameter, etc. These capabilities should include increased integration with other discovery infrastructure for broader data publishing and discovery. Machine Learning and OpenAPIs may help provide these capabilities.
  - Discovery of existing geospatial data and services can be improved by using more advanced analysis (semantics, NLP) of data and services to improve metadata information.
  - Users able to discover (search), view, assemble and obtain desired data and services for a particular area of interest without needing to know the details of how the data and services are stored and maintained by independent agencies, organizations and data custodians.
  - Non-mapped search results (e.g. technical reports, multimedia) should be associated with

mapped search results and viewable in the web browser.

- **New Functionality and Extension**
  - Easily publish/reference information, products and data into the modernized SDI.
  - Integration of new functionality.
  - A SDI is, by nature, federated. It should be as transparent as reasonable to an end-user as to where the information being accessed is sourced from within the federation.
  - Consideration may be given to adding an online information network with an ontology-based interface on top to visualize databases and information sources content. The ontology-based approach would allow for efficient searches once all data and operation concepts are annotated. This approach would also allow for illustration and processing of stakeholder-data relationships, or stakeholder-processing relationships, which could provide valuable insight for other stakeholders with similar requirements, as processes could be copied or adapted more easily.
  - Machine Learning and Cloud Services leveraged against data mined from web services, Open APIs, and other sources, may provide valuable solutions in resolving interoperability challenges.
- **External Systems and Formats**
  - Content may be disseminated to other global, national or regional networks. This increases the visibility of SDI data and information products.
  - Provide connectivity to legacy/heritage systems.
  - Support for scanned documents that provide valuable historic data sets, including charts, maps, forms, other tabular data (both machine and hand written), or hand-drawn sketches.
  - Support for documentary videos, oral histories, and other sources beyond purely numerical data.
  - Enable e-visualization of information in a geospatial, data analysis presentation environment and temporal context.
- **Tailoring**
  - Support both the desktop and mobile environments.
  - Support multilingualism and appropriate character sets.
  - Support targeted users from a diversity of backgrounds. The efficacy of the portal to access information by the uninitiated has been proven to be key to a successful, i.e., well-used SDI.
  - Respect for and support of Indigenous policies for data sharing (e.g., the First Nations principles of OCAP®)
- **Key Service Functionality**
  - A mapping interface showing search results. The map portrayal should be interactive: pannable, zoomable, changeable projection. Mapped items should be interactive: obtain metadata by clicking/hovering, get data values by clicking/hovering.
  - Basic analysis and visualization tools, e.g., navigating long time series, statistical analysis on selected data sets or subsets.
- **Low Bandwidth and Offline Usage**

- Where access to high speed data infrastructures are limited, there tends to be low or no bandwidth available. Applications should consider the support of both online and offline use of data.
- One of its key uses, cumulative effects analysis, is the ability to exploit low cost mobile devices, such as Android tablets, in the Arctic environment for monitoring, gathering and updating data in areas that have no, or poor data communications. Workers/researchers in the Arctic may preload data they may need on to their mobile device using a GeoPackager application. They can then go into the field and add or update current data on the device. When they return to an area with data communication, the GeoPackage will synchronize with the original data.
- Transferring of data via non-internet mechanisms, such as shipping hard drives/thumb drives to customers with very limited internet connectivity. These drive-deployed datasets shall be made available as being directly served from a standards-based Web service, i.e., data storage is transparent to the end user. Again, this can be accomplished using GeoPackage.
- Downloadable datasets in standard formats.

Chapter 10. Conclusions and Recommendations

This CDS consultation process, the RFI, and the Modernizing SDI Workshop, were critical to collect the views of the SDI community and wider stakeholders on SDI development, governance and future directions.

The results form an important step in the evolution of a modernized SDI. Almost all contributors agree on the following conclusions. These are summarized as follows in no particular order:

- Any successful SDI modernization should be guided by “FAIR” data sharing principles to the full extent that other specific considerations such as privacy and propriety will allow.
- With over 75% of the respondents indicating that they cannot access the data they need for CE/RA analysis, any SDI modernization will have to look closely at the underlying causes behind this result and concentrate efforts on improving the delivery of data stakeholders require.
- Coordination of SDI modernization related activities, and collaboration among the various organizations involved, is a critical success factor for a SDI modernization effort. A successful modernized SDI would be a stepping stone to other collaboration activities that could focus on increased data collection, introduction of robust monitoring programs and ideally reduced duplication of effort. Fostering early coordination and planning, and encouraging transparency within the public sector so that collection priorities and data requirements are clearly stated and the most efficient approach can be applied to ensure that end user needs are met.
- With less than 50% of respondents indicating that current SDIs do not meet their needs, additional research will be required into the possible causes of this result and, going forward, what should be done to help increase needs satisfaction.
- It was found that the modernized SDI Reference Architecture must find the right balance between being prescriptive and remaining agile to allow for easy integration of upcoming technologies. This favors SDI implementation as a federation of portals and platforms discoverable by open specifications and standards, rather than as a highly architected infrastructure with tightly coupled data and applications provided as hosted/re-hosted services.
- Machine Learning and Cloud Services may be leveraged against data mined from web services, Open APIs, and other sources, to provide valuable solutions for interoperability challenges.
- An SDI modernization should be community-driven, fostering links across existing data initiatives, and gaining commitment and support from local, regional, national and international governments and umbrella organizations.
- From the analysis of stakeholder needs, five high level overarching requirements can be applied to any SDI modernization.

  1. A modernized SDI should foster data integrity and provide stakeholders with security-based, appropriate access to the spatial data they need. Getting the **right information** to the **right person** at the **right time**.
  2. A modernized SDI should allow access of data on a variety of devices and platforms including mobile, e.g., smartphones and tablets
  3. A modernized SDI should allow different stakeholders, at different locations, to access the

SDI.

4. A modernized SDI should allow for data exchange in an interoperable, appropriate, efficient and secure way that respects the rights of data owners (e.g. the First Nations principles of OCAP®)
5. A modernized SDI will require the continued and increasing use of OGC and other open standards to achieve the four requirements listed previously.

- There will be a requirement to work closely with organizations that support the development of SDI modernization and aim to identify and promote national and regional best practices, assesses existing and new standards in the provision of components of spatial data infrastructures, promotes SDI training and education, and facilitates (external) SDI communication.
- It is important to involve Government Agencies at all levels, including Indigenous nations through a nation-to-nation approach.
- With SDI modernization, there may be an opportunity for a more prominent role of data intermediaries that will help bridge the gap between the providers, and users, of data.
- The increased use of OGC APIs is recommended for any SDI modernization effort. The OGC API family of standards makes it easy for organizations to provide geospatial data to the web. This may aid in more effective discovery and distribution of geospatial information.
- The discovery of existing geospatial data and services can be improved by using more advanced analysis, using semantics and Natural Language Processing (NLP), of data and services to improve the quality of metadata.
- In the future, integration of near real-time observations from both satellites and in-situ sensors will be of increasing importance for CE analysis. Traditionally, this has not been easily achieved due to the proprietary nature of the sensor interfaces. New technologies such as SensorThings API should be considered to ease introduction and use the latest sensor/observation technology.
- Improved Geospatial/Health integration maybe possible using improved analytics to bring together digital health records and health trends with geospatial data (e.g. clusters, hot spots, etc.). SDI modernization may include linkages to the Health SDI currently in development.
- Outreach and awareness activities will help attract new stakeholders and raise awareness of the importance of modernizing an SDI among stakeholders already involved or at least aware of the relevance of an SDI modernization.
- To help in remediating issues due to limited bandwidth in much of the northern environment, a significant portion of the base or core data can be prepared in advance and pre-loaded on mobile devices for field use. This can be accomplished by leveraging the GeoPackage standard.
- All data should be accompanied by metadata. Exploration into minimizing the need for manually generated metadata should be continued.
- Results from this CDS and follow-on activities such as pilot implementations, should be used to further develop and refine a reference architecture for modern SDI development. As part of this development, OGC with the support of its members, potential sponsors, and the community should seek to broaden the scope of applicability of this reference architecture by building a communications strategy to strengthen cross-domain collaboration in SDI modernization development. In particular, affinities between modernized SDI and dynamic digital twins have the potential to enrich the capabilities and value of both approaches to working digitally with

real world issues and challenges.

The above conclusions and recommendations should not be regarded as a definitive list. Instead, these conclusions and recommendations listed here may provide a focus for a future modernized SDI and a possible pilot phase of the CDS.

10.1. Future Work

The work carried out in this CDS and represented in this report is but a first step in both conceiving of and realizing the challenges and opportunities embodied in a future concept of modernized SDI. There is on the one hand the opportunity to be a part of re-thinking the entire idea of infrastructure, as whatever physical, social, or digital constructs can form a common, reusable basis for the full range of human pursuits. There is on the other hand the challenge of pulling together disparate tools and technologies into a coherent, interoperable whole that can accomplish this. There is no single step that can take us all the way to a modernized SDI of the future. Small and iterative steps of innovation, though, where each new design piece leads quickly to experiment and evaluation, have shown their value in achieving real progress.

Among the first steps that should be considered are a pilot implementation of the SDI capabilities outlined in this report for facilitation of CE/RA projects, followed by expansion into other domains of study where spatial information is a common and critical ingredient. The value of a modernized SDI that emerged from these initiatives would be further enhanced by research to build out the evident affinities between spatial data infrastructure, predictive modeling / AI, and dynamic digital twins. Such work would have the potential to significantly increase the types of work that modernized SDI could be used and reused to accomplish.

This report documents the need for modernized SDI to be well thought out, proven in implementation, and yet responsive and sustainable in the face of exploding data and rapidly evolving technologies. This suggests that operationalization of modernized SDI needs to be an equal part of its iterative development, an accessible capability that is at the same time ever becoming still more modern.

Appendix A: Stakeholder Workshop Summary

The following is a brief summary of a Modernizing SDI Workshop held on November 10, 2020.

This event was conducted to further the issues and knowledge around the modernization of an SDI.

A.1. OGC Modernizing SDI: Data Interoperability for Cumulative Effects Workshop

The workshop was presented in three parts: starting with an overview of the challenge of data interoperability in an SDI environment then presenting two panels, in which invited subject matter experts presented deep dives on the challenges, questions, ideas and possible solutions to this issue. Panel sessions followed with an audience question-and-answer period and open discussion.

A.1.1. Part I: Data Interoperability for Cumulative Effects Concept Development Study (30 mins)

Cindy Mitchell (NRCan) and Rob Thomas (OGC) Presenters

The core project team (OGC and Natural Resources Canada) provided background and status of the Modernizing SDI: Data Interoperability for Cumulative Effects work thus far. This overview included findings and trends derived from responses to a Request for Information issued earlier in 2020, along with other key observations based on additional research. The challenge of data interoperability when gathering and integrating data to feed cumulative effects analysis will be illustrated based on real case studies, including the recent Oil Sands Impact Assessment in Alberta, Canada. This overview of the problem at hand lays the groundwork for Parts II and III of the workshop, in which invited subject matter experts took a deep dive on challenges, questions and possible solutions.

A.1.2. Part II: Drilling Down - Articulating the Challenges to Data Interoperability (45 mins)

Lightning talks were presented by an expert panel of data scientists, cumulative effects/environmental assessment practitioners, and data producers. This part of the workshop further explored the challenges to data interoperability as articulated by the lived experience and knowledge of panel participants.

Panelists and Presentations:

- **Maribeth Murray: Arctic Institute of North America** - The Canadian Consortium for Arctic Data Interoperability.
- **Souleymane Touré: Environment and Climate Change Canada (ECCC)/Canadian Wildlife Service (CWS) -** Challenges and Opportunities in Harmonizing CWS Geospatial Data.
- **Tyler Amos and Frédéric Dwyer-Samuel: Nunatsiavut Government** - Summary of Data-

specific Challenges Facing the Nunatsiavut Government with Respect to Environmental Impact Assessments.

- **Dominique Gauvreau: ECCC/CWS** - People & Standards: Human considerations in the use of standards.

A.1.3. Part III: Standards-Based Support for Increased Data Interoperability in an SDI (45 mins)

Lightning talks were presented by an expert panel of solution providers, standards advocates, and OGC members. This part of the workshop focused on next steps towards data interoperability from the SDI, standards and technology based context. Panelists spoke to possible solutions to issues identified in the RFI and CDS findings to date and based on their own lived experience and knowledge.

Panelists and Presentations:

- **Dave Blodgett: United States Geological Survey** - Environmental Linked Features and Observations.
- **Tom Kralidis: ECCC/Meteorological Service of Canada** - Canadian Weather Service SDI Perspectives.
- **Gordon Plunkett: Esri Canada** - SDI for Increased Data Interoperability for Cumulative Effects CDS.
- **Kathi Schleidt: DataCove.eu** - Lessons learned from INSPIRE, the European SDI

A.1.4. Part IV: Panel Response and Open Discussion (45 mins)

1. Panelists from Part II responded to one or more of the possibilities of the ideas and potential solutions presented by Part III panelists.
2. An open discussion period where the audience posed questions to the panel members and core project team regarding potential directions for solutions to data interoperability in an SDI environment.

Links to presenter slide decks are available at https://www.ogc.org/projects/initiatives/modernizingsdi

Appendix B: RFI Questions

The following appendix presents the forty questions contained within the RFI.

These questions were divided into eight categories deemed important to the direction of a modernized SDI. These eight categories were:

1. Stakeholders
2. SDIs and Data Architectures
3. Data for Regional Assessments/Cumulative Effects Analysis
4. Technology and Applications
5. Requirements
6. Usage Scenarios
7. Operation and Organization
8. Other Factors

Link to complete Request for Information: https://portal.ogc.org/files/92706

Stakeholders

1. What is your name, position and contact information?
2. What is the name of the primary organization with which you're affiliated?
3. Which of the following categories best describes your organization?
    - Federal/National government
    - Province/Territory/State (or equivalent sub-national entities)
    - Indigenous community or Inuit, Métis or First Nation
    - Private sector geospatial solution providers and consultants
    - Municipality or equivalent
    - Academic or research institutions
    - Non-governmental organization or advocacy group
    - Other (please state)?
4. Where does your organization operate (country, province, territory, state, region)?
5. Is your primary professional role within your organization a:
    - Scientist concerned with regional environmental assessments and cumulative effects analysis
    - Policy analyst concerned with environmental, climate or economic development policy
    - Geospatial data provider or owner (e.g. data, tools, applications, services)
    - Geospatial data user
    - Technical solutions provider (e.g. software, hardware, standards setting, tools, applications,

innovations, consulting)
    - Other (please state)?
6. Who are the key geospatial data and data standards stakeholders you interact with from local to international levels?
7. Who are the other organizations you routinely engage or collaborate with to access, share and or integrate data?

SDIs and Data Architectures

1. How aware are you/your organizations of Federal/National/Provincial/Territorial/State or other spatial data infrastructures available online today?
2. How significantly do you/your organization rely on spatial data infrastructures for data dissemination or data access?
3. How well does the Federal/National Spatial Data Infrastructure for your location meet your needs?
4. Does your organization currently contribute data and/or services to a Federal/National spatial data infrastructure? If so, please provide a brief description of how this is accomplished, and the scope of data provided.
5. Do spatial data infrastructure currently support your need to make available or access data related to environmental regional assessments and/or cumulative effects analysis?
6. Does your organization have a geospatial data management system? If so, please briefly describe the system's capability.
7. Are you/your organization familiar with OGC standards?
8. Do you currently use open geospatial standards to access data and services? If so, what are the key geospatial standards you use?

Data for Regional Assessments/Cumulative Effects Analysis

1. What data do you/your organization provide that could be included within a national spatial data infrastructure architecture to support regional assessments/cumulative effects analysis?
2. In what formats or by what means do you/your organization share or be most able to share this data?
3. Within the context of data typically utilized for cumulative effects analysis (both temporal and spatial), what current and/or emerging open international standards does you or your organization currently employ:
    - OGC Web Services
    - Geosemantics
    - OpenAPI
    - GeoPackage
    - Self-describing data
    - Other?

4. Do you/your organization release geospatial data that complies with a data standard, classification system or common schema? Please identify the standard, classification system or common schema.
5. What data sets do you use to support data-intensive analyses such as regional assessments or cumulative effects analysis? Are these data freely available through a spatial data infrastructure or other online platform?
6. More generally, are there any global, regional, national or local datasets that you rely on? If so, please list these datasets.
7. Is the data you require:
    - “analysis ready” or “fit for use”?
    - available in the formats you require?
    - updated in the time interval that meets your needs?
8. Are you/your organization able to locate and access all the necessary data required for a fulsome environmental regional assessment or for cumulative effects analyses?
9. What data sets should be more broadly or openly made available (as part of a spatial data infrastructure or other Internet platform) to support environment regional assessments or cumulative effects analysis?
10. Do you/your organization experience challenges when integrating geospatial data from two or more sources? If yes, please describe them.
11. Are data you have access to or need access to protected or otherwise not widely distributed? This could include limited or proprietary data vs. Open Data.

Technology and Applications

1. What current standards, technologies or tools are you/your organization using or considering using to integrate and analyze disparate geospatial data?
2. What emerging technologies and tools are you currently using or investigating. (e.g.: machine-learning/reasoning, data fabrics, data lakes, Blockchain, cloud services, or other evolving standards, technologies and tools).
3. How have these emerging technologies and tools aided you/your organization in improving data architecture, data access and data interoperability?
4. What do you/your organization perceive as the most serious challenge to data interoperability? How might this challenge be overcome?
5. What other types of applications, tools, and services do you believe should be developed or built upon?

Requirements

1. What requirements, (including constraints) do you experience that should be considered for future design and development of an (inter)national spatial data infrastructure architecture?
2. Are there sufficient tools available to help you meet your requirements? Please describe any performance issues you may experience. If so, what are the issues?

3. What privacy and/or confidentiality requirements or concerns are associated with the datasets you employ and/or the analytical results you generate?
4. Are there any Indigenous or First Nations Ownership, Control, Access and Possession (OCAP®) requirements associated with the datasets you employ and/or the analytical results you generate?
5. Are there any data licensing/rights requirements associated with the datasets you employ and/or the analytical results you generate?

Usage Scenarios

1. What scenarios and use cases would you like to recommend as part of future Cumulative Effects Pilot activities?

Operation and Organization

1. What policy, organizational, and administrative challenges do you have that must be addressed to improve a spatial data infrastructure architecture?
2. Are there unique needs that need to be considered at various levels of operations (local, state, regional, tribal, national, international levels, and by various players (government, commercial, NGO, academia/research)?

Other Factors

1. What other success factors or considerations do you see as needed for a successful National spatial data infrastructure architecture?

Appendix C: References

The following normative documents are referenced in this document. Only normative standards are referenced here, e.g. OGC and ISO Standards. All other references are listed in the bibliography.

- OGC 06-121r9, OGC® Web Services Common 2.0.0 Standard
- OGC 06-042, OpenGIS Web Map Service (WMS) 1.3.0 Implementation Specification
- OGC 09-025r2,OGC® Web Feature Service (WFS) 2.0.2 Interface Standard – With Corrigendum
- OGC 17-089r1,OGC® Web Coverage Service (WCS) Interface Standard - Core, version 2.1
- OGC 12-168r6,OGC® Catalogue Services 3.0 - General Model
- OGC ,OGC® Sensor Observation Service (SOS) 2.0 Interface Standard
- OGC 14-065, OGC® Web Processing Service (WPS) 2.0 Interface Standard

Appendix D: Terms and Definitions

For the purposes of this report, the definitions specified in Clause 4 of the OWS Common Implementation Standard OGC 06-121r9 shall apply. In addition, the following terms and abbreviations apply.

D.1. Abbreviated Terms

This clause gives a list of the abbreviated terms and the symbols necessary for understanding this document.

- API Application Programming Interface
- ASPRS American Society for Photogrammetry & Remote Sensing
- BIM Building Information Modeling
- BODC British Oceanographic Data Centre
- CAAS Communication as a Service
- CAD Computer-Aided Design
- CDS Concept Development Study
- CGDI Canadian Geospatial Data Infrastructure
- CGNDB Canadian Geographical Names Database
- CGSB Canadian General Standards Board
- COM Component Object Model
- CORBA Common Object Request Broker Architecture
- COTS Commercial Off The Shelf
- DCE Distributed Computing Environment
- DCOM Distributed Component Object Model
- IDL Interface Definition Language
- CSW Catalog Service for the Web
- DaaS Data as a Service
- DAP Data Access Protocol
- DAB Data Access Broker
- DCAT Data Catalog Vocabulary
- DOT Department of Transportation
- EO Earth Observation
- EOWCS Earth Observation Profile Web Coverage Service
- FGDC Federal Geographic Data Committee
- GEO Group on Earth Observation

- GEOINT Geospatial Intelligence
- GEOSS Global Earth Observation System of Systems
- GeoXACML Geospatial XACML
- GIS Geographic Information System
- GISS Geographic Information System Service
- GML Geography Markup Language
- HDF Hierarchical Data Format
- HTTP Hypertext Transfer Protocol
- IHO International Hydrographic Organization
- IIM Italian Hydrographic Institute
- InaaS Information as a Service
- IoT Internet of Things
- ISO International Organization for Standardization
- ICT Information and Communication Technology
- IT Information Technology
- JSON JavaScript Object Notation
- JSON-LD JSON Linked Data
- KML Keyhole Markup Language
- LINZ Land Information New Zealand
- NSDI National Spatial Data Infrastructure
- MOU Memorandum of Understanding
- NASA National Aeronautics and Space Administration
- netCDF network Common Data Form
- NGA National Geospatial-Intelligence Agency
- NGDA FGDC National Geospatial Data Assets
- NMA Norwegian Mapping Authority
- NOAA U.S. National Oceanic and Atmospheric Administration
- NRCan Natural Resources Canada
- OGC Open Geospatial Consortium
- OPeNDAP Open-source Project for a Network Data Access Protocol
- OSM OpenStreetMap
- PaaS Platform as a Service
- POI Points-of-interest
- RDF Resource Description Framework
- RFI Request For Information

- RFQ Request For Quotation
- SaaS Software as a Service
- SDI Spatial Data Infrastructure
- SDK Software Development Kit
- SDO Standards Developing Organization
- SOS Sensor Observation Service
- SPARQL SPARQL Protocol and RDF Query Language
- SWE Sensor Web Enablement
- SWG Standards Working Group
- UN-GGIM United Nations Committee of Experts on Global Geospatial Information Management
- U.S. United States
- USGS U.S. Geological Survey
- W3C World Wide Web Consortium
- WCPS Web Coverage Processing Service
- WCS Web Coverage Service
- WFS Web Feature Service
- WMS Web Map Service
- WMTS Web Map Tile Service
- WPS Web Processing Service
- WS Web Service
- WSDL Web Services Description Language
- WxS Web <whatever> Service
- XACML eXtensible Access Control Markup Language

Appendix E: Revision History

Table 3. Revision History

Date	Editor	Release	Primary clauses modified	Descriptions
July 8, 2020	R. Thomas	0.1	all	initial version
October 1, 2020	R. Thomas	0.6	all	comments integrate
December 2, 2020	R. Thomas	0.8	all	preparation for publication
February 27, 2021	R. Thomas	0.9	all	preparation for publication
March 5, 2021	R. Thomas & J. Lieberman	1.0	all	preparation for publication

Appendix F: Bibliography

[1] OGC/ISO, TC211: A Guide to the Role of Standards in Geospatial Information Management. Tech. rep . August. New York, NY, USA: OGC/ISO TC211, http://www.tandfonline.com/doi/abs/10.1080/17538940802439549 (2014).

[2] United Nations: Spatial Data Infrastructure (SDI) Manual for the Americas. Tech. rep. New York, NY, USA, https://unstats.un.org/unsd/geoinfo/rcc/docs/rcca10/E_Conf_103_14_PCIDEA_SDI%20Manual_ING_Final.pdf (2013).

[3] New Zealand Geospatial Office: Spatial Data Infrastructure Cookbook. v1.1. New Zealand Geospatial Office. ISBN: 9780473192181., http://gsdiassociation.org/images/publications/cookbooks/SDI_Cookbook_New_Zealand_v1-1_17Nov2011.pdf (2011).