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Open Geospatial Consortium

ENGINEERING REPORT FOR OGC DISASTER PILOT 2023

ENGINEERING REPORT

DRAFT

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I ABSTRACT

This OGC Disaster Pilot '23 (DP23) Engineering Report summarizes technical work done in the Pilot to increase drought and wildfires awareness among various disaster management stakeholders. Pilot participants implemented components of a data flow ecosystem to leverage analysis-ready earth observations and other datasets (ARD) and produce decision-ready indicators (DRI) according to collaboratively developed workflow recipes. DP23 focused on the hazards of drought, wildfires, and floods, the interactions and complications among them, as well as climate change scenario effects on hydropower production, in regions of Canada, United States, and Italy. The Pilot also prototyped providing information to field practitioners in secure package formats and leveraging linked data and structured web page information to optimize public web searches for disaster information.

II EXECUTIVE SUMMARY

For over 20 years, the Open Geospatial Consortium (OGC) has been working on the challenges of information sharing for emergency and disaster planning, management, and response. OGC Disaster Pilot 2023 is to improve the ability of key decision-makers and responders to discover, manage access, qualify, share, and explore location-based information in support of disaster preparedness and response.

A series of specific data workflows have been developed by the Disaster Pilot participants covering drought, wildfires, flooding, crop suitability, and integration of health and earth observation data for pandemic response. These data workflows will produce either Analysis Ready Datasets or Decision Ready Indicators, described in detail in the components below. Case Studies have focused on drought hazards in Manitoba, Canada, wildland fires in California, Arizona, and Fish Lake in Utah, and flooding in the Red River basin in Manitoba. Each workflow includes an introduction to the workflow and the risk or issues it aims to support, a description of the input data and area of study used, the processing and transformation undertaken, the output and results data produced, and the recommendations on the future progress and possibilities for developments. Participants have developed a series of data-specific workflows to generate either Analysis Ready Datasets (ARD) or Decision Ready Indicators (DRI) alongside several tools and applications to support the data discovery, collection, or visualization. Aside from this Engineering Report, three other reports were produced, namely Provider Readiness Guide, User Readiness Guide, and Operational Capacity Guide. Together, the Disaster Pilot 2023 can guide data analysts, disaster planners, first responders, managers, policy and decision-makers to help understand the methodologies, infrastructure, training, and support requirements that help disaster and emergency communities develop robust geospatial tools to support timely response.

Through the OGC Disasters Pilot 2023, the participants achieved hybrid applications-to-the-data EO cloud exploitation platforms that seamlessly bring analysis-ready imagery, in situ, social, economic, environmental, health, and other data streams into scalable cloud environments where advanced processing, modeling, and algorithms can be directly and flexibly applied to them. The OGC Disasters Pilot 2023 also provided immersive and interactive visualizations of 3D-4D disaster and related indicators in contextual environments that overcome conceptual and perceptual barriers to understanding disaster risks, vulnerabilities, and impacts, particularly over longer time scales.

III KEYWORDS

The following are keywords to be used by search engines and document catalogues.

Climate Change, Digital Twins, Disaster Resilience, Drought, Epidemic, Flood, Mudslide, Spatial Data Infrastructure, Wildfire

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1

SCOPE

1 SCOPE

This report summarizes the technical activities undertaken in the execution of Disaster Pilot 2023. These included:

1. stakeholder collaboration on drought and wildfire workflows data and decisions;
2. design of required readiness, resilience, and timeliness of data and processing to support disaster management;
3. design of required workflows for flexible and scalable deployments to support disaster responders in their daily and up-to-date tasks; and
4. publication of visualization tools to promote a better understanding of the spatial and temporal scales at which coordinated disaster management actions are required.

2

NORMATIVE REFERENCES

2 NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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3

INTRODUCTION

3 INTRODUCTION

Today, we have access to a wealth of geospatial data – from space, measured by temperature, pressure, or humidity sensors on the ground, reported by government agencies, or collected by a volunteer's cell phone. We also have a significant advancement in web technologies, AI, and cloud computing. Yet, bringing all this data together to make them useful to benefit livelihoods and communities has remained a significant challenge. The scientific objective of OGC's Disaster Pilot 2023 is to design the workflow standards for bridging the gap between analysis-ready data (ARD) and stakeholders, specifically for drought and wildfires. The workflows will couple ARD with effective organizational and personal collaboration and social, economic, and political contexts.

Additionally, the Pilot explores how standards of sharing geospatial data through web technologies and cloud computing by different centers' participants can be replicated for developing collaboration tools for drought and wildfire response in specific locations, such as the Province of Manitoba and California. The OGC Pilot 2023 envisions using standards for facilitating collaboration among the stakeholders regardless of the geographical location, usage of relevant data regardless of storage location, and disaster management regardless of scale and stage. Additionally, the OGC Pilot 2023 points out that collaborative and socioeconomic factors are as important as geospatial advancements to push the frontiers of integrated data into concrete and timely actions. OGC's Disaster Pilot 2023 supports https://sdgs.un.org/goals[the UN's global sustainable development goals of 2030], as well as the goals of the United Nations Office for Disaster Risk Reduction.

The Disaster Pilot includes the contribution of xx participants from yy organizations listed in Table 1 to develop, exercise, and evaluate the technical capabilities of drought and wildfire workflows (check if that is a correct statement/edit).

4

TERMS AND DEFINITIONS

4 TERMS AND DEFINITIONS

No terms and definitions are listed in this document.

5

ABBREVIATED TERMS

5 ABBREVIATED TERMS

ADES	Application Deployment and Execution Service
AI	Artificial Intelligence
AP	Application Package
API	Application Programming Interface
ARD	Analysis-Ready Datasets
AWS	Amazon Web Services
CDC	Centers for Disease Control and Prevention
CDI	Combined Drought Indicator
CKD	Chronic Kidney Disease
COPD	Chronic Obstructive Pulmonary Disease
CSW	Catalog Service for the Web
DRI	Decision-Ready Indicators
DWG	Domain Working Group
EDR	Environmental Data Retrieval
EMS	Exploitation Platform Management Service
FAO	Food and Agriculture Organization of the United Nations
FME	Feature Manipulation Engine
FPI	Fire Potential Index
GLTF	Graphics Library Transmission Format
GUI	Graphical user interface
ISO	International Organization for Standardization
MODIS	Moderate Resolution Imaging Spectroradiometer
MSC	Meteorological Service Canada
NASA	National Aeronautics and Space Administration

NDVI	Normalzied Differential Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
NRCan	Natural Resources Canada
OBJ	Wavefront Object File Format
OGC	Open Geospatial Consortium
OSINT	Open-Source Intelligence
PM2.5	Particulate Matter 2.5 micrometers or smaller
PTSD	Post Traumatic Stress Disorder
REST	Representational State Transfer
SARS-CoV-2	Sudden Acute Respiratory Syndrome Coronavirus 2
SDI	Spatial Data Infrastructure
SLD	Styled Layer Descriptor
SWG	Standards Working Group
UN	United Nations
USGS	United States Geological Survey
VR	Virtual Reality
WES	Web Enterprise Suite
WFS	Web Feature Service
WHO	World Health Organization
WMS	Web Map Service
WUI	Wildland-Urban Interfaces

6

COMPONENTS

6 COMPONENTS

Components below tool on droughts and wildlands fire analyses. The last component analyzed climate and its effect on energy. The following companies contributed to the components as follows:

Skymantics Europe developed an OGC API that processes the Route Exchange Model (REM) using a synthetic population to plan evacuation routes for those most vulnerable during a wildfire. This model coupled with the work of HSR.Health can complete the population vulnerability assignment. The results from Skymentics, HSR.Health, and Compusult companies are then used by clients such as Duality AI company to visualize the best wildland fire rescue routes.

Compusult used climate information, fire ignition sources, topography, and landscape fragmentation (such as vegetation and atmospheric and socioeconomic variables and wildfire-related CO2 emissions) to build an OGC API GDC to support wildfire risk indicators and visualization of the outputs by Duality AI.

ECERE used various AI approaches, such as the Random Forest classifier, to predict wildfire distribution and spread paths based on vegetation-type maps from imagery of Sentinel-2. ECERE also produced a fire danger index over high-resolution imagery of areas of interest, such as Red River, Manitoba.

USGS, with other Inter-American Collaborators, researched, defined, harvested, and designed ARD and DRI metadata such as geospatial, socio-political, and health data, as well as crowd-sources and citizen science data to enhance timely emergency response during wildfires and droughts.

HSR.Health also analyzed the vulnerable population in a drought-impacted area based on population demographic and health data to produce a Drought Health Risk Index.

RSS-Hydro provided timely deployable and scalable geospatial ARD data from satellites and models for daily water flow availability during drought. Additionally, it offered decision-ready indicators and citizen science observation data to achieve interoperable systems for drought emergency response in Manitoba.

Pixalytics, Safe Software, and UPEI provided applications, management, and visualization tools to show how geospatial data can support emergency and disaster communities. Pixalytics implemented and tested a drought workflow to create a Combined Drought Indicator (CDI) that used precipitation, soil moisture, and vegetation response to drought. Safe Softwater used climate projection data to show how future climate can impact health and drought. UPEI studies general requirements to ensure interoperability of the systems for drought severity and vulnerability analyses.

52°North produced crop suitability maps, summarizing information on whether the geographical areas' environmental conditions meet the long-term crop production requirements.

GISMO, in collaboration with Basil Labs and NRCan, provided a citizen science format and module to assist in developing the crowdsourcing aspect of drought emergency response for Manitoba for detecting the most vulnerable individuals.

For the data service workflow effort, Safe Software took climate model results and fed them to forecast and impact models related to the hazards of interest, such as drought, fire, or flood. This workflow transformed climate services data cubes (NetCDF) to a form of ARD (analysis-ready data), which is more easily consumable by GIS applications.

6.1. Wildland Fire Evacuation Indicator Workflow (by Skymantics Europe)

6.1.1. Introduction to the company and main activities

Skymantics Europe is a technology consulting company founded in 2015 that specializes in developing and prototyping new concepts in Artificial Intelligence, data analytics, and geospatial services. We serve the industries of transportation, natural resources, and Government, among others.

We are OGC members and have had previous experience relevant to the Disasters Pilot 2023, primarily supporting pilot initiatives and standards on routing applied to evacuations. We participated in the Smart City Interoperability Reference Architecture (2018), the Open Routing API pilot (2019), and the Disasters Pilot 2021.

6.1.2. Background and problem description

Emergency evacuation plans are a critical pillar in disaster preparedness. Regional emergency authorities manage and coordinate evacuation plans in population areas exposed to disasters such as wildfires. Plans must be consistently shared and updated among county and municipal authorities, supporting EMTs, traffic officers, first responders, and the general public. To ensure the smooth flow of the affected population using optimal routes, evacuations are usually organized in population blocks or neighborhoods. Evacuation warnings and orders are given per block, which is evacuated in a prioritized manner.

Evacuation priorities have much room for improvement. These are assigned based on distance to fire and shared knowledge about time to fire exposure and required time to evacuate. However, evacuations of large population groups are complex problems, as they depend on population demographics, road network capacity, and traffic management actions taken by police departments/sheriff offices. The average traffic speed will slow as traffic density builds from evacuating one or more population areas. Key transportation crossroads can become bottlenecks, completely blocking the traffic flow and creating the conditions for a catastrophic situation as a natural disaster is approaching.

If additional factors and forecast models are considered, priorities can be predicted and managed more accurately. Emergency managers require better predictive models on the population impacted by a wildfire, the timeline, and the impact's severity. In addition, knowledge of specific vulnerabilities and characteristics of population communities (e.g., mobility options, language, age demographics) is advantageous to applying extra resources or giving indications more efficiently during an evacuation.

6.1.3. Objectives and role in the pilot architecture

Skymantics proposes implementing and demonstrating the D109 Wildland Fire Evacuation Indicator Workflow to guide local/state authorities in planning and executing population evacuations during disasters that evolve in space and time, specifically wildfires. The objectives of this workflow are to:

- Generate evacuation priority indicators that take into account the population's vulnerability to fire and their time to evacuate
- Consider health risk indicators of the people in the area that are relevant in proximity to wildfire
- Enrich evacuation plans with population-specific indicators
- Publish evacuation indicators in a standard way for users to consume and visualize
- Have some basic interaction with users via web client to simulate agents in the field making updates to the environment

Within the pilot architecture, D109 has dependencies from D110 Wildland Fire Health Impact Indicator Workflow (implemented by fellow participant HSR.Health), which completes the vulnerability assignment to populations. The results are intended to be consumed by the D111 Wildland Fire and Drought Immersive Indicator Visualization component (implemented by fellow participant Duality) or by a standalone web client developed by Skymantics.

6.1.4. Methodology

6.1.4.1. Area of study

Three main technology areas have been applied in the implementation of the D109 Wildland Fire Evacuation Indicator Workflow:

Synthetic population: is synthetic data applied to the generation of population demographics. This emerging technology uses Artificial Intelligence (AI) models to create datasets of fictitious individuals and households statistically similar to the actual population in the study area. This shift from production to synthetic data removes privacy limitations and makes the dataset safe to share and publish. In addition, synthetic populations can be aged into the future, scaled, and extrapolated into new population segments to represent hypothetical test scenarios. Applied to disaster response, it generates a realistic population dataset that can be adapted for what-if scenario analysis and does not use Personal Identifiable Information (PII).

Routing: is the geospatial functionality to calculate transportation routes between pairs of points. Although most routing applications are used for navigation, the Skymantics routing engine is used for strategic route planning involving multiple origins and destinations. Evacuation planning is a specific use case of strategic route planning. This routing engine is built on an open-source pgRouting/page API stack, supports OGC standards, and consumes Open Street Map road data.

Geospatial standards: are used to implement web APIs and exchange models. More specifically, OGC API — Features and Processes and Route Exchange Model (REM) are used. Their adequacy is tested in this Pilot for data publication, process execution, and route publication.

6.1.4.2. Technical design

Figure 1 below shows the design of the D109 Wildland fire indicator workflow. It shows the stakeholders, data sources, workflow steps, and Decision Ready Indicators (DRI) generated.

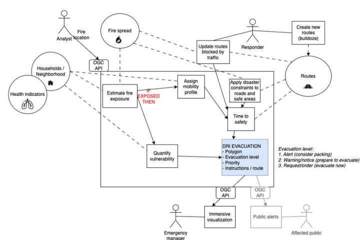

Figure 1 — D109 workflow diagram

Data sources

D109 consumes the following data sources:

Households/neighborhood data and health indicators. This synthetic data set represents the population of the Census areas (block groups in the U.S. and Census subdivisions in Canada — equivalent to neighborhoods). Figure 2 depicts the block groups for the Fish Lake, UT, area of interest. According to the Census, population attributes in a community are statistically representative of the demographics, socioeconomic status, and health conditions encountered in real life. In addition, health risk indicators have been computed by the D110 Wildland Fire Health Impact Indicator Workflow to assign a level of health vulnerability to each household in a neighborhood.

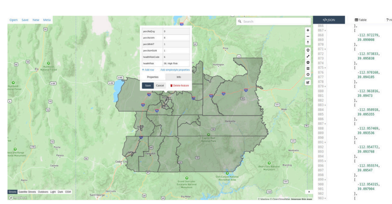

Figure 2 — D109 Selected block groups for the Fish Lake, UT area of interest

Fire spread. In this Pilot, no component generated a directional fire spread probability model according to terrain and weather parameters. The Fire danger indices historical data from the Copernicus Emergency Management Service was used as a substitute. This dataset has a spatial resolution of 0.25 x 0.25 degrees and a daily temporal resolution. The initial spread index combines the OK fuel moisture code and wind speed to indicate the expected rate of fire spread. This index is accepted as a good indicator of fire spread in open light fuel stands with wind speeds up to 40 km/h. Figure 3 depicts the fire spread index in the state of Utah.

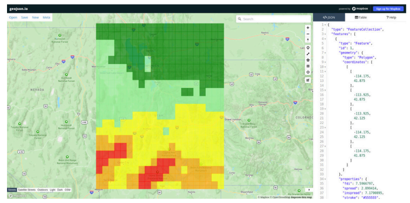

Figure 3 — Initial fire spread index for Utah (August 14h, 2023)

Routes The Open Street Map North America region implementation by Geofabrik was used to create the road network in the areas of interest. Each road segment has geographical attributes, road hierarchy, and a maximum capacity estimated based on an average speed, taken from the maximum speed of the road and the number of lanes of the road. Figure 4 shows the Open Street Map road layer and the center of gravity for the block group population used as points of origin.

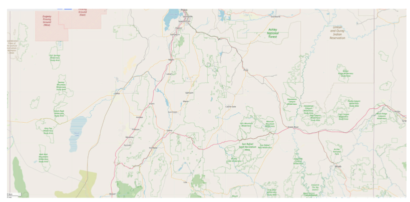

Figure 4-1

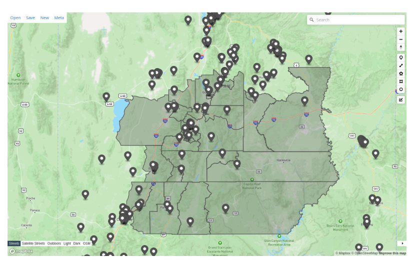

Figure 4-2

Figure 4 — Road layer and center of gravity of block groups

Stakeholders

The following stakeholders are defined as potential user personas with a role in the D109 workflow:

Emergency manager is in charge of preparing and coordinating emergency response resources and maintaining awareness of emergency situations and preparedness in the region. The emergency manager needs access to Decision Ready Indicators and potentially additional

Analysis Ready Data that can be findable, shared, and accessed via mobile, web, or desktop applications to assign emergency resources in a coordinated manner with other municipal and regional agencies. This Pilot also tests the D111 Wildland Fire and Drought Immersive Indicator Visualization component. **Affected public** live in areas impacted by wildland fires and requires information about evacuation levels, time deadlines, and special instructions. This population needs to understand their level of exposure and vulnerability and what actions they are expected to follow in line with evacuation plans in their area. Supporting this is not in the scope of this Pilot. **The analyst** has visibility over the source data, intermediary Analysis Ready Data (ARD), and software components that process data, generate results, and interoperate with other components for advanced indicator generation. Analysts can configure processing and computing parameters via desktop or cloud applications and validate that results are well-structured and functional. **Responder** is a field agent (firefighter, law enforcement, EMT, etc.) that uses mobile apps to interact with the workflow and provide observable inputs. These can be observations of new fires, blocked roads, newly created evacuation routes, levels of traffic, or other unexpected hazards. Responders in the field augment the data captured from EO and sensing.

Intermediary steps and Analysis Ready Data (ARD)

The analyst runs the workflow via OGC API by stating the initial fire location. The first step is the computation of fire exposure based on the fire location and spread probabilities mapped with the geographical distribution of the population in the area. As a result, the exposed neighborhoods are identified. These neighborhoods are characterized in terms of vulnerability based on a) the time to fire exposure and b) the aggregate statistics of the D110 wildfire health risk indicator defined and calculated for each household. A higher aggregate indicator value means higher vulnerability for the neighborhood.

Then, the evacuation time is calculated for each exposed neighborhood, taking into account the point of origin (gravity center of the population density), destination (either selected by the user or calculated automatically), and the mobility profile of each household. For this Pilot, mobility is given by the number of vehicles in the household. The evacuation of all households in the neighborhood is calculated based on the road network and considering road constraints due to traffic capacity limitations or road segments blocked due to proximity to fire.

A field responder can change the road network at any time. They can either mark a road segment as blocked due to an unforeseen hazard or create a new one with a default capacity (e.g., bulldozing a terrain to make it practicable for traffic).

The DRIs are then calculated based on the vulnerability of the exposed neighborhoods and the evacuation time. These DRIs are then exposed to the emergency manager via OGC API.

Decision Ready Indicators (DRI)

The following DRIs are published via OGC API and consumed by the Emergency Manager:

- Polygon representing the boundaries of the affected neighborhood.
- Evacuation level (alert, warning, or evacuation order) based on the time to exposure and required evacuation time.

- Evacuation priority. The areas under evacuation order are assigned priority based on the required evacuation time and the relative vulnerability.
- Evacuation route(s) to be followed by the population in the neighborhood.
- Special instructions for specific demographics or vulnerable populations in the neighborhood. In this Pilot, instructions may include additional transportation needed, the number of households requiring translators, the number of households with elderly people, and the estimated number of people with critical health conditions (Chronic Kidney Disease, Chronic Obstructive Pulmonary Disease, Asthma).

6.1.4.3. Technical or health implementation

Figure 5 below depicts the technical implementation of the D109 workflow.

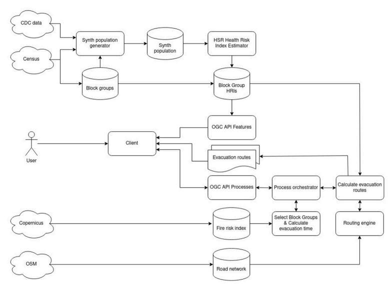

Figure 5 — D109 Technical implementation schema

All components are hosted in the Skymantics cloud environment. The data sources were previously processed offline and contained in the ARD components (block group HRIs, fire risk index, and road network). The block group collection, with the neighborhood's geographical, social, and economic information, can be accessed directly via an OGC API — Features instance.

The user can run the workflow via an OGC API — Process providing the information on the location of a firebreak. The API then calls a process orchestrator in the backend. Based on the fire risk and spread indexes downloaded from Copernicus, the orchestrator selects exposed block groups, calculates evacuation routes and DRIs by calling the Skymantics routing engine, and returns the results via the OGC API-Processes instance. Evacuation routes are stored in JSON files linked from the OGC API — -process results and can be downloaded by the client. Routes are encoded following the OGC Route Exchange Model (REM) standard.

Finally, users can access the results using their client or the Skymantics D109 client developed for this Pilot. This client simulates a web interface accessible to a field agent and has additional interactive features where the user can declare a fire, select destinatinos, block or add road segments before rerunning the workflow.

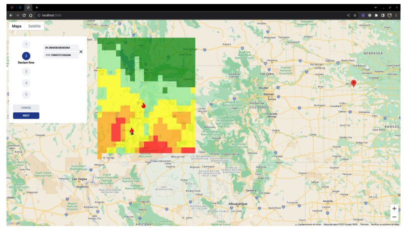

Figure 6 — D109 Web client

6.1.4.4. Scenarios

D109 workflow has been developed in this Pilot to support the following incremental scenarios:

Baseline scenario

The basic scenario represents the situation where a fire has been declared in one single location. The analyst runs the scenario in the affected region by indicating the fire location plus one or more evacuation destinations (selected by hand based on pre-known information on locations of reception centers or municipalities). As a result, evacuation DRIs are generated for the exposed neighborhoods.

Baseline scenario with automatically defined destinations

This scenario is similar to the baseline scenario, with the sole difference that the analyst has not stated the preferred evacuation destinations. Consequently, the D109 workflow will compute the evacuation DRIs based on the estimated most adequate locations to be used as destinations (defined as municipalities that are safe to access and located as far as possible from the fire).

Interactive scenario

This scenario runs as the baseline, with additional interactive features accessed via the Skymantics web client. Before running the scenario, the user (simulating actions from a field agent) can input two types of changes in the road network:

- Road blockages
- New road segments.

Inputs only take effect once the scenario is rerun.

6.1.5. Results

6.1.5.1. Challenges and lessons learned

The development of this pilot component has allowed for experiments with new data elements and the usage of standards for advanced evacuation scenarios. The following challenges have been encountered, which have exposed limitations and room for improvement in several aspects:

Inconsistency of population data sources.

Generating synthetic datasets requires a source of microdata or records directly gathered from a specific observation unit (like a survey sample) and anonymized. Microdata requires processing before it is ready for interpretation, but it preserves the attribute linkages between individual records that can be used to produce statistically similar synthetic datasets. On the other hand, aggregate statistics are ready for interpretation but are unidimensional and do not include correlations between the attributes of individual records, and thus can be only used as a supporting tool to generate distributions of attributes across single dimensions.

U.S. Census microdata proved adequate for generating synthetic datasets, including demographic and socioeconomic attributes of individuals and households. However, other data sources are only in the form of aggregate statistics:

- Health condition prevalence data from the CDC National Center of Health Statistics (NCHS) and National Center for Chronic Disease Prevention and Health Promotion (NCCDPHP)
- U.S. Census data from subdivisions smaller than Public Use Microdata Areas (PUMAs), i.e., Census Tracts and Block Groups.
- Canada Census data. Microdata was unavailable due to technical issues at the Statistics Canada site; only demographic statistics were available.

To solve these gaps, available microdata variables (e.g., age and gender) were used as keys to distribute the statistical variables among population groups. The generated results are consistent with public aggregate statistics. However, there is some loss of accuracy expected as not all affected variables are considered in developing these attributes. In the case of the Canadian Census, some population attributes needed to be included, and the U.S. Census microdata was used to distribute these variables.

Granularity of synthetic population

The granularity of the synthetic population refers to the geographical resolution used to generate groups of a statistically homogeneous population. An optimal granularity level was found at the ” neighborhood ” level (equivalent to Block Group in the U.S. Census as shown in Figure 7, and Census subdivision in the Canadian Census). Suppose the population community is generated at a larger scale (e.g., PUMA). In that case, it does not provide sufficient resolution to distribute inhabited nuclei compared to wildfire edge (i.e., too large an area would be affected). On the contrary, if the resolution is too high (e.g., at the level of a dwelling), we would be generating privacy-sensitive data, which, in addition, would be very likely fake in many aspects.

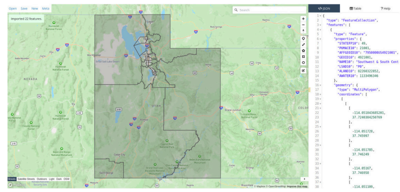

Figure 7-1 — Depiction of Census subdivisions for the state of Utah PUMAs

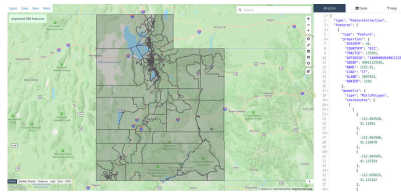

Figure 7-2 — Depiction of Census subdivisions for the state of Utah Census tracts

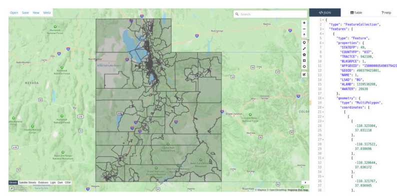

Figure 7-3 — Depiction of Census subdivisions for the state of Utah Block groups

Figure 7 — Depiction of Census subdivisions for the state of Utah.

Due to the limitation above on the unavailability of microdata at the neighborhood level, some inaccuracy has to be expected from this synthetic population. This can be mitigated with additional sources of demographic data curated by local authorities. These data sources are typically not available because they contain sensitive information. Creating a synthetic dataset from these sources can remove these privacy issues and prepare them for sharing and collaboration.

Another, more limiting constraint for the evacuation application is that the area surface is vast in rural neighborhoods. Thus, the geographical center of gravity of the population is likely far from many of the area's inhabitants. This center of gravity is used for the evacuation algorithms as the point of origin of the route. This leads to inaccurate evacuation risk and route calculations for a large share of the area's population. This can be mitigated using additional data layers representing population density distributions within the regions (e.g., Open Street Map dwelling layer).

Lack of fire spread and smoke models

A significant limitation to integrating the evacuation component in the overall DRI flow was the need for components computing:

1. Wildfire edge spread. Fire spread index from COPERNICUS satellite data has been used to compute directional spread speed. However, this model has low spatial resolution and does not incorporate wind attributes.

2. Smoke plume behavior. No smoke effects have been considered, which would considerably impact the population with asthma and COPD and the closure of road segments due to smoke.

The current model was deemed sufficient for the pilot; however, it would be strongly recommended to incorporate specific components that implement such models for future work. The evacuation component would, in turn, incorporate additional information to compute population vulnerability and road blockages more accurately.

Limitations of OGC standards

The publication of evacuation DRIs requires the nesting of properties. Each block group includes evacuation indicators and the list of evacuation routes, which, in turn, have their properties. The complex JSON schema to support this data structure is out of the intended use for OGC API — Features. For this reason, OGC API — Features are inadequate for this purpose, as it only supports nesting by default (unless an extension is used). However, the implementation was carried out with a workaround: OGC API — Features were used to publish collections of flat, static data (polygons representing neighborhoods with demographic information), and the more dynamic results would use other APIs. The clients could merge the results to show a uniform and consistent UI.

The functionalities of running the scenario and publishing dynamic information (indicators and routes) have been implemented in OGC API — Processes. It provides excellent flexibility and adaptability for cases such as this pilot.

Note that OGC API — Routes was not used for three reasons:

- First, the standard of the API is still in draft, as it is still going through substantial changes.
- Second, the intended use of OGC API — Routes needs to be aligned with the needs of this pilot. This pilot demonstrates a use case in which the generation of new routes, the core capability of OGC API — Routes, is kept from the API. Instead, evacuation routes are generated in the backend and managed by the orchestrator without the user's direct intervention. The only way OGC API — Routes could have been helpful for this pilot would have been by using the endpoint /routes/{routeId} once the route is communicated to the client by different means.
- Third, the functionality needed for this project can be provided more straightforwardly with direct links to the route GeoJSON files using the OGC Route Exchange Model format instead of deploying an additional API. As a suggestion for the Routes Standard Working Group, this pilot could be analyzed as a use case to consider adding functionality for OGC API — Routes to act as a repository of routes generated by a third party or an internal process.

Complexity of evacuation route calculations

Complexity of route calculations when using multiple factors. Human in the loop verifying results is still necessary—there is much room for improvement.

- Open street map data is limited

- In extreme situations, evacuating the population at the requested time could be impossible.
- You can not control the human factor (How much time it could take to start the evacuation). This is why you need a human to plan the evacuation. The application only gives the order and the time of each area.

Limitations of Open Street Map data:

Open Street Map datasets are complete and updated. However, the aspects of road speed are only partially captured. There is a large number of road segments that have limited speed limits assigned. Assigning speed limit values to parts is not straightforward since there are no clear separations between rural and urban areas. In addition, there may be local traffic limitations that are not captured. The speed limit is a critical metric since actual speeds and traffic capacity are based on it. Thus, the importance of this value is to be known and accurate.

This limitation can be mitigated by using Machine Learning models that assign estimated speed limit values to missing road segments based on road hierarchy, approximate boundaries of urban and rural areas, and other parameters.

6.1.5.2. Updates and applications

The short-term application that D109 can support would be a network of connected stations performing coordinated evacuation planning at emergency response control centers. Emergency responders could run evacuation scenarios with varying hypotheses, e.g., fire location, safe destinations, and variations in the road network. Analysts could also make changes in underlying assumptions such as population demographics and vulnerability and fire spread models and test the effectiveness of an evacuation plan under varying conditions of the environment.

In the longer term, it would be a critical improvement to involve agents in the field, and even citizens, to access the application via mobile devices and inform about hazards and environmental changes observed during the emergency. This process, if properly implemented and validated, would integrate invaluable data from the field into real-time monitoring of environment evolution. Information from field agents and citizens can complement EO and sensing data and improve the quality of Analysis Ready Data (ARD) used for evacuation planning.

6.1.6. Discussion and future developments

D109 implementation has achieved the Pilot objectives to generate DRIs for emergency responders to assist in evacuation planning and coordination in basic scenarios and limited areas of interest. Potential future developments and workflow improvements would include:

- Support the declaration of multiple fires and calculate compounded vulnerability for the population affected by one or several fire edges.
- Incorporate real-time fire spread models and smoke plume behavior. These features require micro-weather data such as wind, precipitation, and atmospheric pressure.

- Improve the algorithms to calculate route origins, especially for sizeable rural block groups. This could require partitioning these block groups into smaller subdivisions or using additional data layers to infer the population density in these areas.
- Support changes in the road segment capacity configuration per direction, e.g., to make all lanes available for one approach to increase traffic capacity.

6.2. Wildland Fire Health Indicator Workflow (by HSR.health)

6.2.1. Introduction to the company and main activities

Based in Rockville, Maryland, HSR.health is a geospatial data analytics company that specializes in utilizing geospatial technologies, health, social, and environmental data, AI techniques, and public health models to predict the spread and severity of disease — whether infectious, chronic, or social — and assist public health and emergency response decision makers mitigate disease spread and/or allocate resources to treat the affected. The tools and information provided by HSR.health improve overall global public health.

With the goal of striving for health equity and improving global public health, this pilot project is significant because, throughout the years, wildfire frequency, severity, intensity, and overall effects have increased, heavily impacting public health. This project aims to find potential solutions to this public health concern.

For the Wildland Fire Health Indicator Workflow component of the 2023 Disaster Pilot, we developed a Wildland Fire Health Risk Index that identifies a-priori (before the disaster occurs) the underlying health and social posture of the disaster-impacted population. The goal is to provide a useful indicator of where vulnerable populations are to inform resource and personnel allocation before, during, and after the response.

The Wildland Fire Health Risk Index aligns with our contribution to the Drought Health Indicator for this 2023 Disasters Pilot in addition to our Hurricane Health Risk Index (2019 DP, 2022 DP, and 2023 Federated Marine Spatial Data Infrastructure Pilot) and the Bioaccumulation Health Risk Index (2023 Federated Marine Spatial Data Infrastructure Pilot) in serving as a demonstrator over a year for industry use.

6.2.2. Background and problem description

Wildfire frequency, severity, and duration are increasing throughout the Western United States and around the world (WHO, 2023). Defined as an unplanned, unwanted fire in wildland areas, research has found that around 80% of wildfires are human-caused (Thomas et al., 2013). While mostly accidental and exacerbated by climate change, the effects on community health, the environment, and wildlife are substantial. Assessing and understanding the public health effects of wildfires can help develop potential preventative measures as well as mitigations to reduce those effects, and especially for the most vulnerable communities.

Health Effects of Wildfires

- Respiratory: The pollutants from wildfire smoke are a major public health concern for the Western United States. Exposure to contaminants, such as carbon monoxide, nitrogen dioxide, ozone, particulate matter 2.5 (PM2.5), polycyclic aromatic hydrocarbons (PAH's), and volatile organic compounds (VOC's) has been associated with poor health outcomes (WHO,2023). For example, a strong correlation exists between wildfire smoke and a decline in respiratory function (Rossiello & Szema, 2019). Due to this, wildfire smoke can cause illnesses such as, chronic obstructive pulmonary disease (COPD), acute bronchitis, pneumonia, worsening of asthma, and more.

- Cardiovascular: In addition to decreased respiratory function, prolonged exposure to pollutants from wildfire smoke can "trigger heart attacks and strokes'' (ALA, 2022). These damaging effects on the cardiovascular system have led to increases in premature mortality in fire prone areas. According to the American Heart Association (2023), research found that exposure to wildfire smoke also led to increased rates of ischemic heart disease, irregular heart rhythm, pulmonary embolism, and heart failure.

- COVID-19: COVID-19 is a highly infectious disease caused by the SARS-CoV-2 virus (WHO, 2023). Spread via respiratory droplets, this virus directly infects the cells of the upper and lower respiratory tract impacting lung function (Bohn et. al, 2020). Individuals with pre-existing conditions, such as asthma and COPD are at increased risk for severity and complications of disease (Bohn et. al, 2020). For at risk individuals, studies have found a link between increases in COVID-19 infection rates and in wildfires (Yu & Hsueh, 2022). With wildfires causing higher PM2.5 levels and many other pollutants to be released, the number of individuals with respiratory complications also increase. Studies found that the increase in respiratory complications also correlated with an increase in severe COVID-19 and mortality rates during peak fire season. (Harvard University School of Public Health, 2021).

- Direct/Immediate: For residents of fire prone areas and firefighters, there are immediate health effects. Burns, injuries, dehydration, eye irritation, and heatstroke are to name a few of the immediate health effects residents and firefighters experience (Xu et. al, 2020). In addition to the aforementioned health effects, loss of human life is also a major factor when dealing with wildfires.

- Mental Health: The damage from wildfires could potentially worsen the mental health for those already struggling with their mental health. In addition, rates of PTSD, anxiety, and depression are bound to increase exponentially post-wildfire (To et. al, 2021). Low-income individuals, disabled, those with previous mental health issues are the most vulnerable.

- Mobility: In the event of a natural disaster, individuals with mobility issues are the most vulnerable. With limited mobility, evacuating during a wildfire is challenging. This places individuals with mobility issues at increased risk for injuries, respiratory and cardiovascular issues, and premature death.

- Patients with electronic medical devices: During a wildfire or any natural disaster, patients that utilize electronic medical devices are extremely vulnerable. Evacuating can be challenging with electronic devices and in order to safely evacuate, medical equipment might be left behind.

6.2.3. Objectives and role in the pilot architecture

Our goal for this effort is to provide visibility and a demonstration of a predictive health-focused geospatial decision support application that fits into the disaster response workflow and ecosystem.

In addition, we aim to continue advancing our GeoMD Platform towards serving as a Health Data Retrieval API by the addition of an OGC API endpoint to further improve the accessibility of the data and geospatial insights stored on the Platform.

In collaboration with NASA, NOAA, NRCan, we are confident that this project will create a powerful new mechanism to inform the public, local residents, disaster response organizations, the public health community, state governments, and other appropriate communities of the health and social conditions on the ground a-priori to aid in their response to disaster scenarios.

6.2.4. Methodology

Wildland fires affect thousands of people every year in the United States. It is important to understand where vulnerable populations are in fire prone areas and in areas in the direct path of a current wildland fire. HSR.health is producing a health risk index that identifies the vulnerable populations by combining population demographic data and social factors with health conditions. This information can aid response and evacuation efforts by providing emergency response managers and first responders the necessary decision support guidance to assist with response efforts. To facilitate access to the health risk index we have built and leveraged our GeoMD Platform, a Multi-stack, Cloud-native, Health-focused Spatial Data Infrastructure (SDI).

6.2.4.1. Area of study

The Wildland Fire Health Risk Index is being produced for the Western U.S. states of California, Arizona, Utah, and Colorado, as identified by the sponsors.

6.2.4.2. Technical design

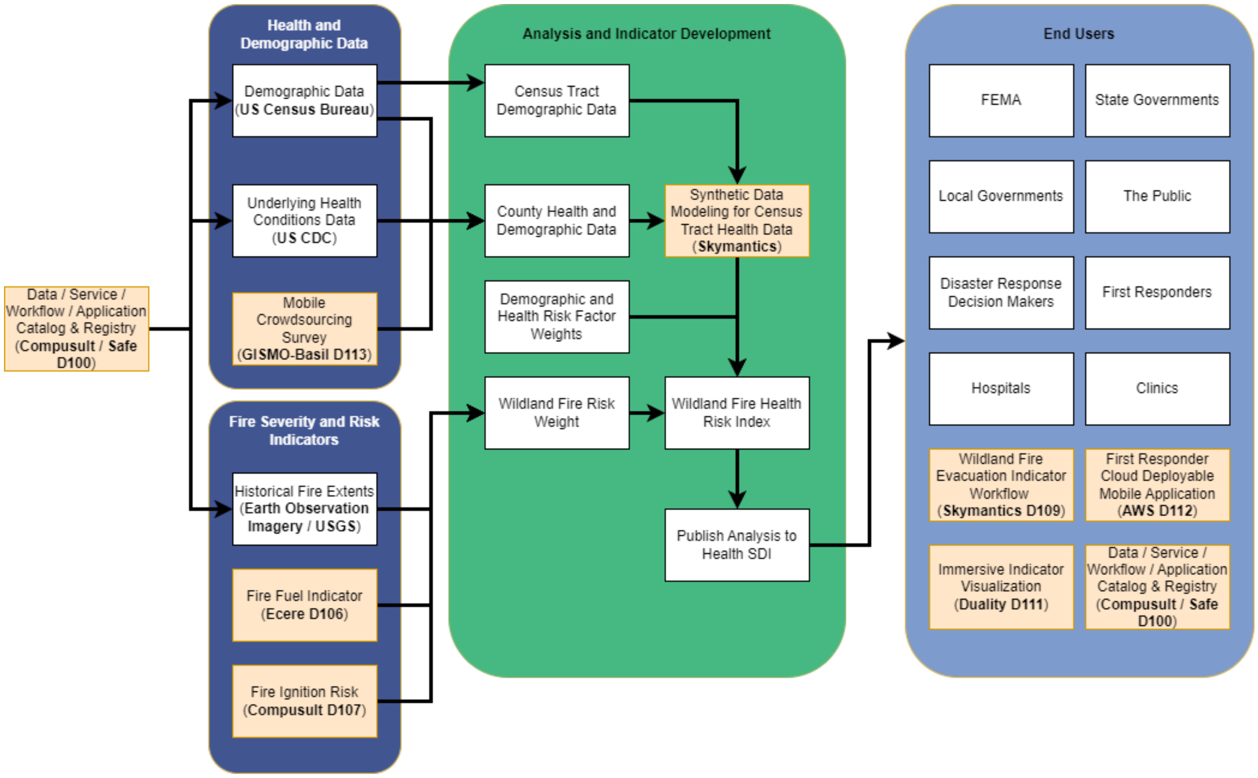

Figure 8 — Wildland Fire Health Indicator Workflow

Data Elements

The key data elements for this project include:

- Cancer prevalence
- People with a disability
- Persons over 65
- Under the age of 10
- Pregnant or breastfeeding women
- Those with chronic health conditions
  - COPD
  - Asthma
  - Dialysis dependent individuals
  - Chronic kidney disease

- House cost burden
- Unemployed
- Low-income
- Mobile homes
- Mo health insurance
- English fluency
- No vehicle
- No high school diploma
- No public transportation access

Datasets and/or data sources incorporated

- Population Characteristics — US Census Bureau
- Underlying Health Conditions — US Centers for Disease Control and Prevention
- Historical Wildland Fire Extents — USGS
- Ignition Risk — Compusult
- Fire Fuel Indicator — Ecere

Solution Architecture

The Wildland Fire Health Risk Index and associated data is published as a data layer and available to stakeholders and fellow pilot participants through our GeoMD Platform. In addition, the Risk Index is made available through the OGC API, and WMS, and WFS data standards over other spatial data infrastructures and data catalogs made available through the pilot.

A dashboard has also been created for the indicator as well. Data sources leveraged for the Wildland Fire Health Risk Index as defined below. HSR.*health* collaborated with Skymantics, Ecere, Compusult, and GISMO-Basil Labs to demonstrate our ability to ingest and analyze data provided by 3rd party sources as input to our workflow. We will collaborate with AWS and Duality who will ingest the output from our risk index. Finally, we collaborated with Compusult and Safe to explore and demonstrate interoperability between the data catalog that they are developing for the pilot and the GeoMD Platform.

6.2.4.3. Technical or health implementation

The persistent demonstrator for the Wildland Fire Health Risk Index is published on HSR_.health_'s Open GeoMD Platform (https://opengeomd.hsrhealthanalytics.org/) and GeoMD Platform (https://geomd.hsrhealthanalytics.org/), which is deployed in the AWS Cloud through both an Esri ArcGIS Enterprise Stack and a Geonode & Geoserver Open Source Stack, as well as through the Compusult catalog made available through the pilot. The data is made available through OGC API (http://opengeomdapi.hsrhealthanalytics.org/), WMS, and WFS data formats and standards. Stakeholders and pilot participants can access the layer through the GeoMD Platform. The Risk Index was made available to AWS and Duality for incorporation into their mobile application and digital twin application respectively. In addition, we collaborated with Compusult and Safe to explore and demonstrate interoperability between their data catalogs and our Health SDI.

6.2.4.4. Scenarios

The Wildland Fire Health Risk Index was produced for the Western U.S. states of California, Arizona, Utah, and Colorado, as identified by the sponsors. The risk assessment is a current snapshot of risk based on the time the work was performed. Efforts to make the Risk Index dynamic and/or applicable to real-time updates should also be explored in future work — to greatly improve its applicability during emergency response scenarios.

6.2.5. Results

The Wildland Fire Health Risk Indicator layers can be accessed from the following links:

- Open GeoMD Wildland Fire Health Risk Index Layer- https://opengeomd.hsrhealthanalytics.org/catalogue/#/dataset/42
- GeoMD Wildland Fire Health Risk Index Dashboard — https://hsr.maps.arcgis.com/apps/dashboards/f784815ac4de42b291d82a911ff88324

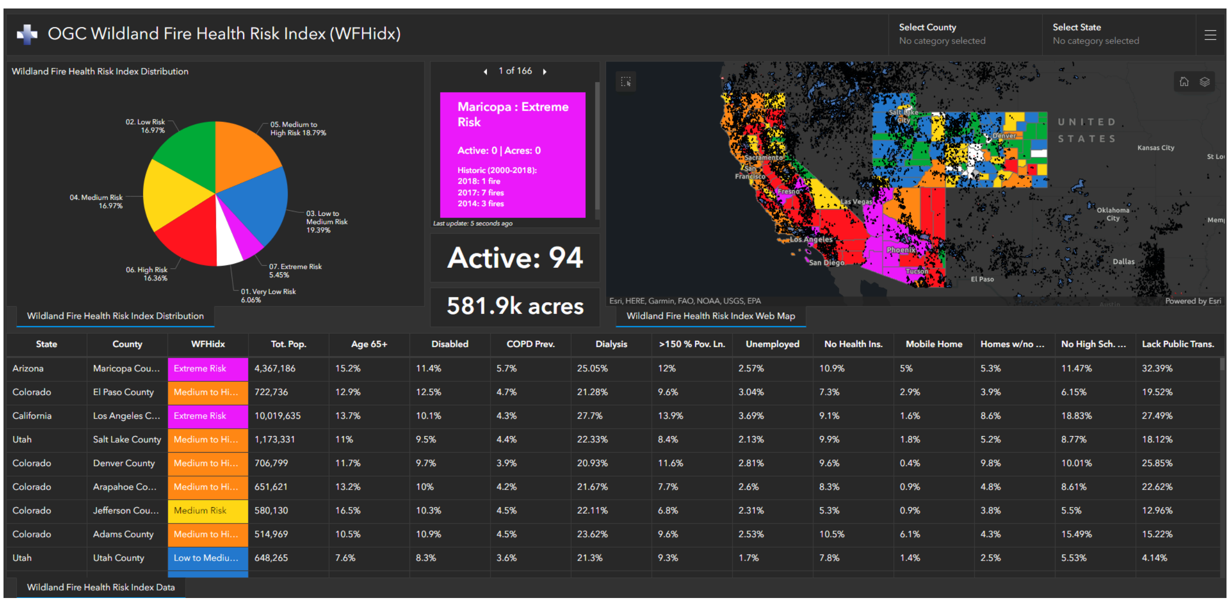

Figure 9 — GeoMD Platform Wildland Fire Health Risk Index Persistent Demonstrator Dashboard

6.2.5.1. Challenges and lessons learned

From the research performed, more data on the most vulnerable populations is needed. While studies were able to identify the health effects of wildfires, study participants would not be grouped in any of the key indicators. It does not provide a full account on the effects wildfires have on fire-prone communities.

6.2.5.2. Updates and applications

Stakeholders for this effort include emergency response managers, first responders, local governments, national governments, and state governments as they are all incentivized to gather and share data and decision support analytics to inform emergency response efforts and speed relief efforts to impacted communities.

6.2.6. Discussion and future developments

Future work to continue to study the vulnerable populations in wildland fire scenarios will allow for the further refinement of the wildland fire health risk index. * *Additionally, in future pilot efforts, we aim to expand the temporal scale of the wildland fire health risk index and incorporate predicted changes due to climate change to create a forward-lookingforward looking health risk index.

6.3. Data — Service — Workflow — Application Catalog and Registry; Wildland Fire Ignition Risk Indicator Workflow (by Compusult)

6.3.1. Introduction to the company and main activities

Compusult, incorporated in 1985, is a diversified information technology company with over 38 years of software development experience and a leading provider of geospatial software solutions. Compusult markets computer software, hardware, and consulting services internationally to government, military, business, technical, and scientific sectors.

Compusult operates from its head office in Mount Pearl, Newfoundland and Labrador, Canada, with a Canadian branch office in Halifax, Nova Scotia, and staff in Ottawa, Ontario. Our European office, Compusult Europe B.V., is in The Hague, The Netherlands. Compusult also operates a U.S. subsidiary, Compusult Systems Incorporated (CSI), in Chantilly, Virginia. CSI provides systems integration, training, and software support to Compusult U.S. military clients through experienced, security-cleared personnel. In addition to providing specialized, on-the-ground support, CSI provides direct support to civilian U.S. customers.

Our innovative products and services include:

- Geospatial Data Discovery and Management Systems
- Mobile Applications/Services
- Asset & Item Tracking / Inventory Control
- Custom and Commercial Software and Electronics
- Assistive Technology for Persons with Disabilities This project is important to us as it allows us to advance our flagship product, Web Enterprise Suite (WES). WES components are based on the Open Geospatial Consortium (OGC) / International Organization for Standardization (ISO) and other interoperability specifications. They comply with many commercial/open-source tools and products and allow seamless connections to the ever-expanding world of geospatial data sources and services. Compusult is a long-standing member of the Open Geospatial Consortium (OGC) that assisted in pioneering specifications like the Web Map Service (WMS), Catalog Service for the Web (CSW), GeoPackage, etc.

Throughout this project, Compusult's WES software will provide a comprehensive viewing environment where OGC APIs have been added to allow an interface to query the catalog, obtain the results, and display the results in complete 2D and 3D viewing environments.

Compusult has been significantly investing in using the OGC API Processes to support the chaining of modules and capabilities to support the analysis of geospatial data and the generation of products that provide insight into climate change and resilience.

6.3.2. Background and problem description

This project requires a central catalog to allow all participants to register and later discover services and data that can be used in workflows. WES Catalog is an OGC-based integrated services registry/catalog and repository. The application provides comprehensive, standards-based catalog creation and management modules, enabling data and service discovery, publishing, access, and maintenance. WES Catalog was initially implemented using the OGC Catalog Service for the Web (CSW) standard. It was upgraded through this OGC Pilot to support the new OGC draft specification OGC API — Records. Backward compatibility has been maintained so clients supporting CSW can still interact with the REST service.

Compusult will provide an instantiation of our SCOTS software product, WES, with updates to comply with the OGC API Process used in the workflows generated by participants.

The Web Enterprise Suite client has been enhanced to provide visualization in both 2D and 3D of the following OGC API standards:

- OGC API Features

- OGC API Coverages
- OGC API Processes
- OGC API EDR Compusult uses OGC API Processes and Coverages with Data Cubes in this project to build a prediction model for Wildland Fire Ignition Risk.

Using Compusult's Web Enterprise Suite (WES), accompanied by open-source components, we created a workflow or "portfolio" for Fish Lake, Utah.

Each portfolio will have information and data common to the area, for example, NOAA World GRIB data.

6.3.3. Objectives and role in the pilot architecture

The OGC Disasters Resilience Pilot 2023 focused on the Decision Workflow Collaboration and Realization: Hybrid applications-to-the-data EO cloud exploitation platforms that seamlessly bring analysis-ready imagery, in situ, social, economic, environmental, health, and other data streams into scalable cloud environments where advanced processing, modeling, and algorithms can be directly and flexibly applied to them. Immersive visualization of Key Indicators in Time, Space, and What-If Scenarios: Immersive and interactive visualizations of 3D-4D disaster and related indicators in contextual environments that overcome conceptual and perceptual barriers to understanding disaster risks, vulnerabilities, and impacts, particularly over longer time scales.

Compusult has enhanced its SCOTS software product, WES, through the Disasters Pilot with updates to support OGC API Records and Products. Along with the current OGC API support in WES, this interface will allow participants to register, search, discover, and visualize the data and workflows.

Using OGC API Processes, GDC, and Coverages, Compusult will provide a workflow where users can assess the fire risk in an AOI specific to the scenario defined. Increased temperatures alone do not necessarily mean more fires will occur; several other climatic and non-climatic factors are also involved, such as ignition sources, fuel loads, vegetation characteristics, rainfall, humidity, wind, topography, and landscape fragmentation.

Users will submit a request to the service with an Area of Interest and time frame to be analyzed for fire ignition risk. Taking those input parameters along with the following, the risk factor will be determined:

- climate information;
- fire ignition sources;
- topography; and
- landscape fragmentation.

6.3.4. Methodology

Compusult has enhanced WES through this testbed to provide access to Geo Data Cubes. Compusult has built an OGC API GDC to support the following models:

- Wild Fire Risk Indicator Each OGC API Processing service will use OGC API coverages, features, and maps to provide output to the user.

Compusult can also ingest data from various sources, store it locally in Geo Data Cubes, Postgres databases, NetCDF, and other formats, and make it available as OGC API Features, EDR, Coverages, Map or Processes.

Our team will deliver a demonstration in several ways. We will:

- use OGC standards to support the visualization of outputs using, in particular, OGC API Processes, Coverages, and Features;
- use our latest capabilities associated with Cesium 3D display of results from OGC APIs to the greatest extent possible and
- provide results from experimentation using Data Cubes. The Fire Potential Index (FPI) is a model of fire ignition risk based on relative greenness, temperature, relative humidity, and land cover classes, created by members of the United States Geological Survey in 2000. This modified version removes the fuel model. FPI calculates the maximum live vegetation ratio by using the Normalized Differential Vegetation Index (NDVI). The average NDVI during a timeframe is used to calculate the relative greenness of the area. Using temperature, relative humidity, and equilibrium moisture constant, it calculates the 10-hour time lag fuel moisture. Areas with non-flammable land cover classifications are removed from the dataset. Finally, the 10-hour time lag fuel moisture, relative greenness, and maximum live vegetation ratio are used to calculate the Fire Potential Index.

The analysis is based on many variables, including:

- atmospheric and climatological variables;
- vegetation variables;
- socioeconomic and the target variables related to wildfires, such as:
  - burned areas;
  - fire radiative power, and
  - wildfire-related CO_2 emissions. Output formats of the process can either be a .zarr file containing integration-ready data of the Fire Potential Index values for the desired geographical locations and time frame or a .png image of the integration-ready data values, color-coded from red to blue to signify high-risk to low-risk fire ignition.

The catalog will be enhanced to support OGC API Records while maintaining backward compatibility with OGC CSW.

The catalog will also be enhanced with a workflow to support OGC API Process workflows built by the pilot participants.

6.3.4.1. Area of Study

Our area of study was Fish Lake, Utah.

6.3.4.2. Technical design

The processing service will reach into the data cube and extract data from the following drivers:

- Normalized Difference Vegetation Index (NDVI)
- soil moisture
- relative humidity
- wind speed
- Temperature
- precipitation Using this data will determine the fire risk in the selected area at the given time.

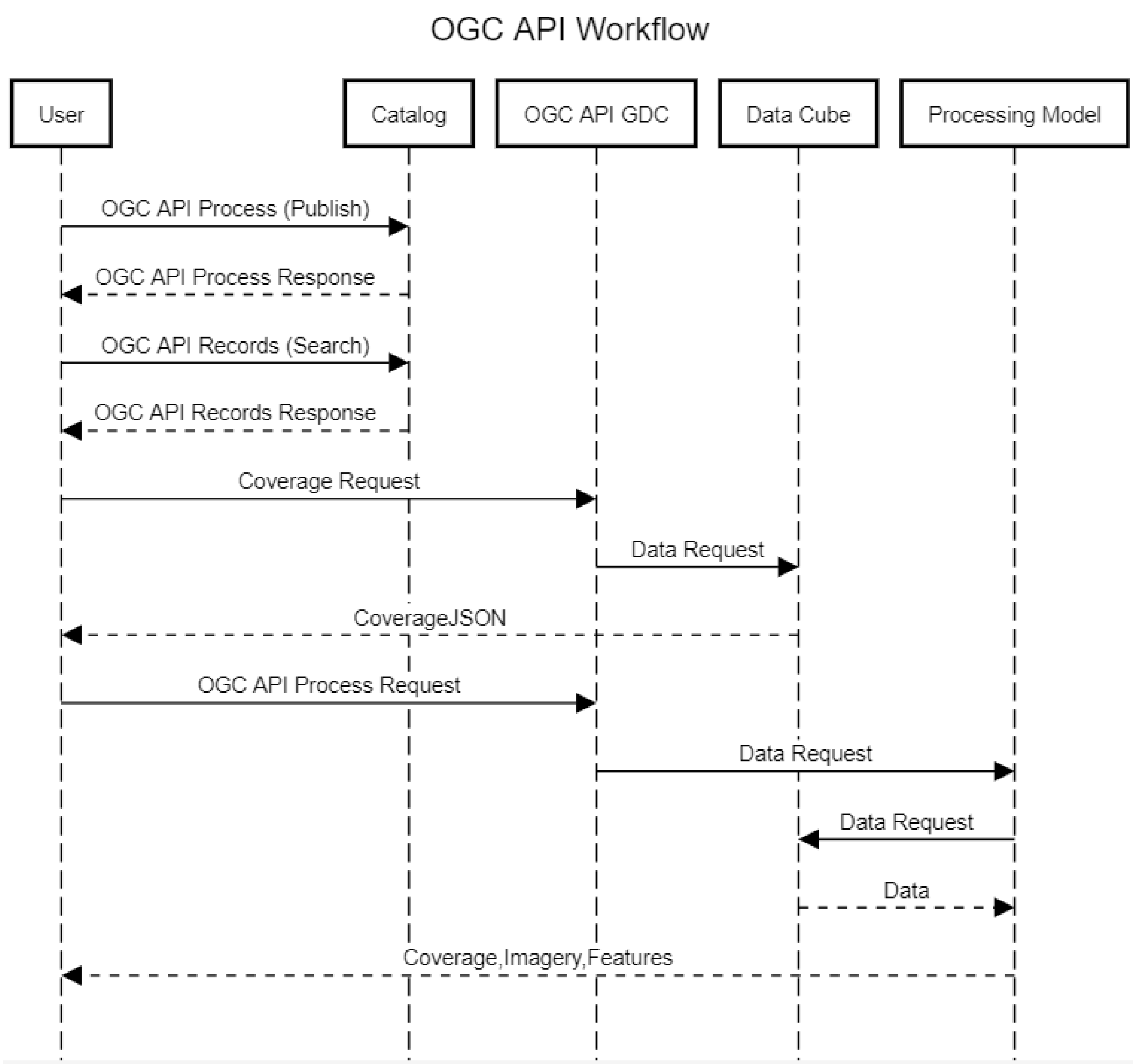

Figure 10 — Compusult OGC API Workflow

6.3.4.3. Technical or health implementation

In the image below, the overall architecture of the project is shown.

Open-source data is harvested from the internet and transformed into Geo Data Cubes. The data cubes are published to the WES Catalog, providing relevant OGC API services for Processes, Coverages, and Features.

SeasFire cube (2022): a global dataset for seasonal fire modeling in the earth system containing:

- 21 years of data (2001-2021) in an 8-days time resolution and 0.25 degrees grid resolution;

- a diverse range of seasonal fire drivers;
- atmospheric and climatological variables;
- vegetation and socioeconomic variables, and
- other target variables include burned areas, fire radiative power, and wildfire-related CO_2 emissions. The OGC API Process services run against the data cubes, take the user's input, and return a unique service of the desired service type. The services will return with OGC API Coverages or OGC API Maps for viewing in the 2D or 3D visualization client.

If applicable, the Geo Data Cube will have services available for visualization that do not require processing; that is, the native data from the cube can be displayed in various OGC formats.

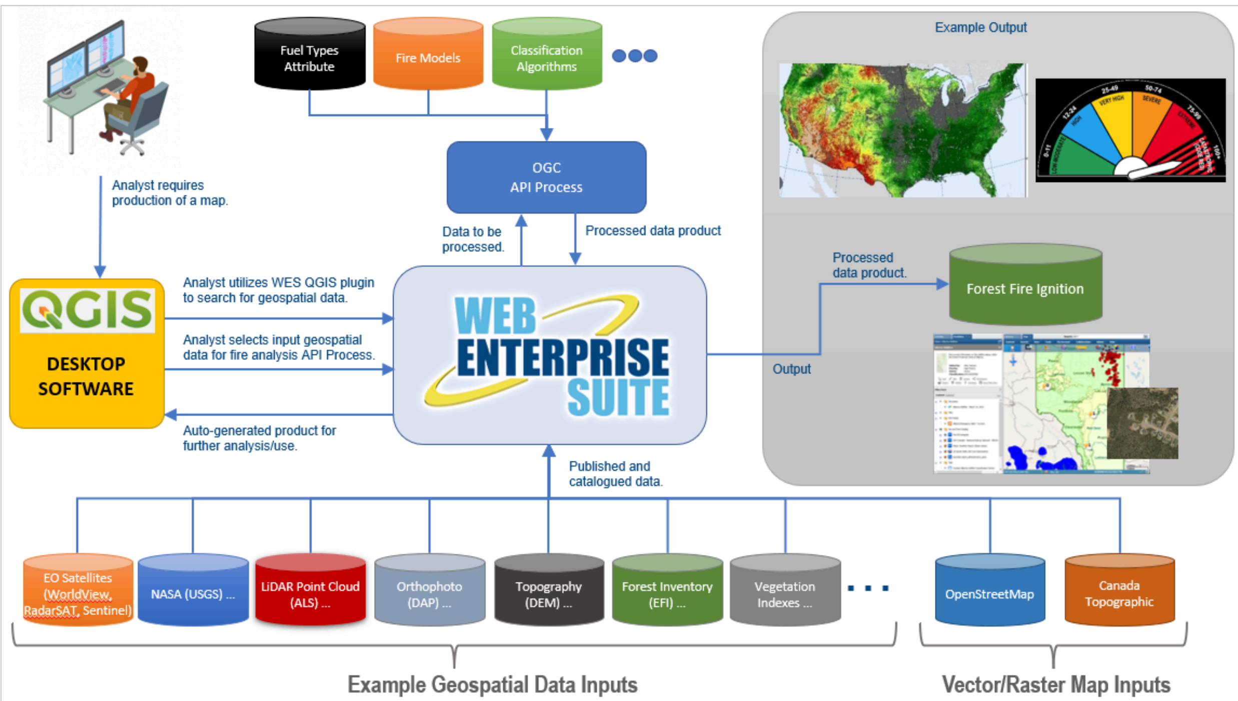

Figure 11 — Compusult WES Workflow

To execute an OGC API process, a user would discover the service in the catalog, provide the inputs as requested by the interface, and visualize the output. The data's location, processing knowledge, and structure are hidden from the user.

6.3.4.4. Scenarios

Compusult will provide a demonstration using portfolios. In WES, workflows are managed by creating an associated WES Portfolio. WES Portfolios provide the ability to work, organize, and track information and content associated with incidents and events an organization is supporting. The WES Portfolio component has been optimized to support the display and management of Common Operating Pictures (COPs) and create situational views that organize and visualize content from disparate data sources and applications for a particular area of interest or topic.

The scenario data will be organized through portfolios to allow easy and intuitive selection for visual display and process execution. The demonstration and video will touch on how the content is discovered in the catalog and added to the scenario.

Our scenario will show the progression of the Fire Potential Index (FPI) leading up to the fire that first started on August 4, 2023. This will be done by running the OGC API Processing service to show the FPI at 8, 6, 4, and 2-week intervals before the fire. Also, the workflow will exercise the temporal aspect of the OGC API Coverages services to show the changes in the following variables over that same timeframe;

- Normalized Difference Vegetation Index (NDVI)
- soil moisture
- relative humidity
- wind speed
- temperature

In addition to visualization of the FPI-related coverages and processes, the workflow will include data over the area, such as road networks, structures, fire perimeters, and containment zones.

Compusult will produce the fire perimeters and containment zones using our GO Mobile product and OGC GeoPackages.

Where applicable, the workflow will also be shown in our 3D client.

6.3.5. Results

These OGC API Process services could help plan, edit, and administer responses to an ongoing climate emergency, such as a fire.

Emphasizes the importance of fuel-related variables, which should be combined with meteorological drivers to assess the likelihood of significant fire events.

The Compusult deliverables will enhance the situational awareness and common operating picture used by disaster response and resilience teams.

The Compusult video will show how users can find the data and services and create a digital twin of a fire risk area.

SWG and DWG communities can use the deliverables to help enhance and test the interoperability between OGC standards, including;

- OGC API Records;
- OGC API Processes; and

- OGC API Coverages.

6.3.5.1. Challenges and lessons learned

3D Visualization implementation of services does not have well-defined styles and needs to be supported by any OGC or other relevant standard without breaking conformance. This was addressed by looking at various metadata and holding local models for OGC Features API, although similar issues exist for OGC Coverages, etc. This issue is fundamental to any 3D application and should be raised to the OGC API Styles SWG. A new style format specific to 3D is required, or an extension to the SLD specification to accommodate various 3D data models (gLTF, Obj, etc.)

Certain coverages return massive amounts of data. This can lead to long network request times that can reduce user experience. There are multiple ways around this, each of which has its drawbacks. Requesting the entire dataset initially allows for a more seamless user experience at the cost of load times. Asking small amounts of data at lower resolutions can have similar benefits to performance but come at the expense of many requests, leading to scalability issues in the form of high server costs. Caching specific requests is also an option implemented, but this still leads to a first request duration that is longer than preferred.

6.3.5.2. Updates and applications

Compusults catalog with the support OGC API records and processes to allow external users to have access to register, search, and discover products and services.

This project has improved access and sharing of data and services and provided easy-to-use GUI and REST interfaces to publish, discover, and use data services using standards-based APIs for interoperability.

6.3.6. Discussion and future developments

Compusult would like to implement coverage tiles and other means of sampling and scaling coverage data. Currently, coverages have a significant overhead, especially when accessing coverage data from GeoDataCube or other large repositories. Overall, performance could be better. With a growing emphasis on 3D visualization, the combined computational expense is significant. Tackling these performance issues to determine a viable option for handling and delivering coverage data is crucial for usability for both 2D and 3D clients.

Compusult would like to develop this workflow further to chain together the many OGC API Processes written by other participants. For example, combining the processes such that output from one is input to another. Compusults Fire Risk Indicator could be enhanced to take the vegetation fuel types, drought severity, and water supply as inputs.

Another missing piece to the OGC APIs is 3D Styling. Currently, none of the specs cover styling requirements for coverages or other APIs, including many types of process responses. Many of these are now using 2D styling, which makes specific tasks inefficient and others impossible. Styling is an essential factor for 3D visualization moving forward.

The SeasFire data cube combines many datasets, primarily provided by Copernicus and NASA MODIS. Compusult used this as a basis for the dataset, extending it with updated data for variables used to calculate fire risk.

6.4. Wildland Fire Immersive Indicator Visualization Workflow (by Duality AI)

6.4.1. Introduction to the company and main activities

Duality AI was founded in the fall of 2018 to solve a complex simulation challenge: how to accurately simulate complex environmental scenarios and use them to gain insights via real-time responses from sensors and machines. The result of this work became Falcon, Duality's digital twin platform, which today helps customers such as Honeywell, P&G, NASA-JPL, and DARPA to create data permeability between the physical and virtual worlds. This is achieved by providing end-to-end enterprise workflows with accurate, modular simulation and high-fidelity visualization for diverse operational scenarios.

Today, organizations are leveraging Falcon to help solve complex engineering problems. By bringing accurate digital twins of environments and operating systems into Falcon, Duality's customers generate high-fidelity data and predictive behavior modeling that enables them to deploy smart systems robustly and at scale. Primary use cases include helping robotics teams streamline the design and validation of their autonomy software and closing behavior and data gaps for AI teams.

Falcon's powerful capabilities enable teams to:

- Acquire and manage simulation-ready digital twins of their real-world assets: relevant environments, dynamic systems, and associated objects.
- Leverage high-fidelity, GIS-based environments for aerial, ground-based, and marine applications.
- Quickly build and customize modular scenarios.
- Run real-time, physics-accurate, deterministic simulation of complex real-world scenarios on massive scales with vast numbers of machines and agents.
- Control every part of any simulation, even at runtime, with a flexible Python API.
- Integrate most autonomy software, AI pipelines, and CI/CD processes.
- Generate accurate behavior and high-fidelity sensor data with a library of configurable simulation-ready sensors.

- Simulate in the cloud and collaborate globally with internal and external partners without computing resource limitations.

Duality's multidisciplinary team includes world-class engineers, simulation specialists, AI/ML experts, and award-winning technical artists with over 70 patents across robotics, simulation, and visualization. Duality AI is headquartered in San Mateo, California.

6.4.2. Background and problem description

As per EPA (United States Environmental Protection Agency), the extent of area burned by wildfires yearly appears to have increased since the 1980s. According to National Interagency Fire Center (USA) data of the 10 years with the most extensive acreage burned, all have occurred since 2004, including the peak year in 2015. Nationwide data compiled by the National Interagency Coordination Center (NICC, USA) indicate since 2000, an annual average of 70,025 wildfires have burned a yearly average of 7.0 million acres. The figure is more than double the average yearly acreage burned in the 1990s (3.3 million acres).

Many federal and state agencies, tribes, local land managers, and other stakeholders get involved and work together to manage wildland fires. Training, planning, and managing resources before, during, and after wildland fires are critical aspects of the strategies to combat wildland fires. The availability of past, real-time, and near-time data, their immersive visualization, and the simulation of various possible scenarios can immensely help various stakeholders and decision-makers.

The enterprise metaverse composed of digital twins promises to solve real-world problems through immersive visualization, collaboration, and training; synthetic data generation; and closed-loop simulation of complex systems and processes such as route planning for disaster evacuation.

The true power of this enterprise metaverse is unlocked by allowing different physical resource managers and data providers, including government agencies, companies, and research teams, to share virtual counterparts of their physical assets and decision-ready indicators (DRIs) in a structured and synchronous way within scenarios of interest. Duality's Falcon has been architected with exactly these kinds of multi-DT and multi-participant workflows in mind.

6.4.3. Objectives and role in the pilot architecture

While scenario makeup, their functional needs and data objectives can vary widely. A shared digital twin catalog and the Falcon workflow combine these modular and reusable pieces in diverse ways to achieve various goals.

Some illustrative examples:

- Immersive visualization for planners and command centers
- What-if analysis over short and long horizons to evaluate competing strategies

- Testing end-to-end deployment of workflows and disaster response that combine autonomous, semi-autonomous, and human-operated systems
- Synthetic data to train AI-ML models for satellite and aerial infrastructure monitoring
- Immersively training first responders
- Educating the community at large by accurately turning data sources into accessible and visceral visual media

Our goal is to create a digital Site Twin of the area of interest (with an area of around 8400 square km) and overlay it with decision-ready indicators (DRIs) generated by our fellow participants from Skymantics, HSR.Health and Compusult. We would demonstrate how immersive visualization coupled with intuitive user interface and navigation can help planners access and act on the data from various sources.

6.4.4. Methodology

6.4.4.1. Area of Study

For this pilot, we have selected around 8,400 square km of area near Fish Lake, Utah.

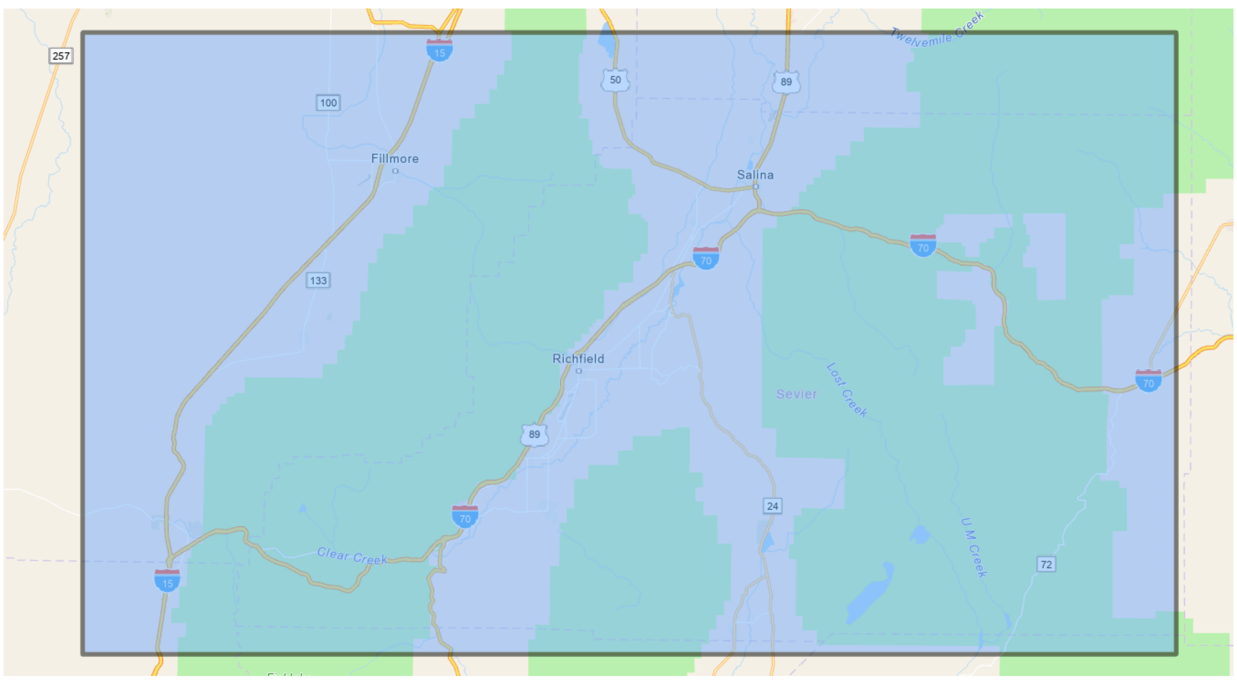

Figure 12 — Area of Interest (Fish Lake, Utah).

6.4.4.2. Technical design

For the OGC Wildland Fire Disaster Pilot 2023, we have extended Falcon's architecture for building Site Twins (described later) to incorporate DRIs. DRIs are acquired and mapped to modular, reusable DTs. These twins could then be combined with a library of other DTs representing terrain, vegetation, energy infrastructure, transportation networks, communication networks, drones, sensors, etc., to have limitless flexibility in defining the scenarios described above and others we have not considered.

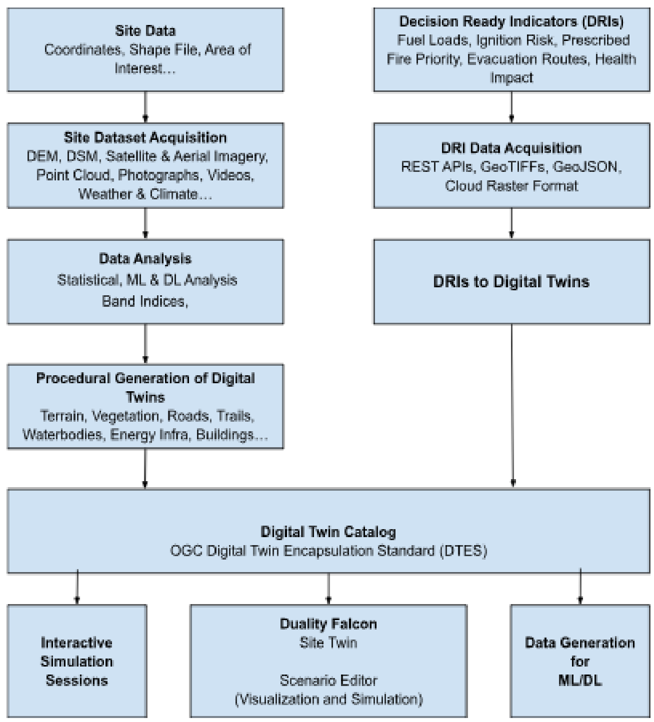

Figure 13 — Falcon's enhanced workflow maps DRIs to DTs in an open-source Digital Twin Encapsulation Standard (DTES) format, which can be combined with other digital twins in a modular way to create a wide variety of scenarios for interactive visualization, planning, validation, and synthetic data generation.

6.4.4.3. Technical implementation

Building Digital Site Twins In Figure 13, the workflow on the left represents Falcon's GIS and AI-powered workflow to build digital Site Twins.

Simulation has always been our best tool for predicting the future. However, these predictions are only valuable if the simulation data has the required fidelity and precision to translate to the real world successfully. Put another way: when exploring any question of interest, the data generated by a simulation is only helpful if it can approximate what would happen in the real world with a high degree of accuracy.

Considering Wildland Fire, decision-makers would like to simulate various scenarios to learn possible evacuation route options and potential bottlenecks, time needed for evacuation, potential health hazards, and hence evacuation priority. Generalized scenarios are insufficient for projects like OGC DP23 — real locations and real-world data are called for.

Digital Site Twins (also called simply **Site Twins**) — virtual environments based on diverse sources of Geographic Information System (GIS) data of actual locations. When semantic information from GIS data is joined with the infinitely adjustable nature of a digital twin, we open the door to any "what if" questions relevant to that environment (limited only by the availability and quality of the GIS data sources). Whether testing the deployment of emergency response plans or evaluating disaster response protocols in an urban or rural setting, the fidelity of the digital twin virtual environment and its accurate representation of the real-world location are necessary to bridge the Sim2Real gap.

Creating Site Twins, after all, can be pretty daunting. This is why Duality researched and developed an AI-powered pipeline that enables our customers to build any desired Site Twins from already available data.

Figure 14 and Figure 15 describe Duality Falcon's GIS and AI-powered pipeline to create Digitaal Site Twins.

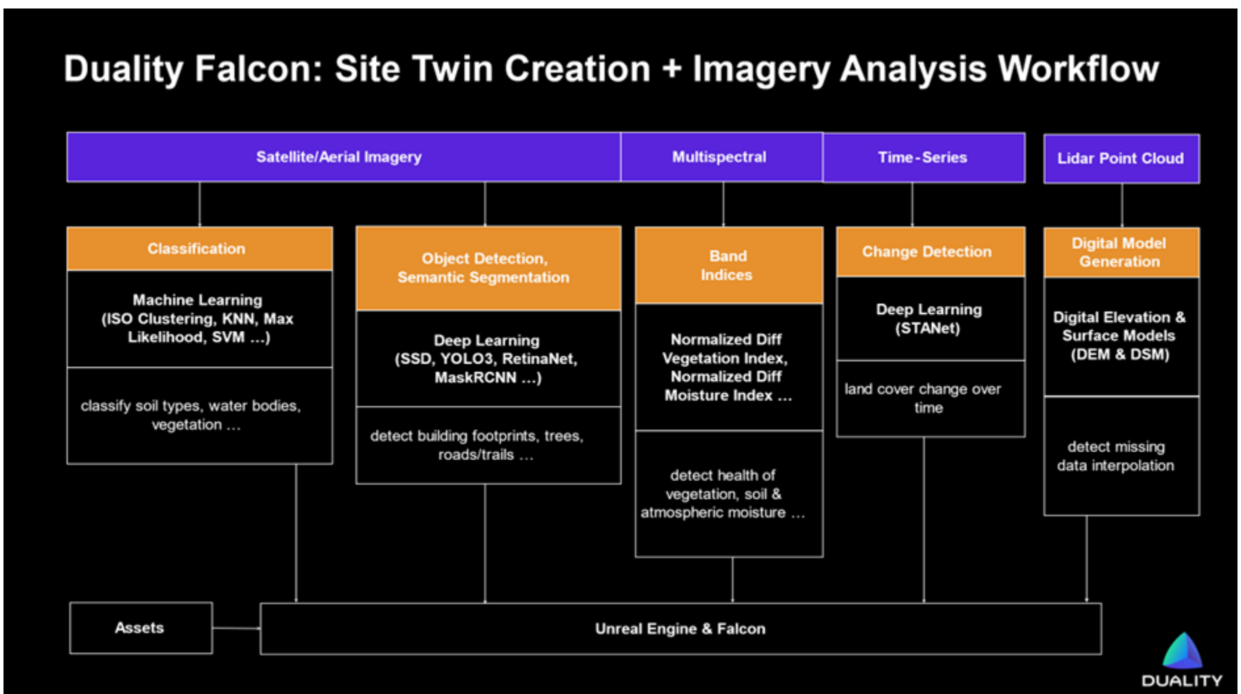

Figure 14 — Workflow of Falcon's GIS and AI-powered pipeline to create Digital Site Twins of the existing real locations for immersive visualization and simulation.

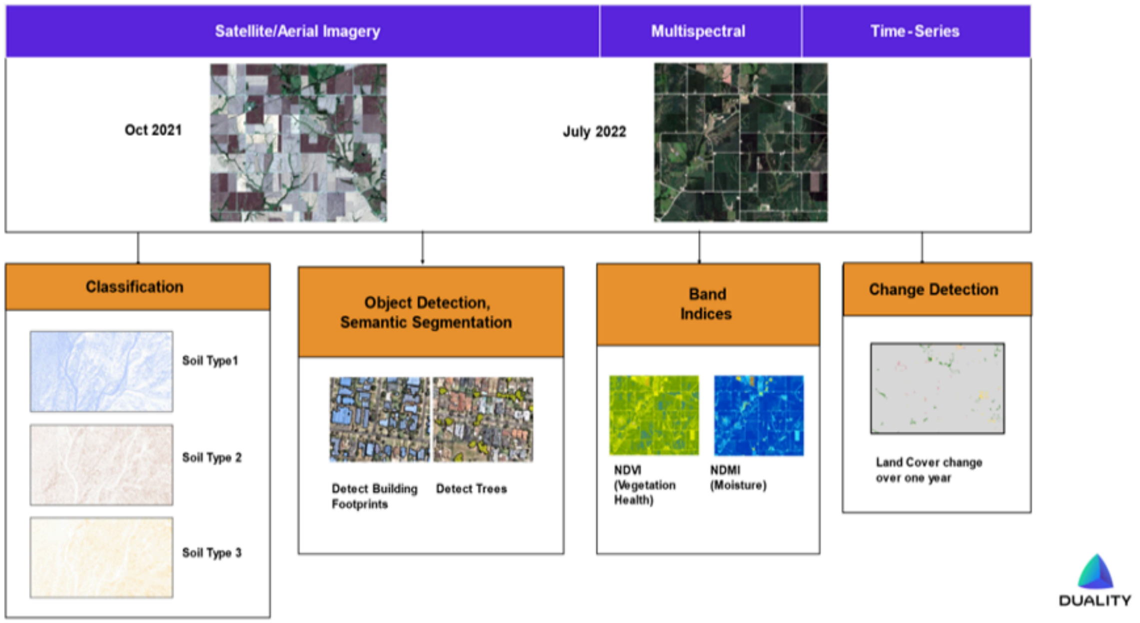

Figure 15 — Workflow with example imagery and analyses through Falcon's GIS and AI-powered pipeline to create Digital Site Twins of the existing real locations for immersive visualization and simulation.

Digital Elevation Model

For the OGC Wildland Fire DP23, Duality is building a Digital Site Twin of around 8,400 square km of Fish Lake National Forest, Utah.

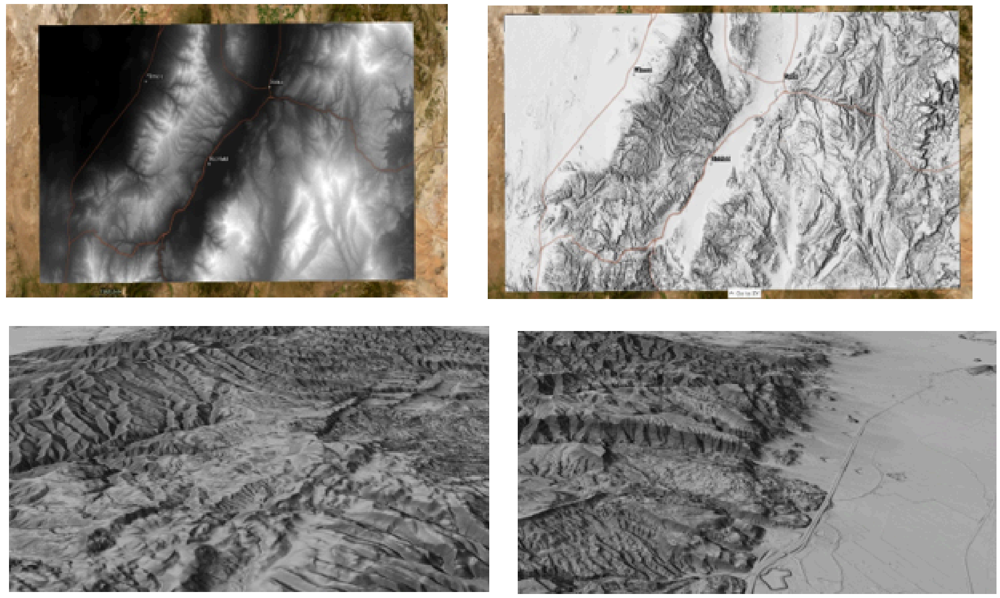

Figure 16 — Fish Lake, Utah's Digital Elevation Model (DEM). This DEM was created by merging and resampling around 200 DEMs from USGS mapping surveys carried out in 2016, 2018, and 2020. The top left image is that of the DEM. The rest of the photos showcase DEM's 3D Hillshade views covering various parts of the terrain.

Satellite Imagery

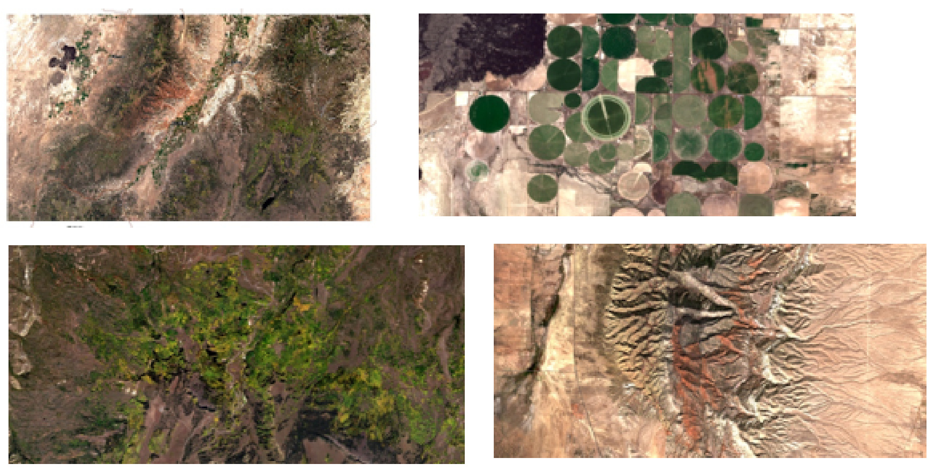

Figure 17 — Sentinel-2 10m resolution Satellite Imagery of the area of interest. The top left image shows the 8400 square km of the size of interest. The rest of the photos showcase soil and _vegetation variations.

AI Analysis of Satellite Imagery

ISO Clustering and Maximum Likelihood Machine Learning models classify the satellite imagery into various soil and vegetation classes. Classification results are exported as the following geo-referenced masks.

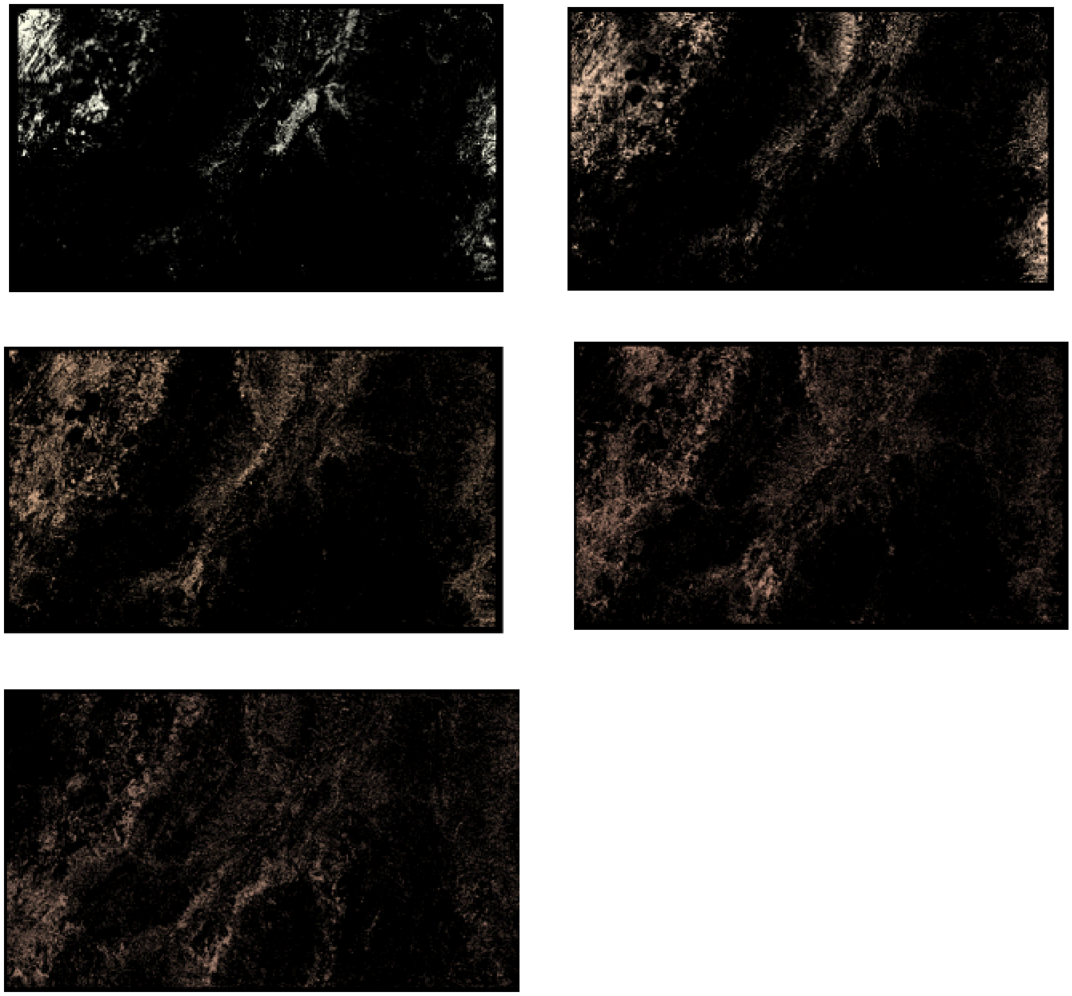

Figure 18 — Soil classification masks. From top to bottom, from left to right, (a) whitish soil, (b) golden brown soil, (c) light brown soil, (d) mid-brown soil, and (e) dark brown soil.

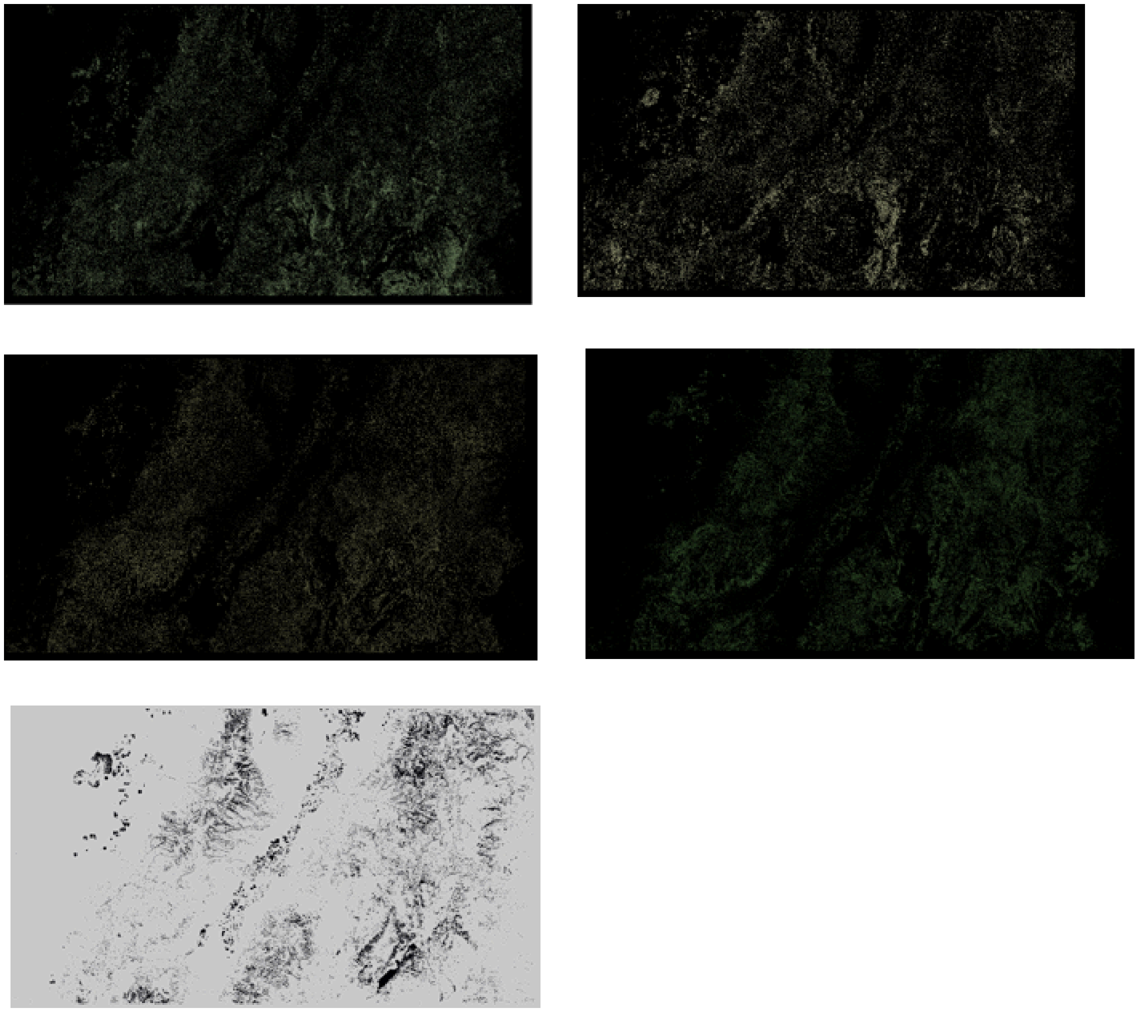

Figure 19 — Vegetation classification masks. From top to bottom, from left to right, (a) light green vegetation, (b) mid-green vegetation, (c) brown green vegetation, (d) dark green vegetation, and (e) black green vegetation.

Road and Street Network

We rely on the AI-powered Satellite/Aerial imagery Semantic Segmentation, Open Street Map, and the United States Census Bureau's Road and Street dataset to build roads and street networks for the area of interest. For Semantic Segmentation, the availability of high-resolution imagery is a must.

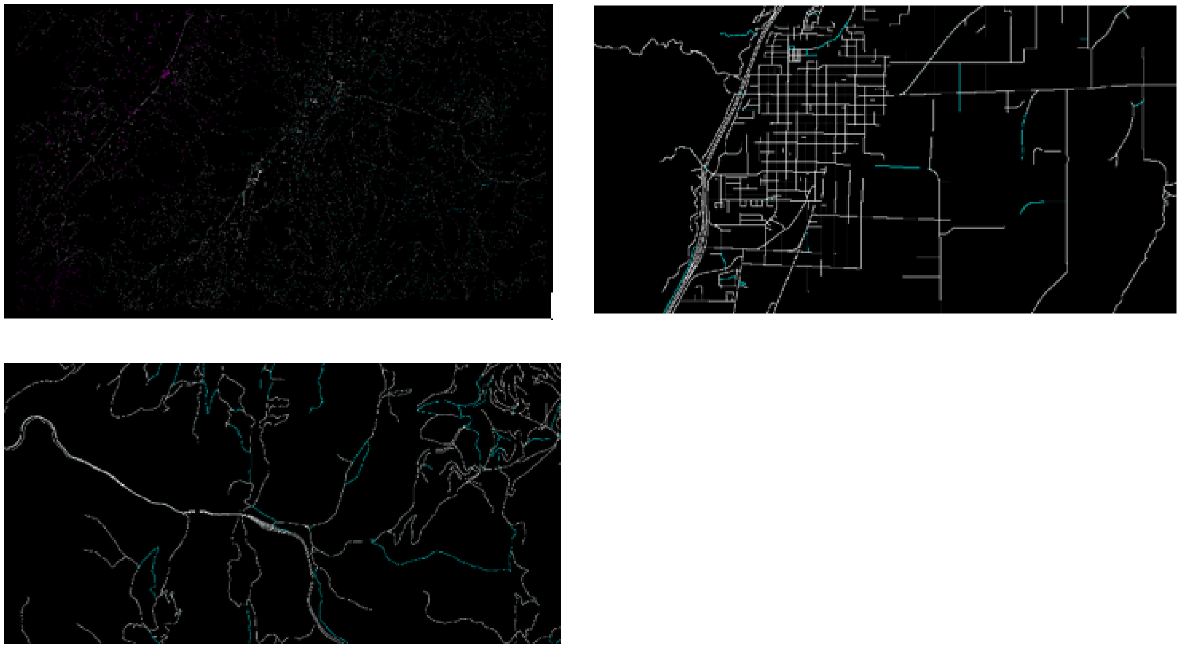

Figure 20 — Acquiring and processing roads and streets network for the area of interest. Source: United States Census Bureau.

Generating Terrain Mesh

In simulation, it makes sense to pre-generate static data. To rebuild it 60 times per second in the simulation wouldn't be ideal as it would consume resources that could be better used for increasing fidelity. DEMs are an example of this kind of static data. Duality uses Side Effects Houdini to generate terrain meshes from DEMs—the Python module *Rasterio* loads in GeoTIFF DEM. Houdini's surface operation nodes create a mesh where the elevation per mesh point is set from the elevation per pixel in the GeoTIFF. Surface operations also process bodies of water by replacing the Lidar-generated surface with a separate water surface mesh. Houdini can interpolate the terrain elevation or approximate actual ground truth with a noise function in areas where the DEM has no data, or the gradient is inaccurate.

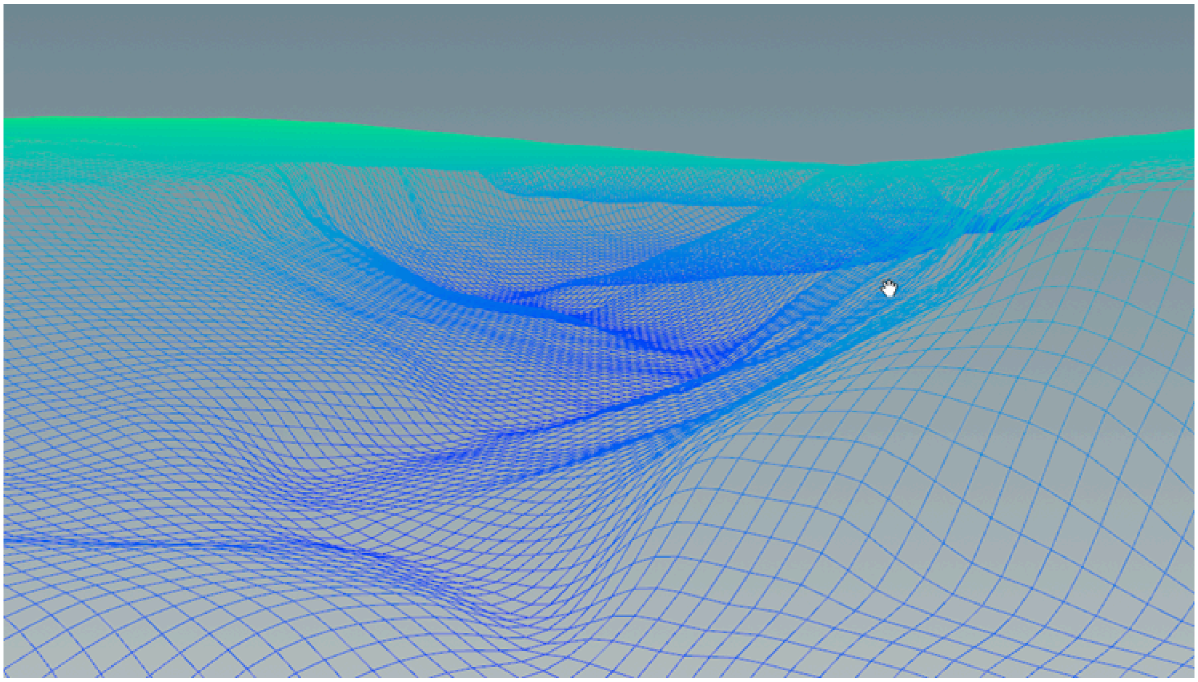

Figure 21 — Generating terrain mesh from DEM.

Creating Terrain Layers

Mesh generated from the DEM and soil, vegetation, road, and street network masks create a 3D environment in Unreal Engine and Falcon. Various masks give the ability to visualize different surfaces correctly, apply physics as needed, and populate foliage, forestry, and rock masses.

Mapping DRIs to Digital Twins

As described in Figure 13, Falcon has been extended to fetch DRI datasets using APIs of the respective DRIs. Falcon subsequently converts these datasets into Digital Twins as specified by the OGC DTES (Digital Twin Encapsulation Standard). Falcon then consumes these DRI Digital Twins through Falcon's Python APIs.

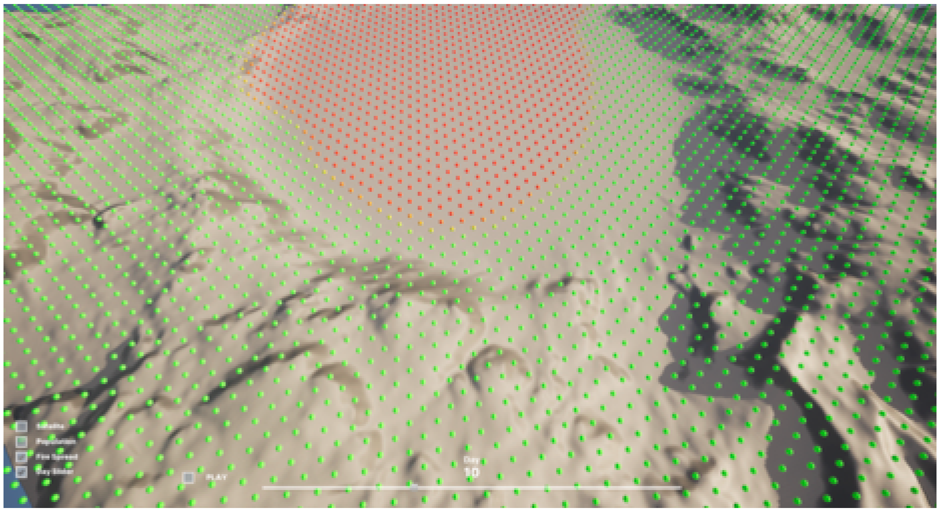

Figure 22 — This work-in-progress image shows (1) the creation of various terrain layers using DEM and soil, vegetation, and road network masks and (2) an example prototype of the Fire Fuel Indicator DRI overlayed on the 3D Site Twin.

6.4.4.4. Scenarios

Duality's Wildland Fire Immersive Indicator Visualization supports the following scenarios.

- Multi-camera navigation of the 3D Site Twin
- Interactive visualization of Skymantics' Evacuation DRI
- Interactive visualization of Health.HSR's Health DRI
- Interactive visualization of Compusult's Ignition Risk DRI
- 30-day time-series visualization representing a wildland fire.

6.4.5. Results

Interactive visualization and navigation of the Fish Lake Digital Site Twin and various DRI scenarios are available through Duality's Falcon platform.

6.4.5.1. Challenges and lessons learned

It has been our first experience building a Digital Site Twin on such a massive scale (representing 8400 square km). We faced numerous challenges while

- processing the Digital Elevation Model and exploring a massive 3D mesh.

- creating soil, vegetation, road network, and water body layers while maintaining optimum resolution, visual fidelity, and video frame rate.

Memory and GPU resources must be improved at such a large scale. A distributed computing environment is a possible solution.

6.4.6. Future Development

As part of this pilot program, we have built the building blocks of a large-scale wildland fire simulation and visualization of various DRIs. In the future, this prototype can be extended to support diverse simulation scenarios and achieve multiple goals.

- Acquire and manage simulation-ready digital twins of the real-world wildland fire assets: relevant environments, dynamic systems, and associated objects.
- Customize modular scenarios.
- Run real-time, physics-accurate, deterministic simulations of complex real-world scenarios on massive scales with vast numbers of machines and agents.
- Control every part of any simulation, even at runtime, with Falcon's flexible Python API.
- Generate accurate behavior and high-fidelity sensor data with a library of configurable simulation-ready sensors.
- Simulate in the cloud and collaborate globally with internal and external partners without computing resource limitations.

6.5. Wildland Fire Fuel Indicator Workflow (by Ecere)

6.5.1. Introduction to the company and main activities

Ecere Corporation is a software development company incorporated in 2005. The company develops the GNOSIS geospatial software suite, including support for hardware accelerated three-dimensional visualization on multiple platforms including Linux, Windows, Android, Web and VR/AR displays. The company's core products are GNOSIS Cartographer, a visualization client, and GNOSIS Map Server, a certified implementation of OGC API standards enabling efficient distribution of large datasets by leveraging multi-resolution tile pyramids. Both of these products are powered by the GNOSIS Software Development Kit, itself based on the Ecere SDK, an open-source cross-platform toolkit including a 2D/3D graphics engine, GUI toolkit and IDE, as well as the eC programming language. Ecere has been an OGC member since 2016, actively participating in the development of several OGC standards and implementing support for them in its GNOSIS software in the course of multiple OGC Testbeds, Code Sprints and Pilots.

6.5.2. Background and problem description

As changing climate exacerbates the risk of wildfire spreading, understanding the catalyzing factors can empower emergency responders and policymakers with knowledge to better manage them. The availablity of fuel from vegetation is one such predictive factor. Different types of vegetation correlate to different density of fuel, and potentially also to different rates at which fire may spread. Using imagery and prediction modeling, a classification of these vegettion types may help identify areas susceptible to higher risk of wildfire spread.

6.5.3. Objectives and role in the pilot architecture

The overall aim of this Disaster Pilot was to implement workflows that can facilitate decision-making and collaboration in the context of a disaster response, and to demonstrate their benefits. Ecere's role in this pilot was to develop an indicator workflow for wildland fire fuel. The primary objective was to set up this indicator workflow taking as input ESA sentinel-2 Level 2A data (including atmospheric correction), using a trained Machine Learning model for classification, and making this indicator accessible through an API conforming to OGC API standards, including *OGC API — Processes* and its draft *Part 3* extension for workflows, *OGC API — Tiles*, *OGC API — Coverages*, *OGC API — Maps* and *OGC API — Discrete Global Grid Systems*. In conjunction with its participation in the Climate Resilience Pilot, Ecere needed to improve the performance and capability of the sentinel-2 datacube offered on the GNOSIS Map Server demonstration end-point, which serves as the primary input for the indicator workflow. Also in conjunction with the Climate Resilience Pilot, Ecere hosted on the same GNOSIS Map Server end-point several datasets retrieved from the Copernicus Climate Data Store climate-related datasets relevant to wildfire spread, including climate data such as temperature and precipitation, as well as derived fire danger indices. These datasets were made available to other participants for access through OGC API standards.

Ecere hopes that the development, availability and future improvements to this Wildland Fire Fuel Indicator as well as the interoperability achieved through the OGC API standards involved will contribute to help stakeholders and responders plan, make informed decisions to better prepare for a wildfire disaster, and save lives.

6.5.4. Methodology

6.5.4.1. Area of study

The area of study is Fish Lake, Utah. The workflow indicator can be used for any area where sentinel-2 imagery is available, which in the case of the sentinel-2 data cube hosted on the GNOSIS Map Server sourced from the AWS open data managed by Element 84, spans the entire global land mass. However, the classification model was trained with a limited amount of data, including the surroundings of Fish Lake, Utah as well as the area surrounding Mount Adams in Washington State, and its performance for other area has not been assessed and may be worst.

6.5.4.2. Technical design

The wildland fire fuel indicator workflow classifies sentinel-2 Level 2A source imagery into high level types of vegetation, which can then optionally be mapped to a fuel density through an additional step.

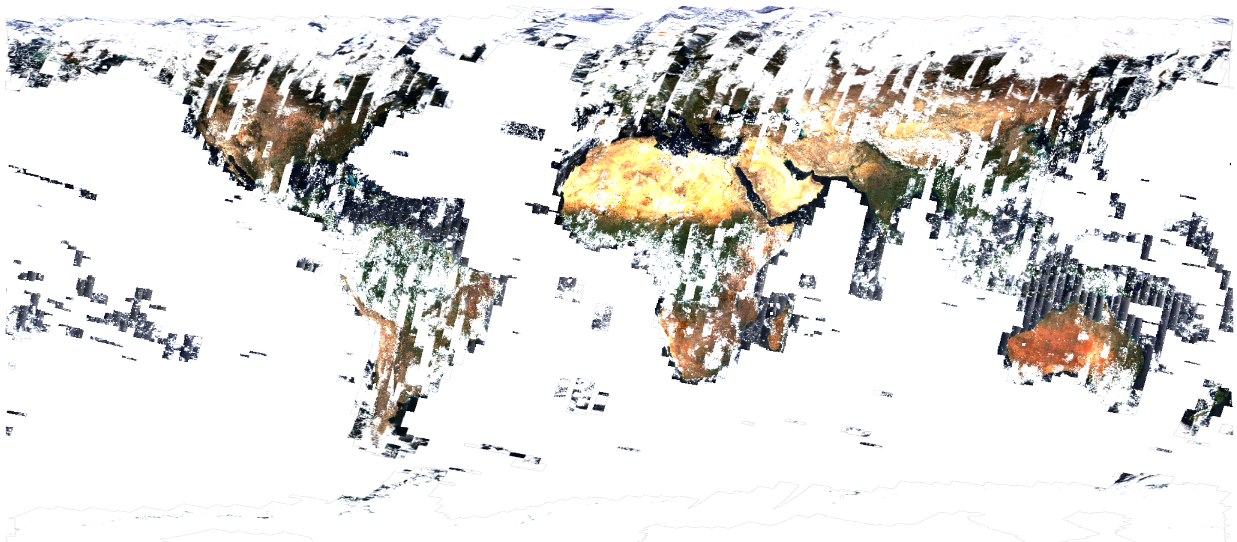

Figure 23 — ESA sentinel-2 data from AWS open dataset managed by Element 84

This prediction is performed with a RandomForest classifier using the Scikit-learn Python library. The RandomForest model is trained using the US Vegetation Fuel Types from Landfire from the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior.

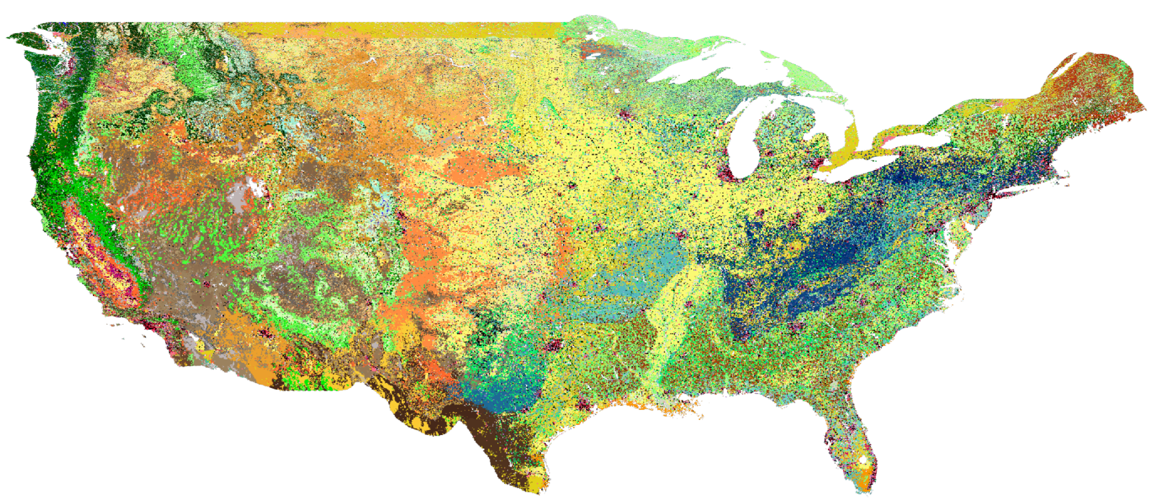

Figure 24 — Fuel Vegetation Types for continental United States (from landfire.gov)

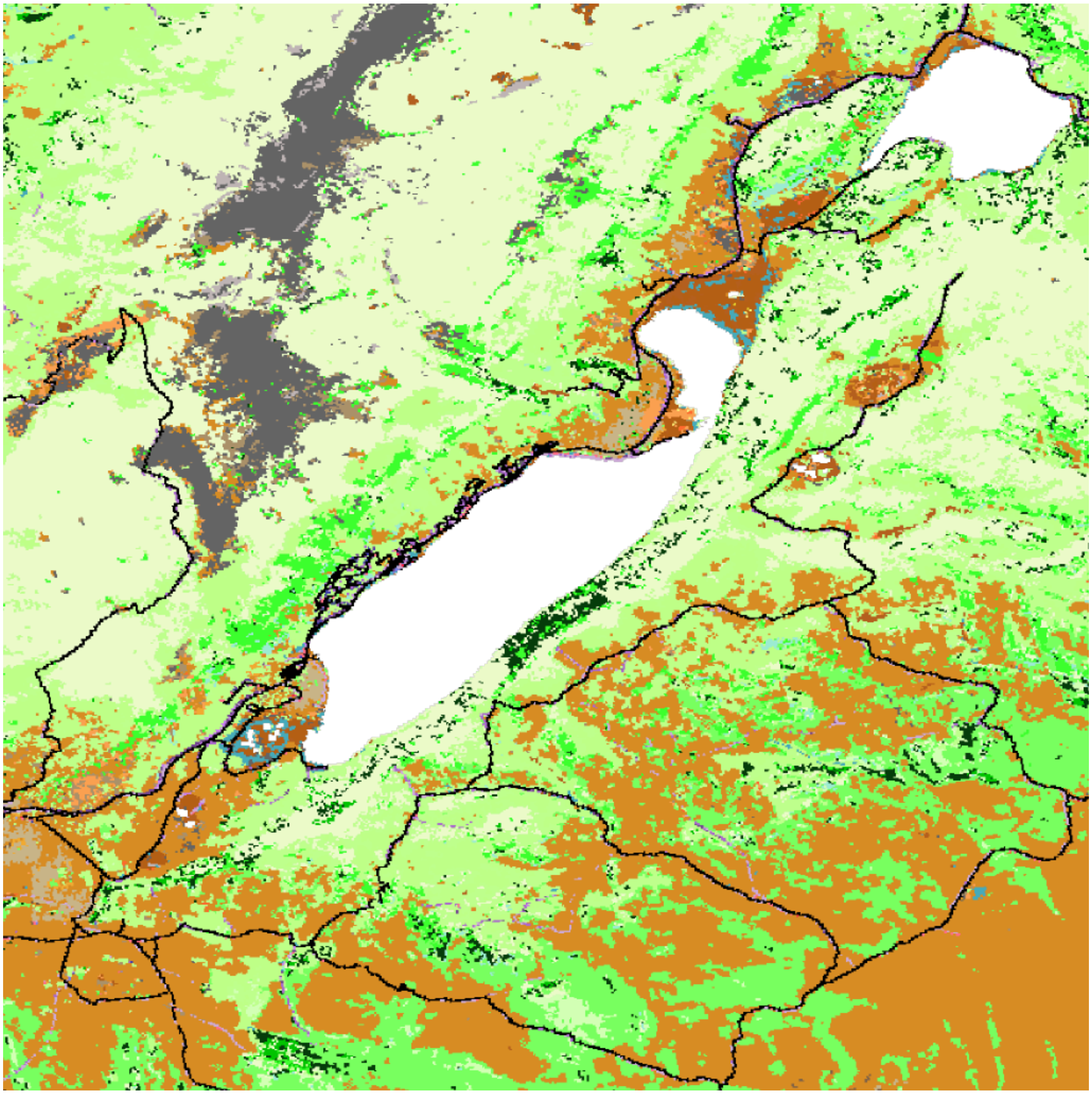

Figure 25 — Fuel Vegetation Types (from landfire.gov) for Fish Lake area

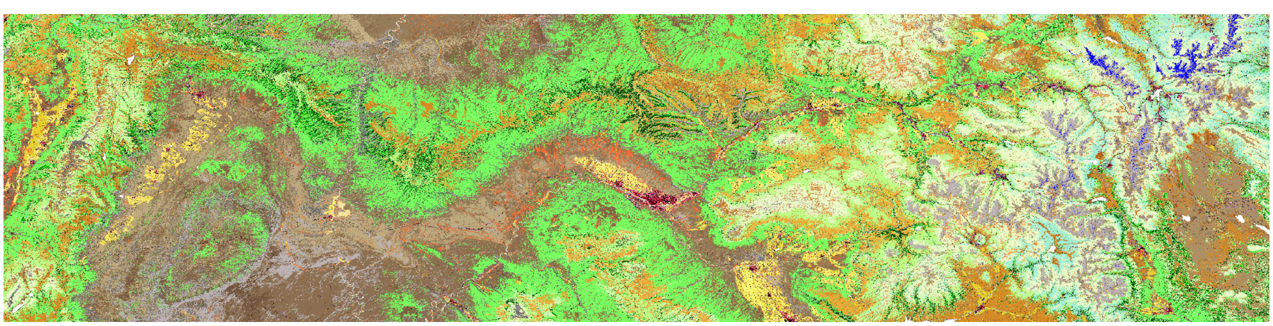

Figure 26 — Fuel Vegetation Types (from landfire.gov) of full training area for Fish Lake (2022)

Since this dataset has a very large number of vegetation types that would be difficult to map to a fuel density and would also either require very large and complex classification trees or yield poor results, these numerous types are first mapped to ten high level vegetation types. These high level vegetation types are shown in the following table, together with the fuel density percentage to which they were mapped (for the sake of demonstration, and not intended to be sound or valid for any practical purpose). The hexadecimal string for the color with which both the types and density were represented in rendered styled maps is also included in this table.

Table 1 — High level vegetation types and density mapping

CLASS ID	COLOR	HIGH LEVEL FUEL VEGETATION TYPE	FUEL DENSITY	DENSITY COLOR
11	`#0000FF`	Open Water	0%	(transparent)
12	`#9FA1F0`	Snow/Ice	0%	(transparent)
20	`#343434`	Urban	70%	`#FFB200`
31	`#BFBFBF`	Barren	5%	`#F0E68C`
80	`#FFD277`	Agriculture	60%	`#FFD700`
2001	`#646464`	Sparsely Vegetated Systems	30%	`#6b8E23`
2008	`#CBFFAB`	Trees	100%	`#FF0000`
2064	`#CCB687`	Shrubs	80%	`#FF8C00`
2122	`#FFCC33`	Grassland	40%	`#808000`
2908	`#403DA8`	Developed area	60%	`#FFD700`

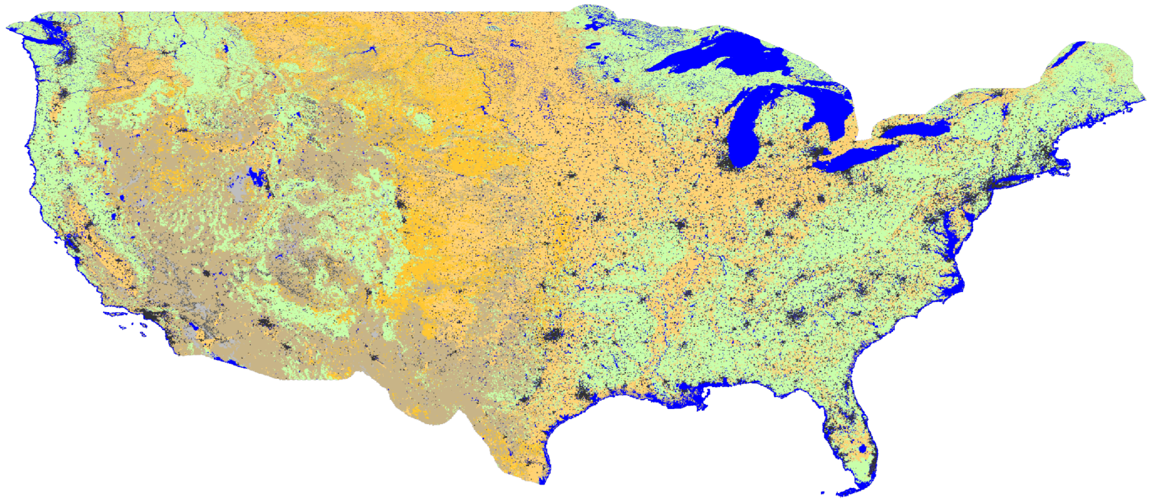

Figure 27 — Remapped High Level Fuel Vegetation Types for continental United States

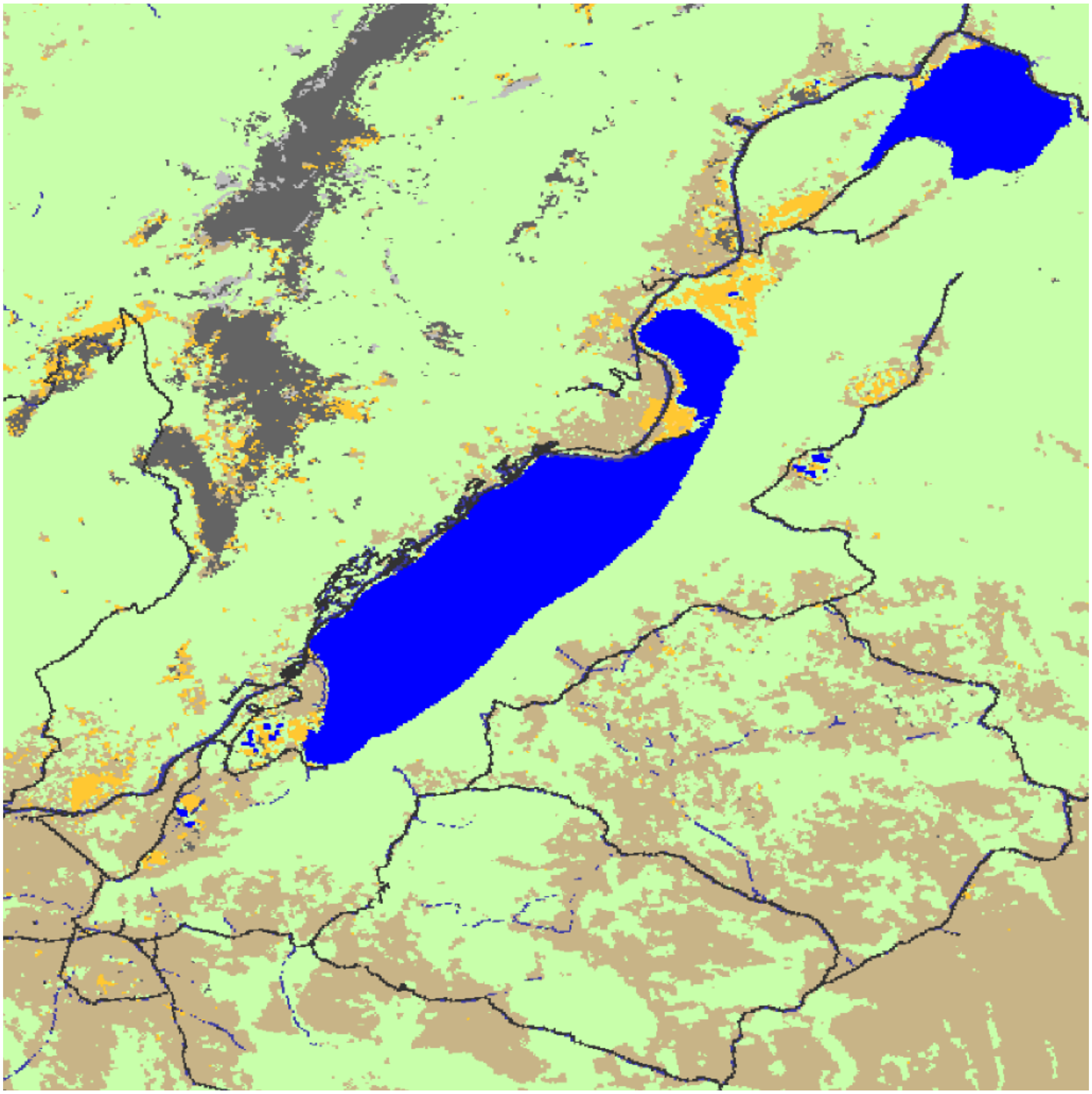

Figure 28 — Remapped High Level Fuel Vegetation Types for Fish Lake area (2022)

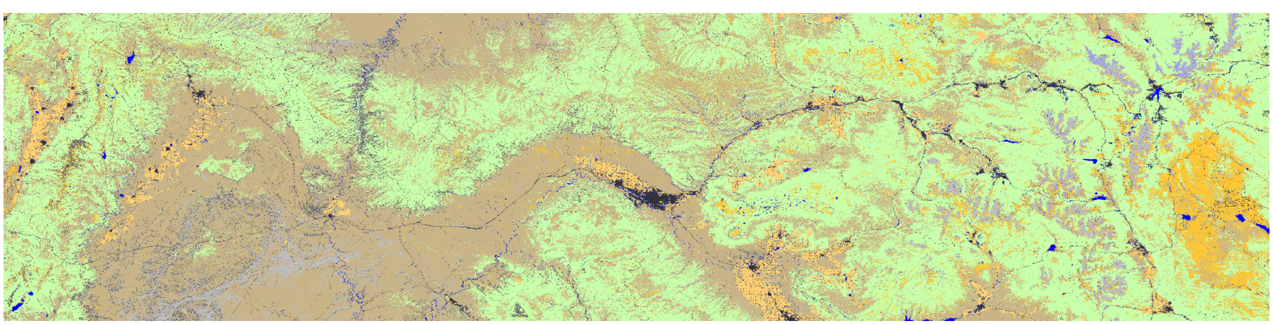

Figure 29 — Remapped High Level Fuel Vegetation
Types of full training area for Fish Lake (2022)

The training was done using all bands available from the AWS open-data sentinel-2 dataset, for three separate seasons in 2022: spring (May 15-25), summer (July 15-25) and autumn (September 15-25).

Figure 30 — Sentinel-2 Imagery of Fish Lake (September 15-25, 2022)

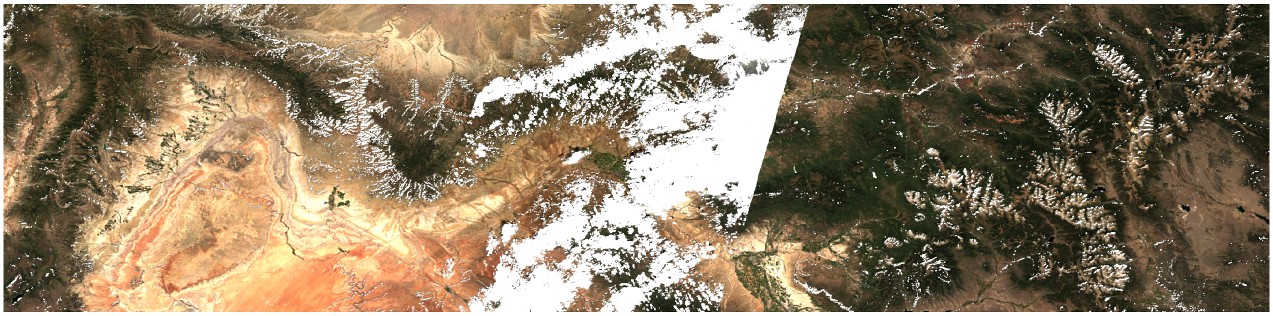

Figure 31 — Sentinel-2 Imagery of training area for Fish Lake (September 15-25, 2022)

A filter was first applied based on the Scene Classification Layer (SCL) band to elimate clouds (medium and high probability, cirrus, cloud shadows), as well as no data, saturated / defective, dark area, using the OGC Common Query Language (CQL2) filtering expression:

```
(SCL >=4 and SCL <= 7) or SCL=11
```

Figure 32

This SCL band is also used as an input to the training and prediction.

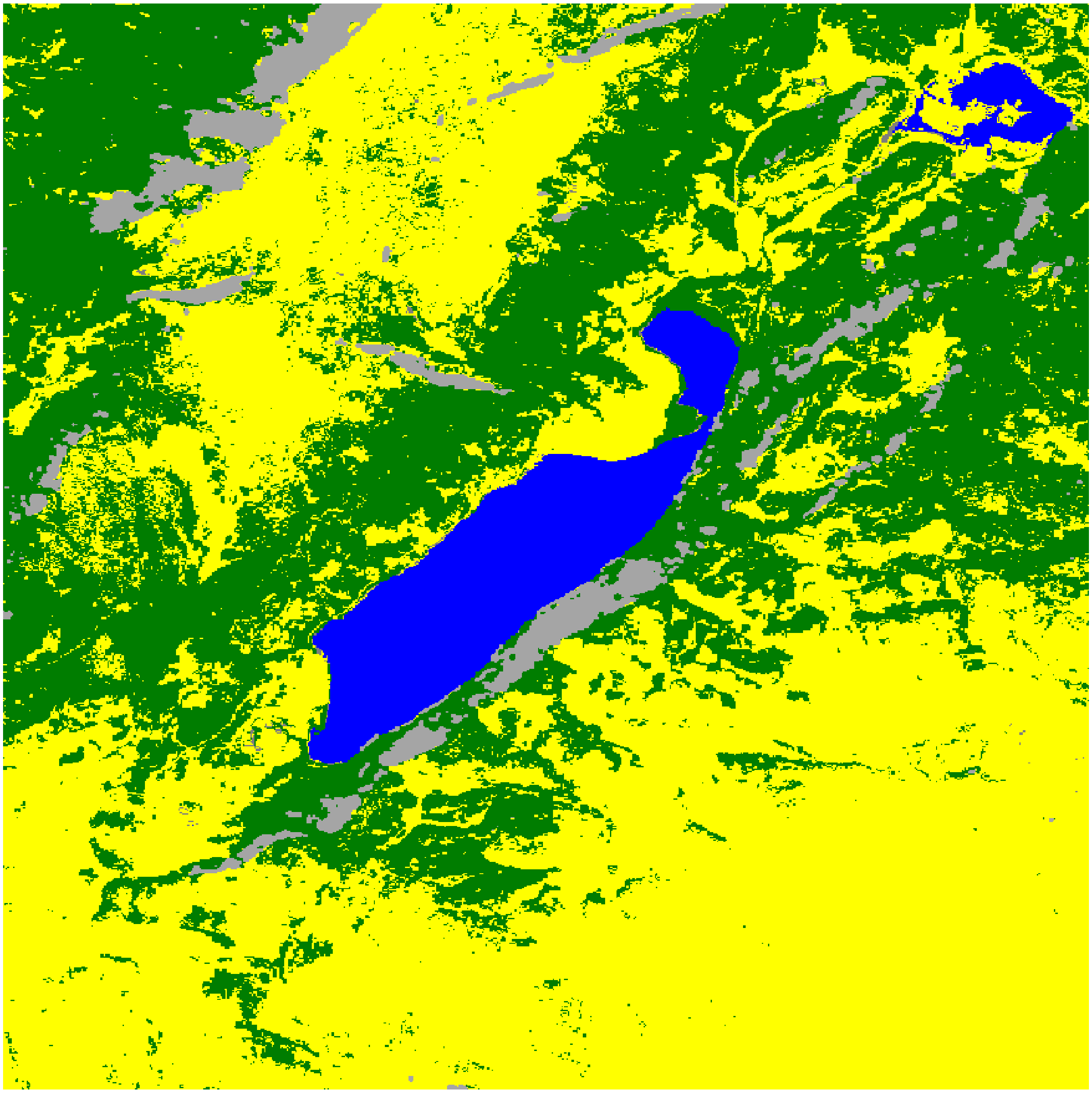

Figure 33 — Sentinel-2 Scene Classification Layer (SCL) of Fish Lake (September 15-25, 2022)

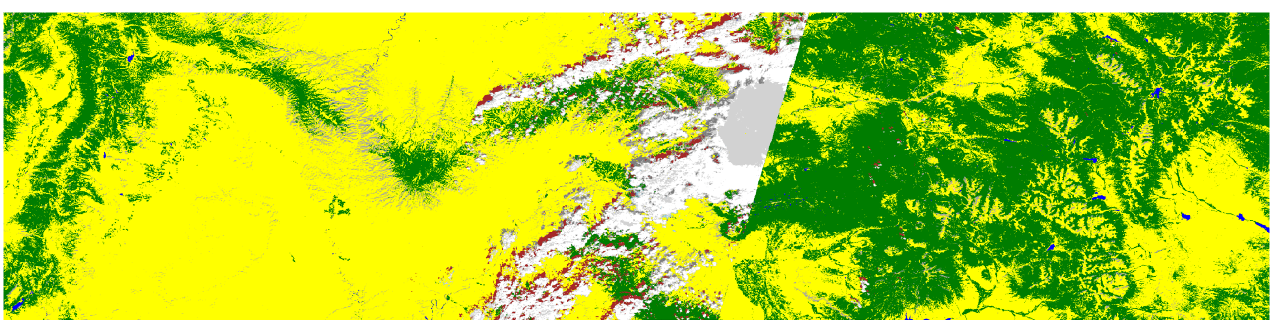

Figure 34 — Sentinel-2 SCL of training area for Fish Lake (September 15-25, 2022)

In addition, an intermediate Enhanced Vegetation Index (EVI) raster is pre-computed as an additional input sample for both training and classification, using the formula:

```
2.5 * (B08 - B04) / (1 + (B08 + 6 * B04 - 7.5 * B02))
```

Figure 35

making use of the Near-Infrared, Red and Blue bands.

Figure 36 — Sentinel-2 Enhanced Vegetation Index (EVI) of Fish Lake (September 15-25, 2022)

The model was trained for a small area surrounding Fish Lake in Utah (`subset=Lat(38.475:38.625),Lon(-111.780:-111.630)`, seen above), a larger region extending North-East from Fish Lake to a snowy area (`subset=Lat(38.475:40),Lon(-111.780:-105.5)`, seen below), and Mount Adams in Washington State (`subset=Lat(46.0546875:46.23046875),Lon(-121.640625:-121.2890625)`, seen in *Results* section below).

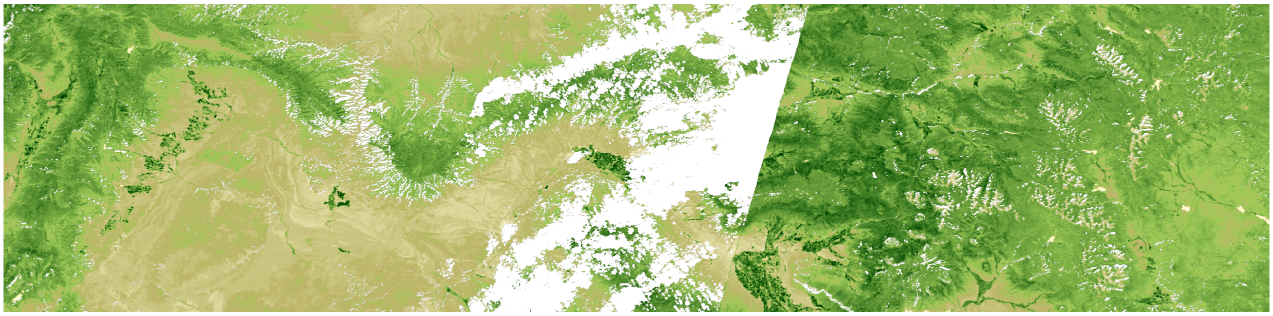

Figure 37 — Sentinel-2 EVI of training area for Fish Lake (September 15-25, 2022)

The exact same seasonal sentinel-2 data is used during the prediction resulting from triggering the indicator workflow, for the year of the specified time of interest (the month and day of the request are ignored).

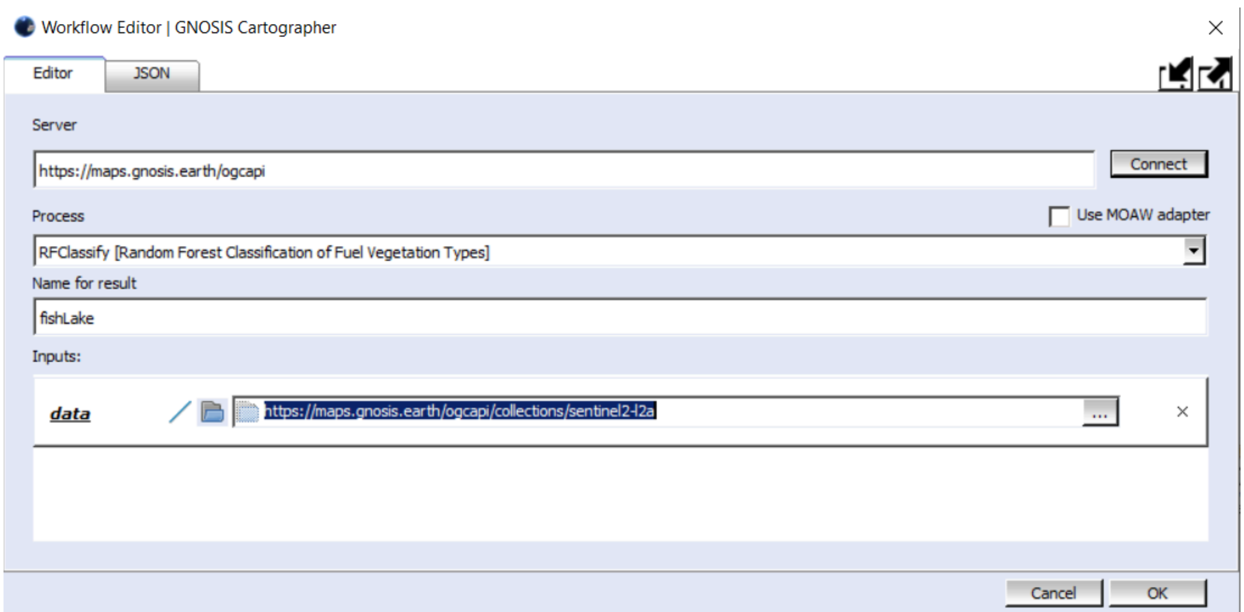

Figure 38 — Workflow Editor tool from GNOSIS Cartographer client

6.5.4.3. Technical implementation

The work done in this project built on previous efforts such as the crop classification process done as part of the 2020-2021 GeoConnection project investigating Modular OGC API Workflows (OGC 21-033), OGC Testbed 17 — GeoDataCube API (OGC 21-027), OGC Testbed 18 — Identifiers for Reproducible Science (OGC 22-020r1), OGC Testbed 19 — GeoDataCube API and the OGC Climate Resilience Pilot (OGC 23-020).

The workflow for high level classification of fuel vegetation types is accessible on the GNOSIS Map Server at https://maps.gnosis.earth/ogcapi/processes/RFClassify and can be executed using *OGC API — Processes*, including using the draft *Part 3: Workflows and Chaining* extension "collection output", allowing to trigger processing and retrieve outputs using OGC API data access standards such as *Tiles*, *Coverages*, *DGGS* and *Maps*. The output is primarily intended to be retrieved as GeoTIFF for the raw data values (gridded coverage) and PNG or JPEG for a pre-rendered map.

The remapping of the US Fuel Vegetation Types from landfire.gov to high level vegetation types was accomplished using the *PassThrough* process also available on the GNOSIS Map Server end-point, providing an opportunity to use the "input fields modifiers" requirements class of *OGC API — Processes — Part 3*, using https://maps.gnosis.earth/ogcapi/collections/wildfire:USFuelVegetationTypes as the source collection, `fvt ⇐ 4802` as a `filter`, and the following expression as the `"properties"` value allowing to derive to new fields from existing ones:

```
fvt = 11 ? 11 :
  fvt = 12 ? 12 :
    (fvt >= 20 and fvt <= 24) or
    fvt = 2860 or
    fvt = 2861 or
    (fvt >= 2901 and fvt <= 2905) ? 20 :
      fvt >= 31 and fvt <= 32 ? 31 :
        (fvt >= 80 and fvt <= 82) or
        (fvt >= 2862 and fvt <= 2865) or
        (fvt >= 2960 and fvt <= 2970) ? 80 :
          (fvt >= 2001 and fvt <= 2007) or
          fvt = 2218 or
          fvt = 2219 or
          (fvt >= 2221 and fvt <= 2223) or
          (fvt >= 2496 and fvt <= 2499) or
          fvt = 2685 or
          fvt = 2686 or
          fvt = 2710 or
          fvt = 2730 or
          fvt = 2736 or
          fvt = 2737 or
          (fvt >= 2791 and fvt <= 2794) or
          fvt = 2831 or
          fvt = 2879 or
          fvt = 2973 or
          fvt = 2986 or
          fvt = 2987 or
          fvt = 2996 or
          fvt = 4601 or
          fvt = 4602 or
          fvt = 4615 or
          fvt = 4616 ? 2001 :
            (fvt >= 2008 and fvt <= 2063) or
            (fvt >= 2112 and fvt <= 2120) or
            fvt = 2151 or
            fvt = 2152 or
            (fvt >= 2154 and fvt <= 2162) or
            (fvt >= 2165 and fvt <= 2167) or
            fvt = 2170 or
            (fvt >= 2172 and fvt <= 2174) or
            (fvt >= 2177 and fvt <= 2180) or
            fvt = 2185 or
            fvt = 2187 or
            fvt = 2193 or
            fvt = 2194 or
            fvt = 2197 or
            (fvt >= 2200 and fvt <= 2208) or
            (fvt >= 2226 and fvt <= 2232) or
```

```
fvt = 2235 or
(fvt >= 2238 and fvt <= 2246) or
(fvt >= 2260 and fvt <= 2267) or
fvt = 2271 or
fvt = 2278 or
(fvt >= 2301 and fvt <= 2385) or
fvt = 2387 or
fvt = 2389 or
fvt = 2391 or
(fvt >= 2394 and fvt <= 2401) or
(fvt >= 2403 and fvt <= 2408) or
fvt = 2410 or
fvt = 2413 or
fvt = 2415 or
fvt = 2430 or
fvt = 2433 or
(fvt >= 2444 and fvt <= 2481) or
fvt = 2483 or
fvt = 2485 or
fvt = 2489 or
fvt = 2501 or
fvt = 2502 or
(fvt >= 2505 and fvt <= 2513) or
(fvt >= 2517 and fvt <= 2519) or
(fvt >= 2523 and fvt <= 2536) or
(fvt >= 2543 and fvt <= 2560) or
fvt = 2562 or
(fvt >= 2564 and fvt <= 2566) or
(fvt >= 2570 and fvt <= 2574) or
(fvt >= 2577 and fvt <= 2591) or
fvt = 2595 or
(fvt >= 2600 and fvt <= 2605) or
fvt = 2607 or
fvt = 2621 or
fvt = 2622 or
fvt = 2630 or
fvt = 2641 or
fvt = 2642 or
fvt = 2644 or
(fvt >= 2646 and fvt <= 2650) or
fvt = 2654 or
fvt = 2667 or
fvt = 2675 or
(fvt >= 2677 and fvt <= 2679) or
fvt = 2681 or
fvt = 2714 or
fvt = 2748 or
(fvt >= 2760 and fvt <= 2753) or
fvt = 2761 or
fvt = 2763 or
fvt = 2764 or
fvt = 2774 or
fvt = 2776 or
fvt = 2779 or
fvt = 2780 or
(fvt >= 2786 and fvt <= 2790) or
fvt = 2800 or
fvt = 2802 or
(fvt >= 2808 and fvt <= 2810) or
(fvt >= 2812 and fvt <= 2816) or
(fvt >= 2833 and fvt <= 2836) or
(fvt >= 2839 and fvt <= 2841) or
(fvt >= 2843 and fvt <= 2846) or
```

```
(fvt >= 2850 and fvt <= 2852) or
(fvt >= 2855 and fvt <= 2858) or
(fvt >= 2866 and fvt <= 2877) or
(fvt >= 2880 and fvt <= 2882) or
(fvt >= 2885 and fvt <= 2888) or
fvt = 2890 or
fvt = 2894 or
fvt = 2895 or
fvt = 2897 or
fvt = 2898 or
fvt = 2972 or
fvt = 2976 or
fvt = 2978 or
fvt = 2980 or
fvt = 2982 or
fvt = 2983 or
fvt = 2985 or
(fvt >= 2988 and fvt <= 2991) or
(fvt >= 2993 and fvt <= 2995) or
(fvt >= 4413 and fvt <= 4423) or
(fvt >= 4462 and fvt <= 4469) or
(fvt >= 4484 and fvt <= 4492) or
(fvt >= 4604 and fvt <= 4609) or
(fvt >= 4611 and fvt <= 4614) or
(fvt >= 4618 and fvt <= 4623) or
fvt = 4800 or
fvt = 4801 ? 2008 :
  (fvt >= 2064 and fvt <= 2111) or
  fvt = 2121 or
  (fvt >= 2124 and fvt <= 2128) or
  fvt = 2132 or
  fvt = 2153 or
  fvt = 2168 or
  fvt = 2169 or
  fvt = 2186 or
  fvt = 2190 or
  fvt = 2199 or
  (fvt >= 2209 and fvt <= 2217) or
  fvt = 2220 or
  fvt = 2234 or
  fvt = 2270 or
  (fvt >= 2275 and fvt <= 2277) or
  (fvt >= 2279 and fvt <= 2282) or
  fvt = 2386 or
  fvt = 2390 or
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  fvt = 2414 or
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  fvt = 2436 or
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  fvt = 2494 or
  fvt = 2522 or
  fvt = 2539 or
  fvt = 2540 or
  fvt = 2561 or
  fvt = 2567 or
  fvt = 2568 or
  fvt = 2575 or
```

```
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fvt = 2631 or
(fvt >= 2634 and fvt <= 2640) or
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fvt = 2672 or
fvt = 2676 or
fvt = 2680 or
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(fvt >= 2688 and fvt <= 2692) or
fvt = 2701 or
fvt = 2704 or
(fvt >= 2715 and fvt <= 2720) or
fvt = 2731 or
fvt = 2747 or
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fvt = 2762 or
(fvt >= 2771 and fvt <= 2773) or
fvt = 2777 or
fvt = 2778 or
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(fvt >= 2783 and fvt <= 2785) or
fvt = 2811 or
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fvt = 2818 or
fvt = 2821 or
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fvt = 2893 or
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fvt = 2975 or
fvt = 2984 or
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fvt = 4424 or
fvt = 4425 or
(fvt >= 4429 and fvt <= 4437) or
(fvt >= 4443 and fvt <= 4445) or
fvt = 4448 or
fvt = 4453 or
fvt = 4472 or
fvt = 4603 or
fvt = 4617 or
fvt = 4627 or
fvt = 4628 ? 2064 :
  fvt = 2122 or
  fvt = 2123 or
  (fvt >= 2129 and fvt <= 2131) or
  (fvt >= 2133 and fvt <= 2150) or
  fvt = 2163 or
```

```
fvt = 2164 or
fvt = 2171 or
fvt = 2176 or
(fvt >= 2181 and fvt <= 2184) or
fvt = 2191 or
fvt = 2195 or
fvt = 2224 or
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fvt = 2236 or
fvt = 2251 or
(fvt >= 2272 and fvt <= 2274) or
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fvt = 2411 or
fvt = 2412 or
(fvt >= 2416 and fvt <= 2424) or
(fvt >= 2426 and fvt <= 2429) or
fvt = 2431 or
fvt = 2434 or
fvt = 2435 or
fvt = 2437 or
fvt = 2438 or
fvt = 2440 or
fvt = 2442 or
fvt = 2443 or
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fvt = 2484 or
(fvt >= 2486 and fvt <= 2488) or
fvt = 2569 or
fvt = 2491 or
fvt = 2492 or
fvt = 2495 or
fvt = 2503 or
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fvt = 2576 or
(fvt >= 2592 and fvt <= 2594) or
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(fvt >= 2804 and fvt <= 2807) or
fvt = 2819 or
fvt = 2820 or
fvt = 2822 or
fvt = 2823 or
fvt = 2838 or
```

```
fvt = 2848 or
fvt = 2854 or
fvt = 2859 or
fvt = 2889 or
fvt = 2896 or
fvt = 4426 or
fvt = 4427 or
fvt = 4438 or
fvt = 4446 or
fvt = 4447 or
fvt = 4449 or
fvt = 4450 or
fvt = 4461 or
fvt = 4610 ? 2122 :
  (fvt >= 2908 and fvt <= 2947) ? 2908 :
    fvt > 4802 ? 9999 :
      (1*fvt)
```

Figure 39

6.5.4.4. Scenarios

Fish Lake, Utah is the area of focus for this demonstration of the Wildland Fire Fuel Indicator Workflow. For this scenario, the user is identifying high risk vegetation areas susceptible to intense rapid spread of fire. The user creates cartographic maps featuring the use of spatial analysis to help policymakers anticipate priority response needs, and determine how best to prepare.

For the scenario, in conjunction with the Climate Resilience Pilot, Ecere also hosted on its GNOSIS Map Server demonstration endpoint these datasets from the Copernicus Climate Data Store, which may be used directly by the user or as inputs to other indicator workflows, but were not used as input to the Wildland Fire Fuel Indicator Workflow:

- CMIP5 (Coupled Model Inter-comparison Project Phase 5) Climate data at a single and multiple pressure levels for 2016-2025
- Fire Danger Indices from the European Centre for Medium-Range Weather Forecasts (ECMWF) Copernicus Emergency Management Service (CEMS)

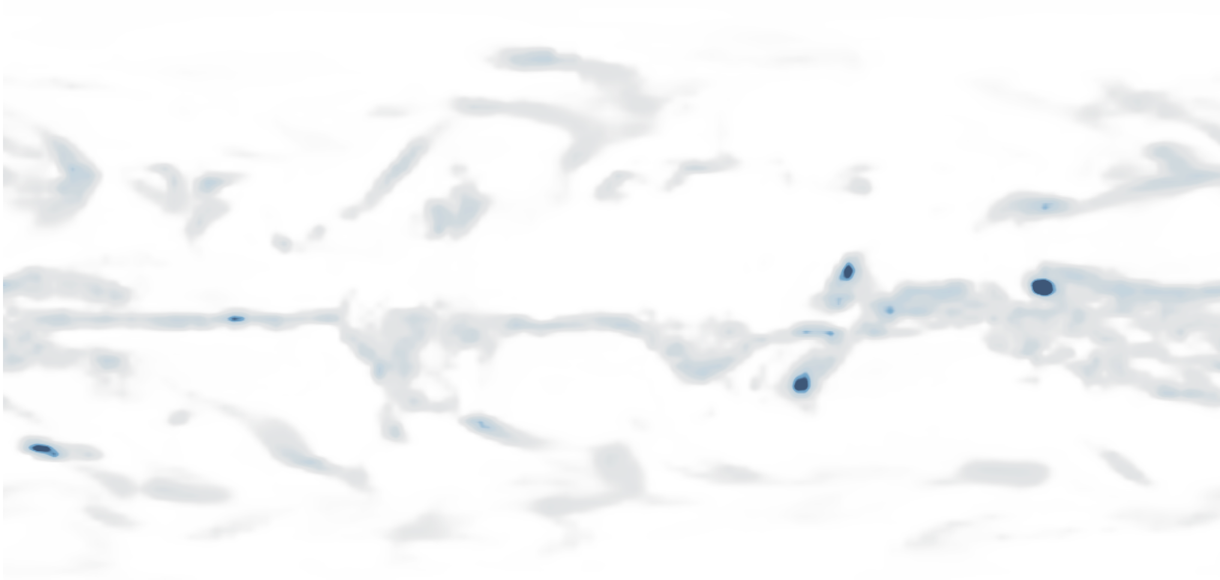


Figure 40 — CMIP5 Precipitations (from Copernicus Climate Data Store) hosted on GNOSIS Map Server

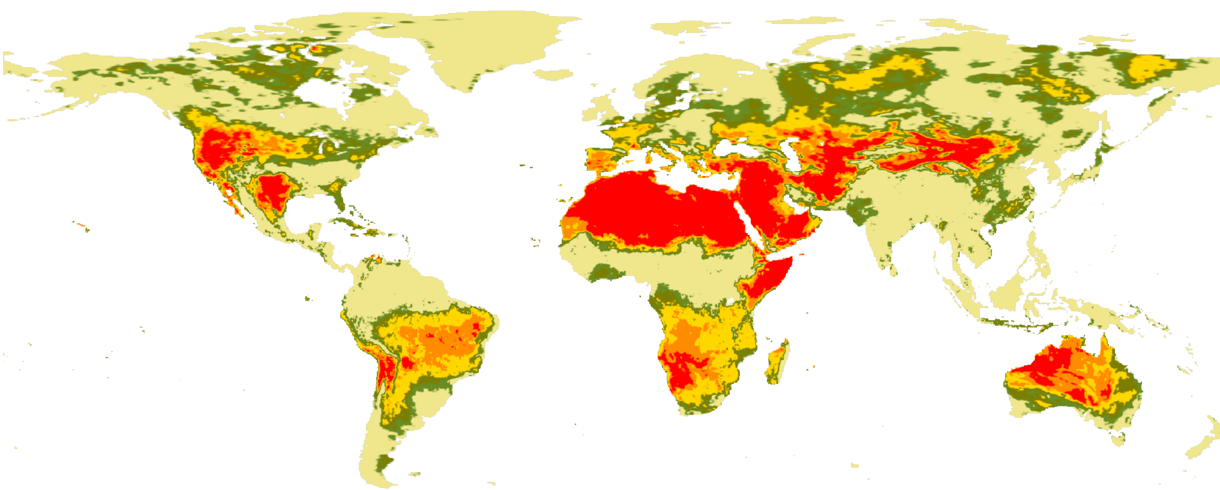


Figure 41 — ECMWF CEMS Fire Danger indices (from Copernicus Climate Data Store) hosted on GNOSIS Map Server

A High Resolution Digital Terrain Model for Red River in Manitoba from Natural Resources Canada is also hosted on the server, and could have been used in the context of a Manitoba Drought scenario.

Figure 42 — High Resolution Digital Terrain Model of Red River, Manitoba (from Natural Resources Canada) hosted on GNOSIS Map Server

6.5.5. Results

A persistent virtual collection of the Wildland Fire Fuel indicator workflow, indicating predicted high level vegetation fuel types, is available on the GNOSIS Map Server demonstration end-point at https://maps.gnosis.earth/ogcapi/collections/wildfire:S2VegetationFuelTypes.

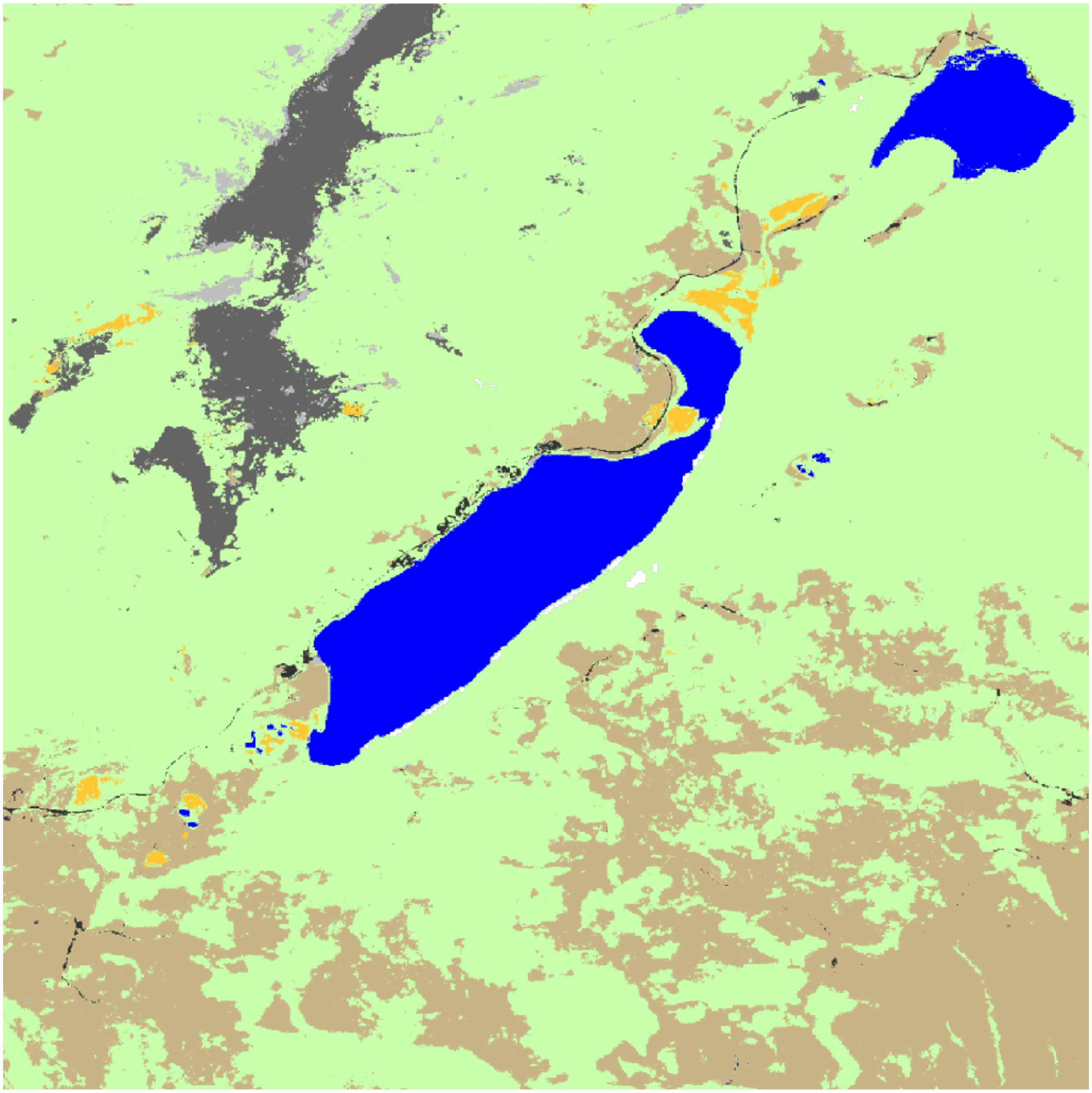


Figure 43 — Wildland Fire Fuel Indicator Workflow -
Predicted high level fuel vegetation types (Fish Lake, 2022)

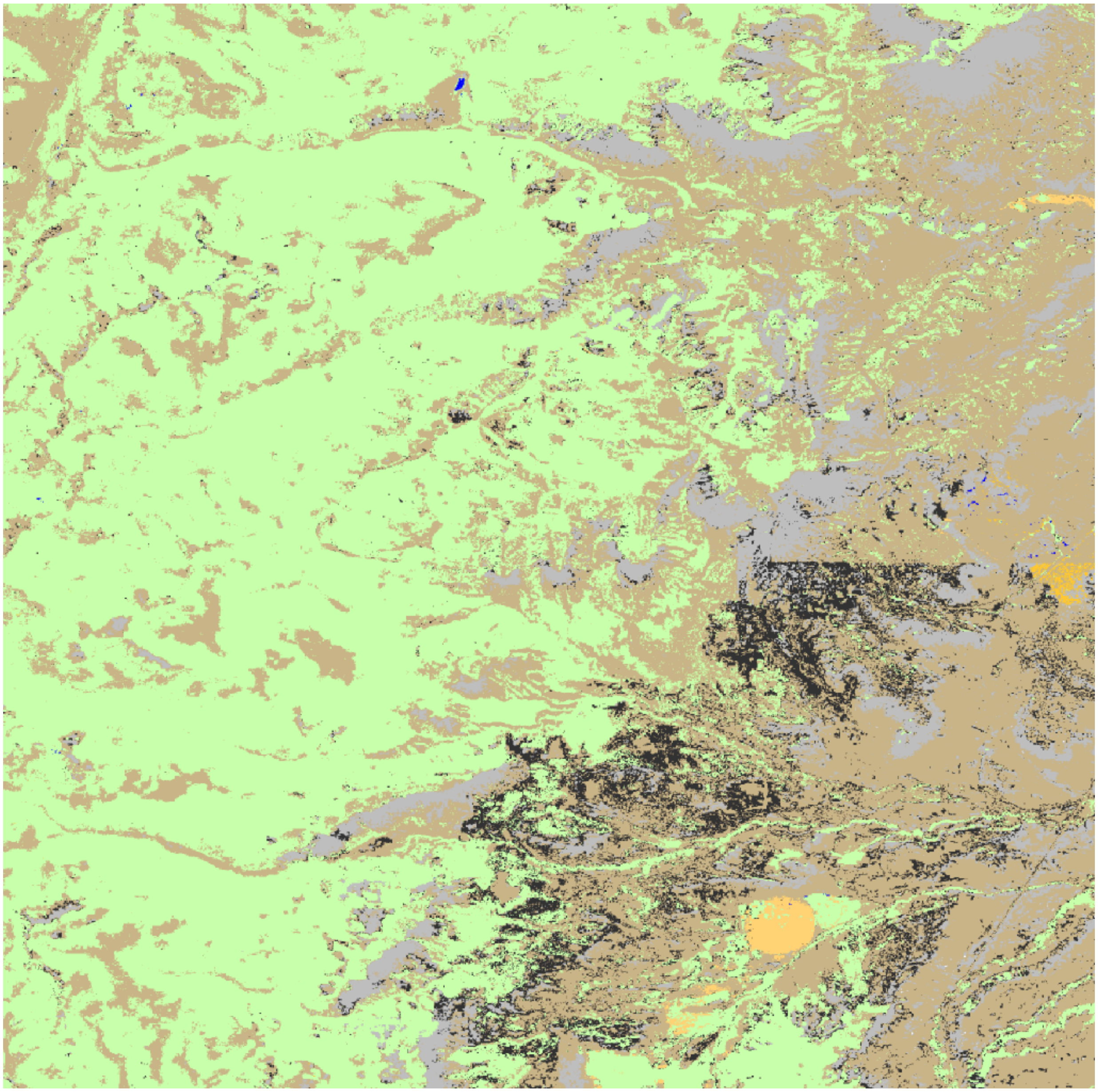


Figure 44 — Wildland Fire Fuel Indicator Workflow - Predicted high level fuel vegetation types (North-East of Fish Lake, 2022)

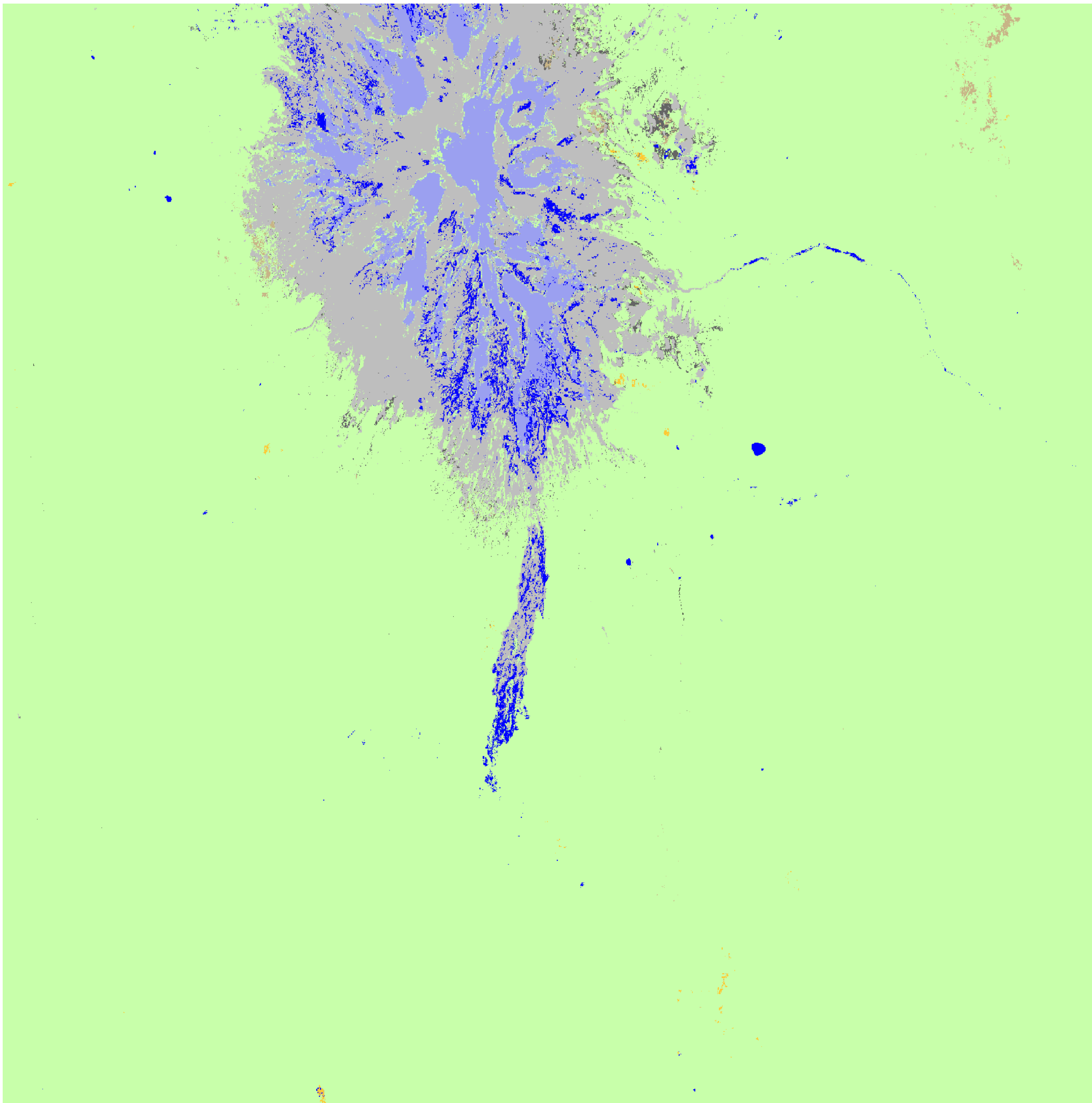


Figure 45 — Wildland Fire Fuel Indicator Workflow - Predicted high level fuel vegetation types (Mount Adams, Washington State, 2022)

A virtual collection mapping these vegetation fuel types to a density of fuel on a scale of 0% (no fuel, such as for open water) to 100% (very high amount of fuel, such as for trees), using a rudimentary mapping (for the sake of demonstration, and not intended to be sound or valid for any practical purpose), is available from:

https://maps.gnosis.earth/ogcapi/collections/wildfire:S2VegetationFuelDensity.

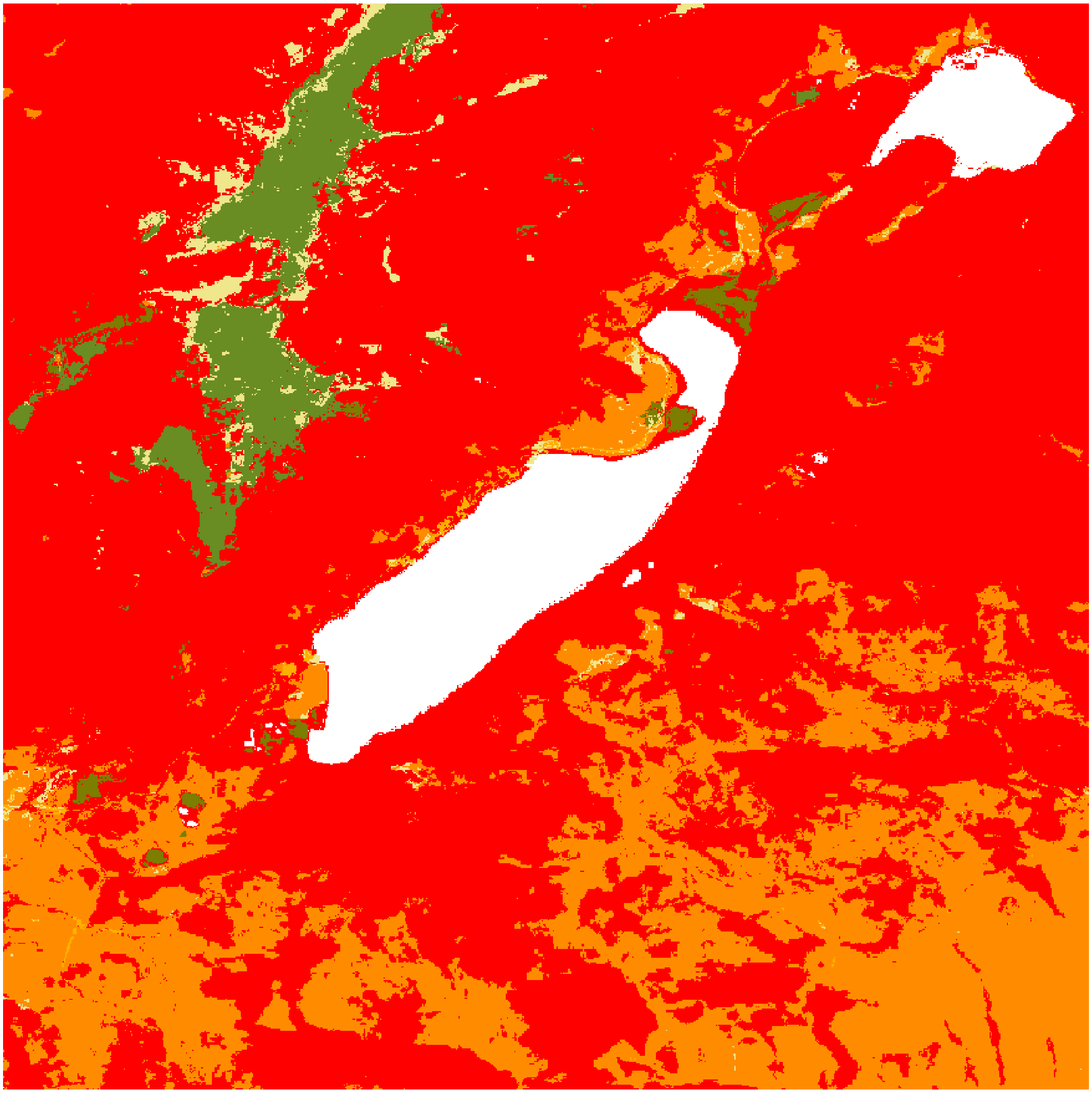


Figure 46 — Wildland Fire Fuel Indicator Workflow - Mapping predicted vegetation types to fuel density

6.5.5.1. Challenges and lessons learned

Training a model using different areas poses challenges as it yields RandomForest classifiers with incompatible estimators. In order to address this problem, this compatibility is assessed based on the resulting classes and the training process maintains a list of potentially more than one classifier. During prediction, the output of these different classifiers must be re-combined in a sensible manner to produce a single meaningful result.

Remapping the fuel vegetation types to a higher level classification through derived fields expressions, in order to demonstrate more meaningful and comprehensive results, was cumbersome in this case as it required very long expressions. In the case of requesting coverage tiles across server boundaries, this resulted in 414 HTTP errors due to very long URL queries, which required adjusting server configurations. Since conditional expressions are not part of the initial version of the OGC Common Query Language (CQL2), GNOSIS CMSS expressions were used instead. The server required adjustments to URL encoding and decoding since the usual representation for the and operator (`&`) as well as the `?` conditional operator in CMSS conflict with the encoding of query parameters inside URLs for HTTP GET requests.

The use of a larger area of study with which to generate a training model would yield more accurate results, but would also require significantly more time for downloading and processing satellite imagery, training the machine learning model, as well as result in larger classification decision tree which would in turn slow down prediction as well.

6.5.5.2. Updates and applications

The use of a further improved version of this wildfire indicator could potentially help stakeholders and responders plan and make informed decisions in preparation for wildfire disaster scenarios.

6.5.6. Discussion and future developments

Ecere considered a number of ways in which the indicator could be further improved:

- One aspect would be using deep neural networks instead of decision trees for classification, which may yield better prediction results and scale better to different areas and times of interest.
- The performance of the indicator itself could also be greatly improved, notably by keeping the machine learning model loaded in memory instead of constantly reloading it.
- There is also still room for improvement for the underlying sentinel-2 datacube hosted on the GNOSIS Map Server demonstration end-point, such as by improving how the Cloud Optimized GeoTIFF tiles are being requested through HTTP range requests.
- Newer scenes since October 2022 are not currently available from the sentinel-2 datacube and needs to be added. An automated mechanism to update the datacube with the newest data at least on a daily basis is also planned.
- Using additional input data for both training and prediction would also be of interest, including other wildfire fuel-related datasets available from *landfire.gov*, such as Fire Behavior Fuel Models, Canadian Forest Fire Danger Rating System, Forest Canopy Base Height, Forest Canopy Bulk Density, Forest Canopy Cover, Forest Canopy Height, Fuel Vegetation Cover, Fuel Vegetation Height, as well as the fire danger indices and climate data available from the Copernicus Climate Data Store.
- After completing the above, concretely assessing the value of accuracy and value of the indicator for stakeholders, requesting feedback from domain experts, addressing issues and implementing suggested improvements.

6.6. Data — Service — Workflow — Application Catalog & Registry (by Inter-American Collaborators)

For this activity, collaborators and stakeholders came together to research, architect, and engineer solutions that address gaps and barriers to utilizing Spatial Data Infrastructures and geospatial capabilities that utilize a data service workflow and application registering to improve discovery, access, and use of geospatial data, information, and services to support resilience. SDI's require collaboration among government agencies, research institutions, private companies, and individuals who work together to harness the power of spatial data to make informed decisions, solve complex problems, and improve various aspects of our world through location-based insights.

The collaborators in this component of the pilot included FGDC Geopathways, Voyager Search, Esri, AmeriGEO, HSR Health and FGDC partners. Additional organizations from the federal, state, local, commercial, and academic sectors contributed expertise, content, infrastructure, license, software, and other resources that were integrated into the registry as well as many providers. This component of the engineering report provides insight to the orchestration, architecture, development and engineering work of the collaborators, and provides use case demonstrations for interested communities.

6.6.1. Introduction to the company and main activities

6.6.1.1. About FGDC, USGS and GeoPathways

The USGS is a primary Federal source of science-based information on ecosystems, land use, energy and mineral resources, natural hazards, water use, and availability, and updated maps and images of the Earth's features available to the public. The United States Federal Geographic Data Committee (FGDC) is an organized structure of Federal geospatial professionals and constituents that provide executive, managerial, and advisory direction and oversight for geospatial decisions and initiatives across the Federal government. The FGDC GeoPathways Initiative fosters and cultivates the future cohort of Geospatial Analysts and professional users specializing in geospatial data. The GeoPathways Initiative is rooted in the FGDC's extensive 25-year history of advancing geographic information utilization, mainly through establishing the National Spatial Data Infrastructure (NSDI). Over 34 GeoPathway interns participated in the OGC's 2023 Disaster Pilot and helped us deliver on three in-kind deliverables.

6.6.1.2. About AmeriGEO

The AmeriGEO initiative is a framework that seeks to promote collaboration and coordination among the Group on Earth Observations members in the American continent, "to realize a future wherein decisions and actions, for the benefit of the region, are informed by coordinated, comprehensive and sustained Earth observations and information". Of the 35 sovereign states in the Americas, 21 countries have become formal members of the Group on Earth Observations, with others as observers.

6.6.1.3. About Voyager Search

Voyager Search's mission is to offer state-of-the-art search and retrieval solutions, aiding organizations in realizing the full potential of their data. They provide innovative technology that seamlessly links data, workflows, and decision-making processes, ultimately enabling organizations to make smarter, more informed decisions with increased speed.

6.6.1.4. About ESRI

Esri stands as the foremost global entity within geographic information system (GIS) software, location intelligence, and cartography. For over five decades, we have provided invaluable assistance to clients through the application of geographical science and geospatial analysis, a domain we aptly refer to as The Science of Location.

6.6.1.5. Main activities

The collaborating organizations worked together to address the following objectives:

- Establishment and integration of service(s) and associated application(s) supporting near-real-time registration, search, and discovery of ARD data sources, DRI workflows, and DRI-focused applications.
- Discovery of and access to geospatial framework datasets, contextual social-political-health data, and crowd-sourced / volunteered observations from impacted areas.
- Synchronous request-response and asynchronous publish-subscribe-notify interactions.
- Harvesting of ARD and DRI metadata to support other federated disaster information data platforms.

6.6.2. Background and problem description

When disasters strike, emergency responders and decision-makers need timely access to actionable information that reduces the loss of life, limb, and property. The ability to search, acquire, and utilize data with efficient workflows that provide decision-makers with authoritative data at an accelerated pace before, during, and after a disaster. Wildfires have become increasingly devastating and frequent in recent years, posing significant challenges to public safety and the environment. These wildfires are often exacerbated by prolonged periods of drought, which create the ideal conditions for rapid fire spread.

Similarly, droughts, oil spills, climate (energy and GHG nexus) impacts not only water availability but also, environmental health, food security, as agriculture heavily depends on reliable water resources. These circumstances necessitate comprehensive strategies for water resource management and conservation, while fostering citizen science initiatives to monitor and address the impending water crisis.

Organizations who are collaborators to this registry added high-value datasets that support indicators such as: economic stress, drought mortality risk, food security risk, economic security, and socioeconomic security. They provided map service layers that displayed analysis ready data (ARD) in the form of ArcGIS map service layers.

In response to these escalating threats, there is a growing need for modernized SDI's that improve the utility and currency of locational data in order to foster enhanced interoperability between stakeholders who respond to and/or are affected by such disasters. The prototypes developed in this pilot provides innovative standards based solutions that support stakeholders in addressing barriers, improving disaster planning, management operations, and enhances public understanding of these challenges.

6.6.3. Objectives and role in the pilot architecture

For this pilot, participants focused on research and engineering of an ISO 11179 complaint registry that supports W3C DCAT, ISO, and OGC standards. Collaborators engaged stakeholders throughout the community to understand their requirements for geospatial framework datasets that address specific indicators, and worked broadly with local-to-global providers to mobilize high-value social, economic, and environmental data. These sources were used to generate a wide range of datasets and models made available for search and retrieval that supports disaster resilience. This includes national and international governmental, commercial, academic, and organizational resources utilizing standard and non-standard open and proprietary application interfaces that comply with W3C DCAT, ISO, and OGC standards. Collaborators engineered workflows that supported manual and automated ingesting of data and other content from open sources around the world across a wide variety of entities and geographies.

Objectives in the pilot architecture include:

1. Research, development, and testing of GIS solutions.
2. Clearly defining indicators to mobilize high-value and high volume datasets.
3. Improving discovery, access, and usability.
4. Providing efficient workflows that support data transformation to insights, intelligence, and knowledge.

6.6.4. Methodology

6.6.4.1. Area of study

The registered data holdings, and services were integrated into three OGC compliant GIS platforms where a variety of use cases were conducted to determine discoverability, accessibility, and useability of the content, data and services. The use cases for the engineered solutions were applied in North America, Central America, South America and Africa.

6.6.4.2. Topical and Thematic Areas of Study

Disasters:

- Wildfires
- Droughts
- Floods
- Oil Spills

Disaster Resilience — Natural hazards have become increasingly devastating and frequent in recent years, posing significant challenges to public safety and the environment. These wildfires are often exacerbated by prolonged periods of drought, which create the ideal conditions for rapid fire spread. In response to these escalating threats, there is a growing need for innovative solutions to mitigate wildfires and droughts, improve disaster management planning and operations lifecycle, and enhance public understanding of these complex phenomena.

Wildfires have become increasingly devastating and frequent in recent years, posing significant challenges to public safety and the environment. These wildfires are often exacerbated by prolonged periods of drought, which create the ideal conditions for rapid fire spread. In response to these escalating threats, there is a growing need for innovative solutions to mitigate wildfires and droughts, improve disaster management planning and operations lifecycle, and enhance public understanding of these complex phenomena.

Climate Resilience:

- Ecosystems Health
- National Capital Accounting
- Energy Security
- Mitigation of Greenhouse Gas Emissions

6.6.4.3. Technical Design

The team initiated the project with a people, process, and tools engagement strategy that began with stakeholder interviews and discussions to better understand the challenges, barriers, and issues they experience discovering, accessing, and utilizing geospatial data and information. These stakeholders included wildland firefighters, executives, data providers, solution architects, scientists, and other stakeholders. Key challenges of the design included:

- Knowledge of available resources

- Discovering, acquiring, and utilizing resources
- Geospatial literacy
- Extracting decision indicators from the “mass” of analysis-ready data provided

Technical design included researching and testing open-source and commercial products that provide standards-based registry and search capabilities to respond to address the gaps and barriers identified by stakeholders. The team selected TerriaJS, a GIS open-source framework for web-based geospatial cataloging, search, and workflow, ArcGIS Online and ArcGIS Hub which are accessible in a cloud-based GIS environment that provides cataloging, search, development of workflows, access to models and additional software for processing data and Voyager Search which is a spatially enabled data cataloging and information retrieval solution that provides workflow and model integration capabilities. Open data and OGC standards were utilized whenever possible along with custom programming to access resources identified by stakeholders.

6.6.4.4. Technical or health implementation

Utilizing the three platforms aforementioned the collaborators worked with stakeholders register content and utilize automated retrieval methods and approaches to establish discovery and access capabilities. OGC and open-source API standards along with additional access methods were utilized with connector frameworks to discover, extract, transform, and load GIS data, imagery, applications, tools, models, and other resources. In this report the collaborators in a step-wise approach utilized each of the technologies to develop and engineer solutions that respond to stakeholder requirements. In each section objectives, architecture, standards, foundational data, themes and topics are highlighted.

6.6.4.5. D100.1 Open Source Registry | TerriaJS

6.6.4.5.1. Introduction

Natural disasters and the effects of climate change are becoming more frequent and severe, it’s crucial to have efficient systems in place to both mitigate and respond to these challenges. Disasters and climate resilience coordination combined with streamline access to vital Information is crucial to modern emergency management and climate adaptation strategies.

The collaborators in this component of the pilot selected TerriaJS an open source GIS platform that is architected to support W3C, ISO, and OGC standards to demonstrate the ability to develop efficient registries and workflows to support. The TerriaJS GIS Platform provides cataloging, mapping, analytics and workflow capabilities. The Terria map enables collaborators and stakeholders to search, view, and explore catalogs of geographic tiles and services. URL-encoded parameters can be used in TerriaJS to extend and augment map visualization and behavior, initiate workflows using OGC web processing and other standard API services.

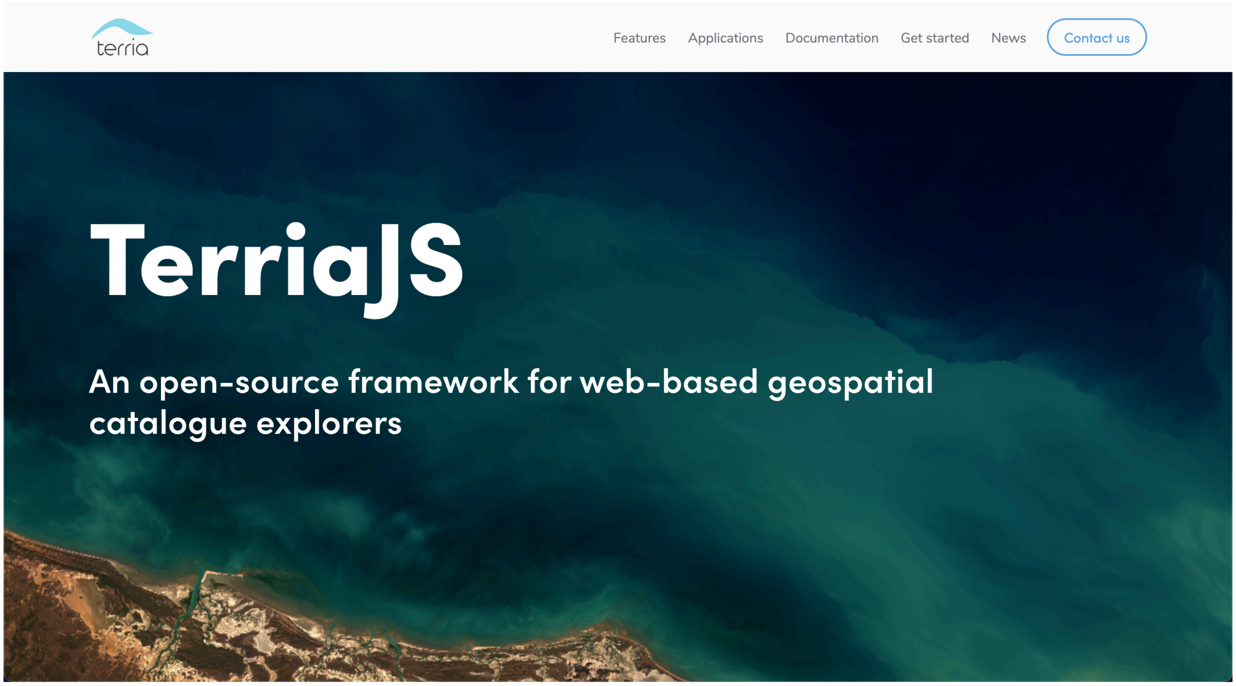


Figure 47 — The TerriaJS landing page

Role based access to content can be established through additional programming. TerriaJS used in conjunction with Open Standards-based APIs, can connect different types of datasets, or service types and can be configured as TerriaJS loads. Stakeholders also have the ability to add OGC compliant web services. TerriaJS utilizes JSON formatted files to add content, workflows, access models, and return results. TerriaJS isn't currently a cloud based service offering but can be run in the cloud. Collaborators in this project leveraged existing TerriaJS instances hosted by inkind contributors including AmeriGEOSS, GeoPlatform.gov, Digital Earth Africa and established a test instance running in a service-based virtual environment. Collaborators also established a demonstration that will be ported into the OGC persistent demonstrator.

Pilot Elements Addressed

Table 2

Architecture & Engineering:	Registries	Workflow	Mobility	Visualization				
Data Themes:	Land Use	Biodiversity	Social	Health	Climate	Economic	Infrastructure	
Data Topics:	Governance	Authoritative	Profiling	Quality	Provenance	Lineage	Reproducibility	Analysis Ready
Topical Elements:	Disaster Resilience	Wildfires	Drought	Flood	Climate	Ecosystems Health		

Video of Geoplatform visuals of the TerriaJS interface demonstrating wildfire indicators and live fires detected on October 18, 2023.

Link: https://vimeo.com/880531873?share=copy

6.6.4.5.2. TerriaJS Step 1. Establishing the TerriaJS Registry

Stakeholders identified key indicators that formed decision-making and sources of authoritative data including socio-economic, environmental, Earth observations and other data that could support the development of analysis ready data. The collaborators completed an inventory of the most relevant data to address the use cases identified by stakeholders, identified modes and methods to access the data through standard and non-standard methods, and developed the JSON code required by TerriaJS for each resource identified by stakeholders into the catalog, and then established workflows that respond to stakeholder indicators.

The process to add each of the resources requires approximately four to five lines of code to add each item into the catalog or TerriaJS supports 15 different native catalog types for bulk loading of content from catalogs such as CKAN, CSW and ArcGIS. The image in the AmeriGEO figure provides an example of the code developed and implemented on the AmeriGEOSS Terria Catalogue. The code represents web services that provide information on population migrations that may be attributed to environmental changes. The code for the following figure represents web services that provide health indices for mortality risk, and health medical supply needs index at different government geographical unit levels.

AmeriGEOSS / config.json

Top

Code | Blame | 3430 lines (3405 loc) · 305 KB | Code 55% faster with GitHub Copilot | Raw


```json
                    "name": "Human Footprint",
                    "type":"group",
                    "items":[
                        {
                            "name": "1993 Human Footprint",
                            "type":"wms",
                            "url": "https://sedac.ciesin.columbia.edu/geoserver/ows?service=wms&version=1.3.0&request=GetCapabilities",
                            "layers":"wildareas-v3:wildareas-v3-1993-human-footprint"},
                        {
                            "name": "2009 Human Footprint",
                            "type":"wms",
                            "url": "https://sedac.ciesin.columbia.edu/geoserver/ows?service=wms&version=1.3.0&request=GetCapabilities",
                            "layers":"wildareas-v3:wildareas-v3-1993-human-footprint"
                        }
                    ]
                },
                {
                    "name": "Population Dynamics",
                    "type": "group",
                    "items": [
                        {"name": "Global Estimated Net Migration by Decade: 1970-1980",
                            "type":"wms",
                            "url": "https://sedac.ciesin.columbia.edu/geoserver/ows?service=wms&version=1.3.0&request=GetCapabilities",
                            "layers":"popdynamics:popdynamics-global-est-net-migration-grids-1970-2000_1970-1980"},
                            {"name": "Global Estimated Net Migration by Decade: 1980-1990",
                            "type":"wms",
                            "url": "https://sedac.ciesin.columbia.edu/geoserver/ows?service=wms&version=1.3.0&request=GetCapabilities",
                            "layers":"popdynamics:popdynamics-global-est-net-migration-grids-1970-2000_1980-1990"},
                            {"name": "Global Estimated Net Migration by Decade: 1990-2000",
                            "type":"wms",
                            "url": "https://sedac.ciesin.columbia.edu/geoserver/ows?service=wms&version=1.3.0&request=GetCapabilities",
                            "layers":"popdynamics:popdynamics-global-est-net-migration-grids-1970-2000_1990-2000"}
                    ]
                },
                {
                    "name": "Total Population",
                    "type": "group",
                    "items": [
                        {"name": "Global Population 1-8th Degree_Total Pop Base Year 2000",
                            "type":"wms",
                            "url": "https://sedac.ciesin.columbia.edu/geoserver/ows?service=wms&version=1.3.0&request=GetCapabilities",
                            "layers":"popdynamics:popdynamics-1-8th-pop-base-year-projection-ssp-2000-2100-rev01_total-pop-ssps-byr-2000"}
```


Figure 48 — TerriaJS Catalog coding process that is required to register data, workflows, and tasks into TerriaJS. Adding services into AmeriGEO TerriaJS for human migration.

```
{
  "catalog": [
    {
      "name": "Disaster Pilot Indices",
      "type": "group",
      "items": [
        {
          "name": "Health Indices",
          "type": "group",
          "items": [
            {
              "name": "Louisiana Mortality Risk Index",
              "type": "wms",
              "url": "https://opengeomd.hsrhealthanalytics.org/geoserver/geonode/ogc_la_tract_mri/wms?
              service=wms&version=1.3.0&request=GetCapabilities",
              "layers": "ogc_la_tract_mri",
              "description": "The HSR.health COVID-19 Mortality Risk Index for Louisiana was developed for the Open Geospatial
              Consortium's 2021 Disasters Pilot.  The Mortality Risk Index is the mortality rate weighted prevalence of the age
              demographics of the population inconjunction with co-morbidities like diabetes and cancer.  The index values range from 0
              to 100 with 0 being the least risk and 100 being the highest risk. Data sources used to create this index include: U.S.
              CDC, and the U.S. Census Bureau"
            },
            {
              "name": "County Health Risk Index",
              "type": "esri-featureServer",
              "url": "https://services6.arcgis.com/Z3WOwmt1JSptvdPT/arcgis/rest/services/National_Health_Risk_CNTY/FeatureServer/0",
              "description": "The HSR.health Health Risk Index was developed for the Open Geospatial Consortium's 2019 Disasters
              Resillience Pilot.  The Health Risk Index's purpose is to inform emergency responders and decision makers on the underlying
              health posture of Disaster Impacted populations to inform the health-response to those disasters.  This layer is the county
              level of this analysis and expands upon the social vulnerability index through the addition of health metrics. The data
              sources used to create this index include: U.S. CDC, U.S. Census Bureau, U.S. CMS, The Dartmouth Institute for Health
              Policy and Clinical Practice, U.S. HHS, AmeriGEO."
            },
            {
              "name": "ZIP Code Health Risk Index",
              "type": "wms",
              "url": "https://opengeomd.hsrhealthanalytics.org/geoserver/geonode/layernationalziphurricanehealthriskindex/wms?
              service=wms&version=1.3.0&request=GetCapabilities",
              "layers": "layernationalziphurricanehealthriskindex",
              "description": "The HSR.health Health Risk Index was developed for the Open Geospatial Consortium's 2019 Disasters
              Resillience Pilot.  The Health Risk Index's purpose is to inform emergency responders and decision makers on the underlying
              health posture of Disaster Impacted populations to inform the health-response to those disasters.  This layer is the county
              level of this analysis and expands upon the social vulnerability index through the addition of health metrics. The data
              sources used to create this index include: U.S. CDC, U.S. Census Bureau, U.S. CMS, The Dartmouth Institute for Health
              Policy and Clinical Practice, U.S. HHS, AmeriGEO."
            },
            {
              "name": "Peru Admin 03 Medical Supply Needs Index",
              "type": "wms",
              "url": "https://opengeomd.hsrhealthanalytics.org/geoserver/geonode/ogc_peru_ppe_needs_20210303/wms?
              service=wms&version=1.3.0&request=GetCapabilities",
              "layers": "ogc_peru_ppe_needs_20210303",
              "description": "The HSR.health Medical Supply Needs Index for Peru was developed for the Open Geospatial Consortium's 2019
              Disasters Resillience Pilot.  The Medical Supply Needs is an estimate of the Personal Protective Equipment needed for any
              particular geography based upon the population, the severity of covid, and the prevalence of at-risk populations.  Data for
              the medical supply needs index came from Platforma Nacional de Datos Abiertos, Statista, Instituto Nacional de Estadistica
              e Informatica, Google, The Humanitarian Data Exchange, and Open Street Maps."
            }
          ]
        },
        {
          "name": "Infrastructure Data",
          "type": "group",
          "items": [
```


Figure 49 — TerriaJS Catalog coding process that is required to register data, workflows, and tasks into TerriaJS. Adding services into AmeriGEO TerriaJS for health indices.

Video showing how to manually add data into the TerriaJS Registry.

Link: <https://vimeo.com/880531439?share=copy>

References

TerriaJS Supported Catalog Groups: https://docs.terria.io/guide/connecting-to-data/catalog-groups/

Image Content of TerriaJS Configuration: https://github.com/geo-geoss/AmeriGEOSS/blob/master/config.json

6.6.4.5.3. TerriaJS Step 2. Search and Discovery

Once the catalog was established stakeholders were asked to search the registry to determine the efficiency in discovering, accessing, and use of resources of interest. Stakeholder testing included textual and parameter based searches, use of faceted and folder based filtering to retrieve data and services. Collaborators and stakeholders provided feedback that included recommendations to improve the descriptors provided for each content item, to classify/organize, tag content in the registry to make it easier to find content, and to register additional high-value datasets provided by stakeholders. These recommendations were implemented to increase the amount of metadata that was provided to improve search and discovery.

The below reference links provides an example from HSR Health that integrates health indices into the TerriaJS registry:

1. https://data.amerigeoss.org/ameriterria/#/https://analytics.hsrhealthanalytics.org/hsrterriamap/hsr_health_terriav7.json
2. https://analytics.hsrhealthanalytics.org/hsrterriamap/hsr_health_terriav7.json

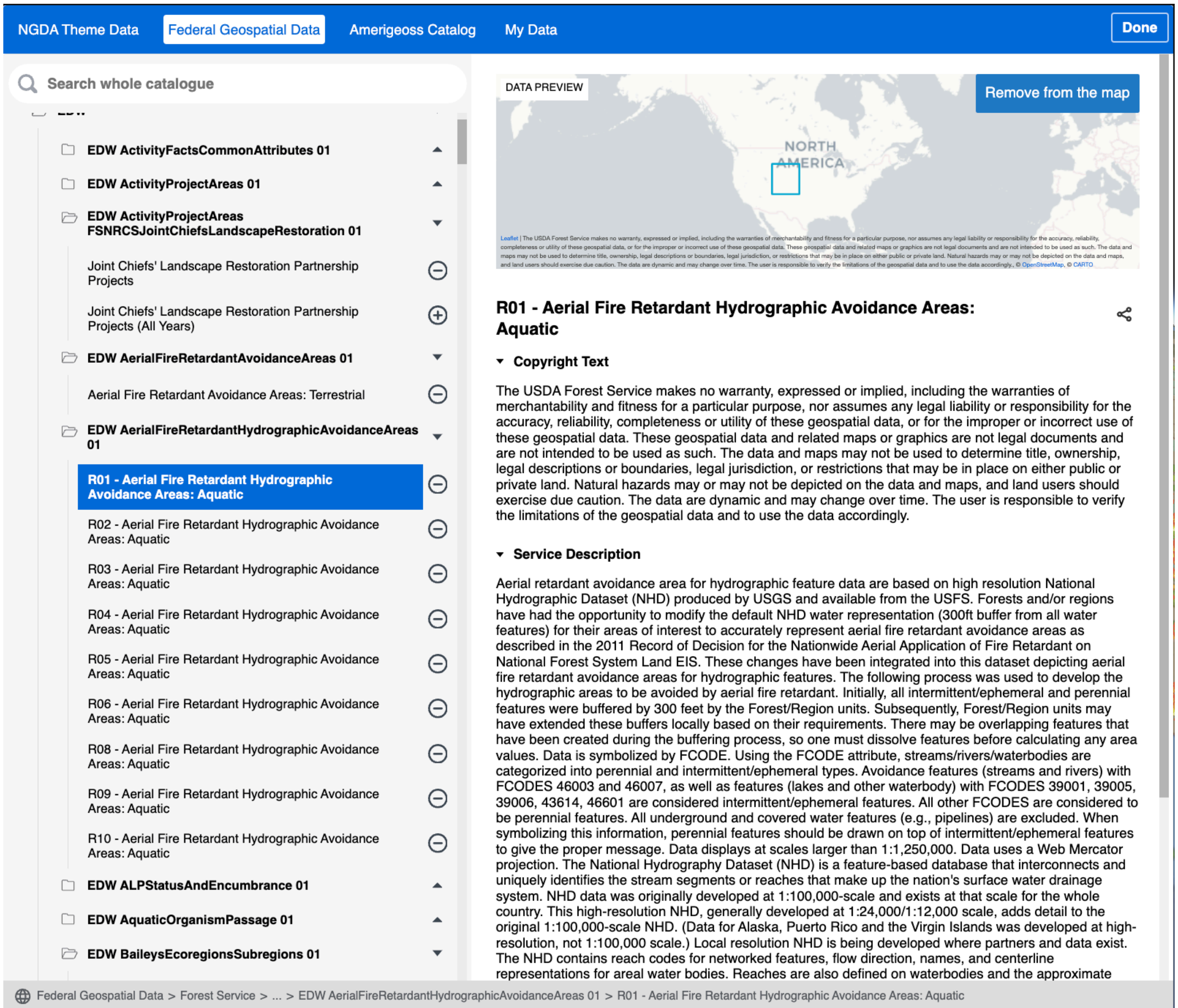


Figure 50 — NGDA fundamental data is represented in this visual from the U.S. GeoPlatform.gov with search options, and curated categorized datasets.

6.6.4.5.4. TerriaJS Step 3. Mapping and Analytics

6.6.4.5.5. Use Case #1. Communities at Risk

Resilience in the context of disaster and climate change extends beyond environmental impacts and physical infrastructure and preparedness; it also encompasses the capacity to address public health issues that may arise as a result of these events. As the climate evolves, so does natural hazards that include drought, wildfires and hurricanes, and the distribution of disease vectors like mosquitoes and ticks, leading to an increased risk of vector-borne diseases such as malaria, dengue fever, and Lyme disease. Furthermore, zoonotic diseases that transfer between animals and humans, like COVID-19, can be exacerbated by environmental changes particularly in relation to changing temperatures, humidity and drought conditions. While our ability to influence the environment may be more challenging and limited, we can better influence particular preparatory human factors. Building resilience against these health threats necessitates adaptable public health systems, analysis ready data, monitoring, forecasting, early warning mechanisms, and interdisciplinary approaches that consider both ecological and human factors. An integral component of climate and disaster resilience lies in our ability to safeguard public health by addressing the growing challenges posed by natural hazards including the frequency and occurrence of vector-borne and zoonotic diseases in a changing world.

In this step participants tested the ability to find and use SDI foundational data, topical and thematic data products, in TerriaJS to address public health threats related to changes in climate and natural hazards. Participants were asked to search for resources, map the resources and build a story using the built in TerriaJS story feature, include map layers and content that addresses health, economic, wildfire, drought, weather, wind and other data points to provide insights and intelligence to support understanding and decision-making.

HSR health is a provider of GEOHealth data, insights and intelligence. During Step 1, HSR Health provided analysis-ready indicator-based data products that were coded for infestation into TerriaJS. Generative health analytics provided mortality risk indicators based on foundational data, socio-economic and environmental data that was registered into the registry.

The video link below illustrates content discovered and accessed in TerriaJS catalogues and added to the map. Content added to the map includes socio-economic information related to fire risk, active fires, drought mortality risk indicators and are projected using OGC WMS and ArcGIS rest services.

Video of the HSR Health Risk Index across various locations in the United States in TerriaJS.

Link: https://vimeo.com/880552857?share=copy

6.6.4.5.6. Use Case #2. Open and Participatory Science

During the course of the pilot, collaborators in support of **DP23 D113 Crowdsourcing and Open Science** objective, engaged citizen scientists to map features with the goal of demonstrating transactional interoperability of crowdsourced contributed data ingestion into GIS platforms. Our open science community is utilizing OpenStreetMap, OSM Hydrant, OSM Buildings and Streets.gl to map and visualize structures, vegetation, fences, power lines, fire hydrants, water towers, roads, terrain and other features that can be used to understand potential sources of fuel for a fire. For example, we have illustrations of our OpenStreetMap US projects shown below of Beaumont, California that was affected by the 2023 Rabbit Wildfire from July 14 to 22. The other illustration shows our OpenStreetMap US project of Maui, Hawaii which was affected by the 2023 Maui Wildfires that occurred from August 8 to 11. For these projects, the open science community successfully mapped hundreds of structures, trees, fences and other features that contribute to disaster risk in order to support the enhancement of ARD (Analysis Ready Data) and DRI (Decision Ready Indicator) services. These activities aim to deliver information applications to local citizens and open scientists to allow them to map areas and build datasets, optimizing open-source hybrid-cloud services, and eventually scaling mobile-ready applications that can improve disaster awareness, risk reduction and prevention in any area of interest that these practices could be applied to.

Video showing a walkthrough of the GeoPathways OpenStreetMap US project for Beaumont, California.

Link: https://vimeo.com/880517423?share=copy

Video showing a walkthrough of the GeoPathways OpenStreetMap US project for Kahului, Hawaii.

Link: https://vimeo.com/880517468?share=copy

TerriaJS, ArcGIS and Voyager support the use of OGC compliant tile services. Collaborators and stakeholders were generally able to retrieve these new features within minutes after adding. In support of **DP23 D110 Immersive Visualization**, the community also tested the ability to ingest the added features into OSM Buildings and Streets.gl that support OGC 3D titles standards. The below graphic illustrates community mappers adding features into OSM and then visualizing the content in OSM Building and Streets.gl.

6.6.4.5.7. Use Case #3. Communities and Drought

In the year 2022, droughts have taken a toll on communities across the world, affecting regions as diverse as Africa, Canada, and the United States. These arid conditions have threatened agricultural livelihoods, access to clean water, and food security, leading to dire consequences for communities.

- In Africa, especially in countries like Ethiopia and Somalia, prolonged droughts have exacerbated food shortages and water scarcity, further stressing vulnerable populations.
- Canada has experienced severe droughts in its western provinces, impacting its agricultural output and natural ecosystems.
- Similarly, the United States has not been immune to the effects of drought, with states like California grappling with water shortages and wildfires.

TerriaJS, a 3D open-source data visualization software, uses drought analysis-ready data and has emerged as a powerful tool for stakeholders to tackle drought-related challenges. By mapping and modeling geographical data in three dimensions, decision-makers can gain a holistic view of a community's spatial and temporal drought dynamics. This enables them to make more informed decisions, allocate resources efficiently, and implement targeted solutions to mitigate the impacts of drought and promote resilience in these affected communities.

The below pictures illustrate content discovered and accessed in various TerriaJS catalogues and added to the map. Content added to the map includes socio-economic information related to fire risk, active fires, drought mortality risk indicators and are projected using OGC WMS and ArcGIS rest services.

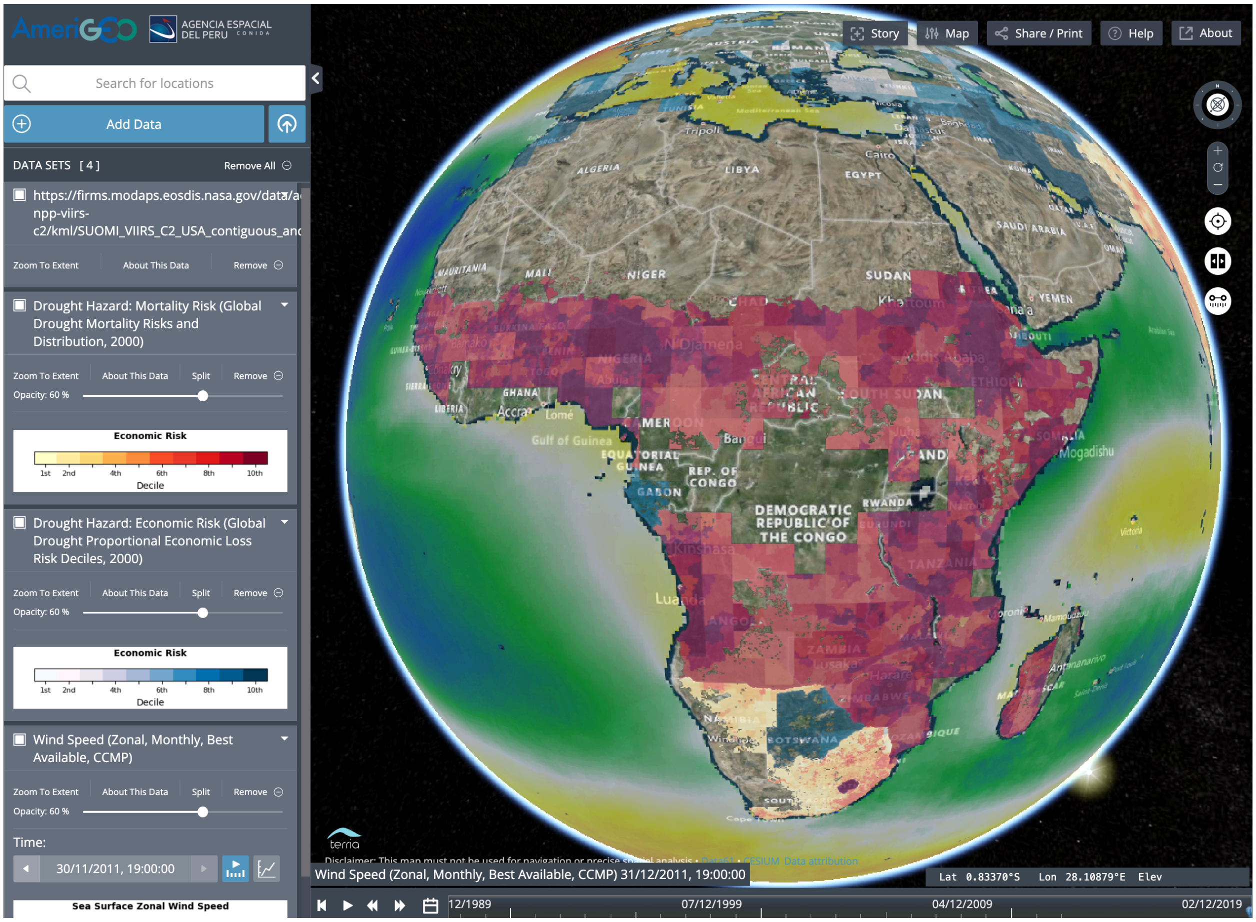


Figure 51 — This visual represents a search for drought related indicators and the results mapped in Africa within AmeriGEO TerriaJS.

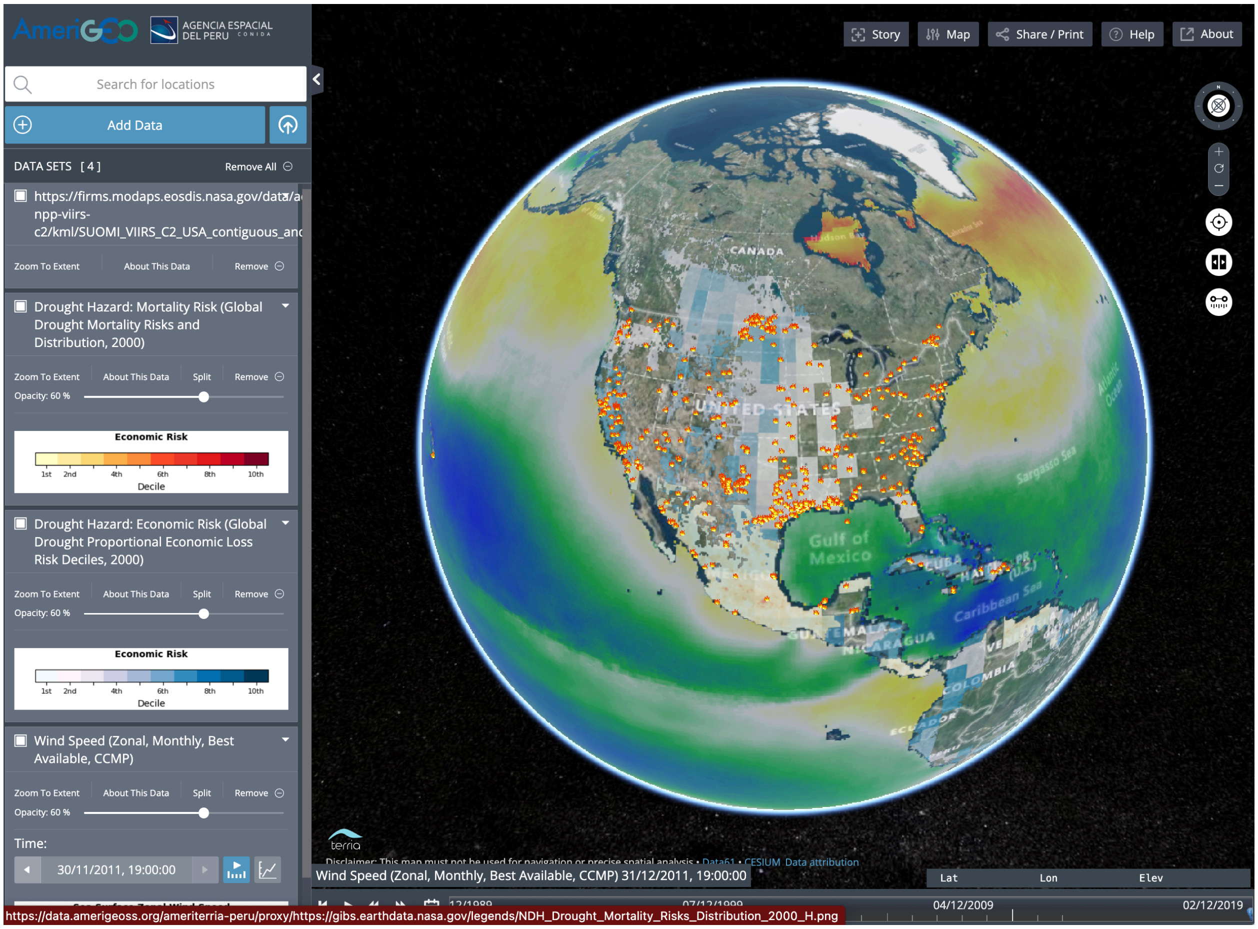


Figure 52 — This visual represents a search for wildfire related indicators and results mapped in North America utilizing NASA Firesense and other data available in AmeriGEO TerriaJS.

Terria AmeriGEO Demo 1 Reference: https://terriamap.geoplatform.gov/#share=s-bcQElvnmMWnu1JeQjIe7r5VhGAE

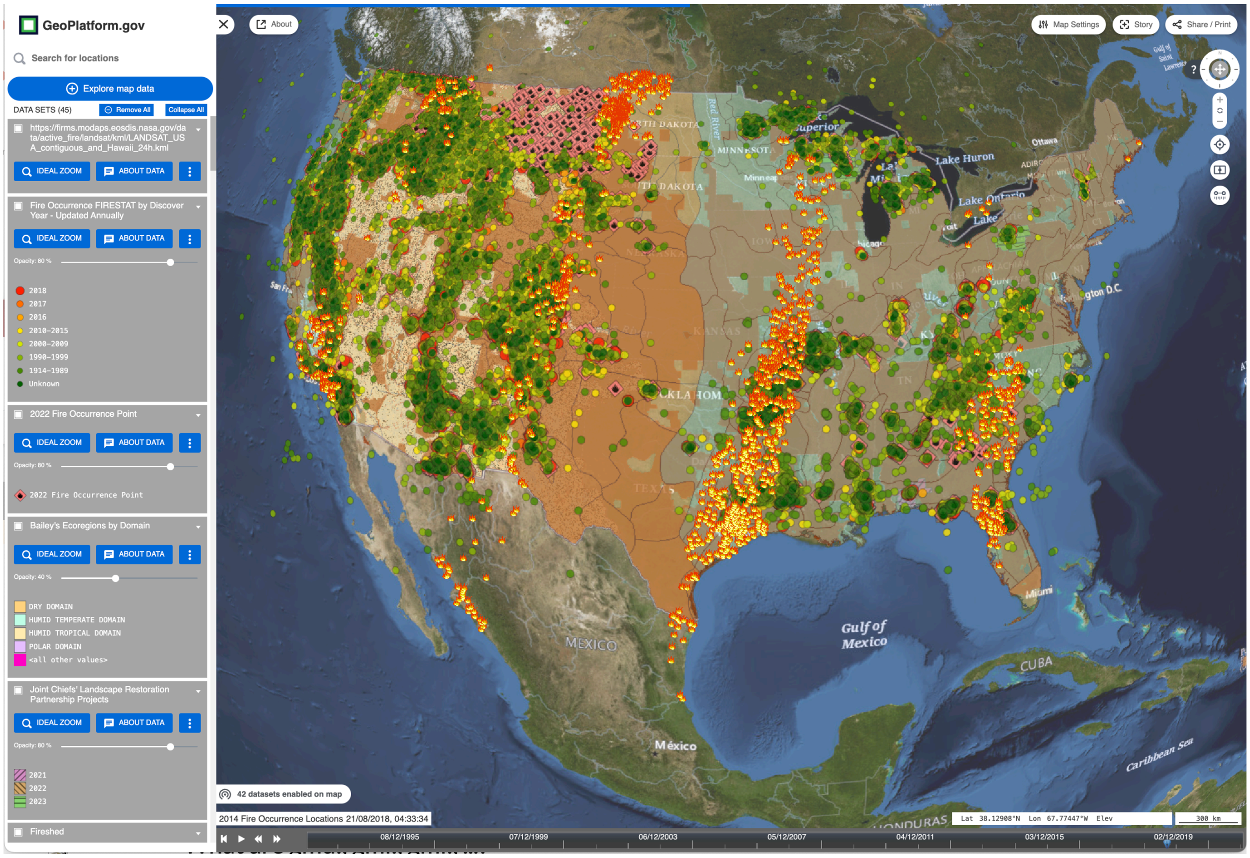


Figure 53 — This visual represents a search for fire related data in the United States and results mapped in AmeriGEO TerriaJS.

Terria AmeriGEO Demo 2 Reference: https://terriamap.geoplatform.gov/#share=s-mLywZze5w8HUhikrWtn5juhtrIo

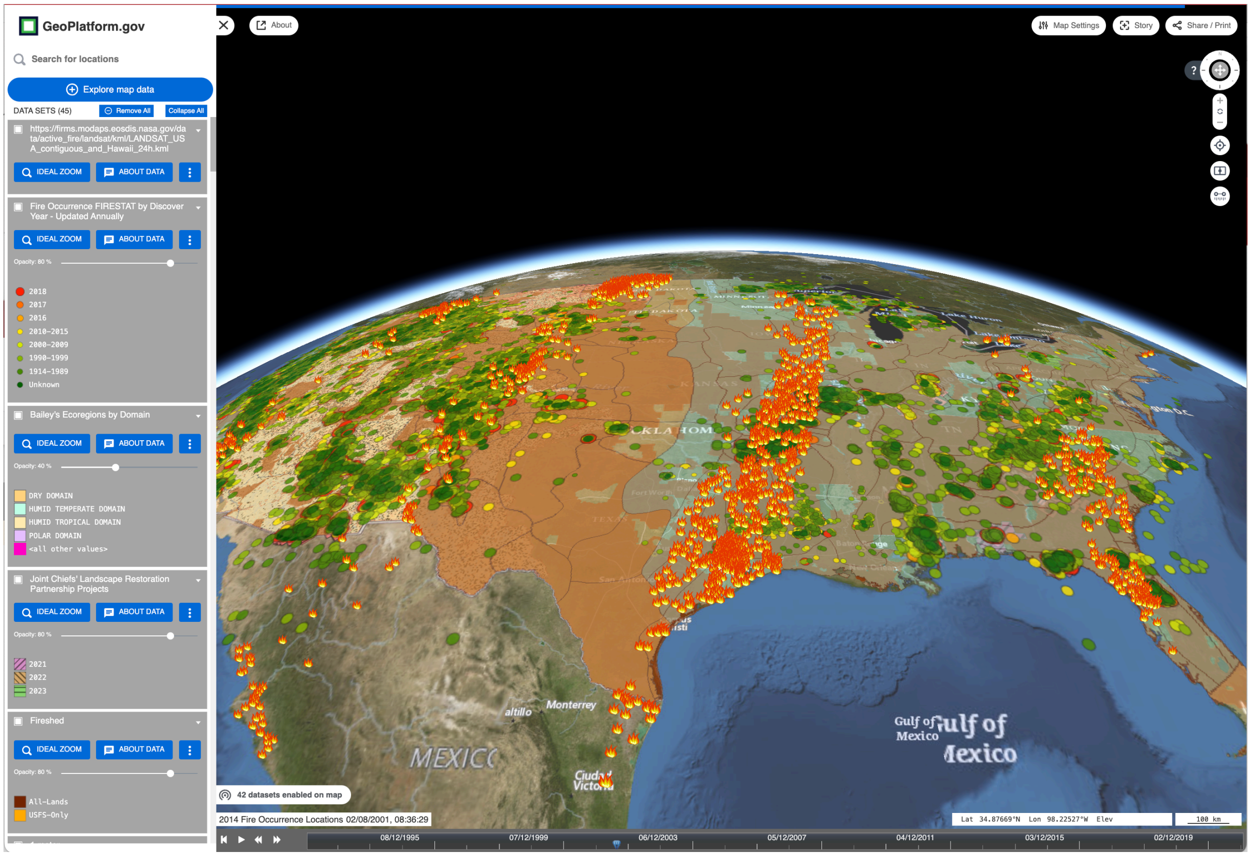


Figure 54 — This visual represents a search for fire related data in the United States and results mapped in AmeriGEO TerriaJS from an oblique view.

6.6.4.6. TerriaJS Step 4. Workflow and Analytics

Workflows in TerriaJS are established in a similar fashion to establishing a catalog using JSON where a call can be made to models that are hosted by partner organizations. Other supported data formats can be used including both geospatial (GeoJSON, KML, WMS) and non-geospatial (CSV, JPG, JSON). Using TerriaJS, practitioners can easily analyze the underlying data from map features or external data sources, using rich and interactive charts, running statistical analysis and exporting the results. Participants can select a location, enter parameters and TerriaJS will provide responsive information using OGC standard protocols.

TerriaJS Reference WPS in Terria: https://docs.terria.io/guide/connecting-to-data/catalog-type-details/wps/

Additional information related to GeoPlatform TerriaMap can be found at Terria Map Demo.

Video demonstrating a variety of workflows that include providing vegetative cover, streamflow, land surface temperature, NDVI, forestry, global protected areas and global administrative boundaries by entering parameters in AmeriGEO ClimaTerria.

Link: https://vimeo.com/880519823?share=copy

6.6.5. D100.2 Proprietary Registry | Esri's ArcGIS Online Disaster Hub

6.6.5.1. Introduction

Resilience coordinators and emergency responders require access to social, economic and environmental data that may include social, economic, environmental data, and specific documents and information to effectively plan for, respond to and recover from disasters. Coordination among various stakeholders, such as government agencies, non-governmental organizations, and local communities, is fundamental. Effective communication and collaboration between these entities enable better preparation, response, and recovery efforts during disasters and changing climate conditions. This coordination should encompass sharing critical data and information, aligning response strategies, and ensuring a unified approach to resilience-building.

Through stakeholder engagements collaborators learned that 47 States and more than 100 Counties, Cities and academic institutions utilize ArcGIS Hub to support their open data and GIS catalogue requirements. Utilizing ArcGIS hub the team was able to add OGC standards-based resources and files into the registry. The video link below demonstrates a source being added into the ArcGIS Hub to make the resource discoverable, accessible, and usable by collaborators and stakeholders.

(Link to ArcGIS Disaster Hub: https://ogc2023pilots-geoplatform.hub.arcgis.com)

Video of ArcGIS Data Registry including the home page, featured data, applications, data categories, data search, and map viewer.

Link: https://vimeo.com/880513076?share=copy

6.6.5.1.1. Pilot Elements Addressed

Architecture & Engineering:

- Registries
- Catalogs
- Workflows
- Mobile Apps
- Immersive Visualization
- Connectors

Data Themes:

- Environment

- Transportation
- Boundaries
- Economony
- Health
- Climatology

Data Topics:

- Governance
- Authoritative
- Lifecycle Management
- Profiling
- Quality
- Provenance
- Lineage
- Reproducibility
- Analysis Ready

Topical Elements:

- Disaster Resilience
- Wildfires
- Drought
- Flood Climate
- Ecosystems Health

6.6.5.2. ArcGIS Step 1. Content Registration into ArcGIS Online

The collaborators worked to identify key resources identified by stakeholders through the ArcGIS online network, ESRI Atlas, and many open data resource catalogs and repositories. The team registered over 533 total resources through ArcGIS Online. The hub registry supports the use of WC3 DCAT standards to provide an open API endpoint for stakeholders to programmatically search and retrieve content. The time to register each of these resources on average took 3 to 5 minutes each and if adding metadata it needed to be done manually, taking longer than 5 minutes per resource. ArcGIS Hub supports various file formats for data and resources, allowing stakeholders to work with a wide range of content. The hub also allows federation of open data groups within the ArcGIS ecosystem and partners can provide access to group content that can be manually added. The collaborators investigated the potential to bulk register resources into the ecosystem and the partner was able to demonstrate this capability in one of the collaborators' environments. The table below shows some common file formats that you can use within the ArcGIS Disaster Hub.

Provider data from national, state, county, local, commercial and international entities were registered into the hub through manually, federated, and API's curated into the Hub environment to support efficient search and discovery capabilities for the community. The video provided below shows a visual on how a contributor manually registers a resource into the ArcGIS Disaster Hub registry.

Video of process for the manual entering of data to the ArcGIS Hub Registry.

Link: https://vimeo.com/880538128?share=copy

6.6.5.3. ArcGIS Step 2. Establish ArcGIS Hub Community for discovery and access

Collaborators worked together to establish a hub community (hereafter referred to as "the registry") to register data, applications, tools, services, and educational resources to improve disaster resilience. The hub community supports the use of Standard HTML coding, OGC standards, the ability to add many file formats, and provides a W3C DCAT standard API connector to support programmatic access to the catalog by developers.

6.6.5.4. ArcGIS Step 3. Test Discovery of Content

After completing the content registry process in ArcGIS online, and establishing the hub community, collaborators and stakeholders utilized the search and discovery capabilities of the registry to evaluate the ability to quickly find and use responsive data and content. The registry provides many out of the box features that allow stakeholders to refine initial searches further.

This hub features an intuitive search box, enabling users to conduct queries based on locations and specific facets. It offers a suite of filters to refine these searches further, ensuring greater precision in the results. Additionally, the system retains a history of past searches, providing users with convenient access to their previous queries for future referencing.

Search and Discovery Options:

1. Text Search
2. Saved Search
3. Location
4. Facets
5. Filters

Video showing a walkthrough of the FGDC GeoPathways Community Resilience Registry Hubsite.

Link: https://vimeo.com/880513162?share=copy

Video showing a walkthrough of the AmeriGEO ClimaTerria Hubsite.

Link: https://vimeo.com/880501852?share=copy

6.6.5.5. ArcGIS Step 4. Data Profiling and Enrichment

Provider data from National, State, County, Local, commercial and international was registered into the hub through manually, federated, and API's curated into the Hub environment to support efficient search and discovery capabilities for the community.

Pilot Elements Addressed

Table 3 — Table of Supported ArcGIS Hub Formats

Spatial Data Formats	Tabular Data Formats	Document Formats
Shapefiles (SHP)	Comma-Separated Values (CSV)	Portable Document Format (.pdf)
GeoJSON	Excel spreadsheets (XLS, XLSX)	Image files (.jpg., .jpeg, .png, .tif, .tiff)
Keyhole Markup Language (KML/KMZ)	Database formats (SQL, SQLite)	Microsoft Excel (.xls, .xlsx)
File Geodatabase (GDB)	JSON	Microsoft PowerPoint (.ppt, .pptx)
GeoTIFF	XML	Microsoft Word (.doc, .docx)
OGC Formats (WMS, WFS, WCS)	Many other tabular data formats	

6.6.5.6. ArcGIS Step 5. Mobile Workflow and Ingest

Stakeholders highlighted the general need to address barriers to field-based data collection from participants. Participants in the pilot worked to demonstrate the ability to ingest data using geo-enabled mobile applications. Hikers, campers, forest rangers, and citizen scientists can help protect their favorite outdoor areas, by collecting data to assess and mitigate fire threats. Our collaborators developed a mobile app that allows stakeholders to take plant pictures with ESRI's QuickCapture and send the geo-located data to a hosted feature service layer. Utilizing workflow generated by python code in ArcGIS Notebooks, the ingested data is processed through Plant.id and Pl@ntNet API models to determine flammability, based on the health and species of the targeted plant. The processed data is registered into the feature layer and a notification is sent to the end-user. The user of the application is able to view insights on the potential flammability of the vegetation.

10:44
FLORA Fire Index
Should we add your t... to Open Street Maps
About Section/Log In
FLORA Flammability Index
Powered by
Pl@ntNet
The plant species identification service used
, is based on the Pl@ntNet API. Click to visit.
FGDC.GOV
FEDERAL GEOGRAPHIC DATA COMMITTEE

Figure 56 — The mobile interface of the ArcGIS QuickCapture FLORA Fire Index application.

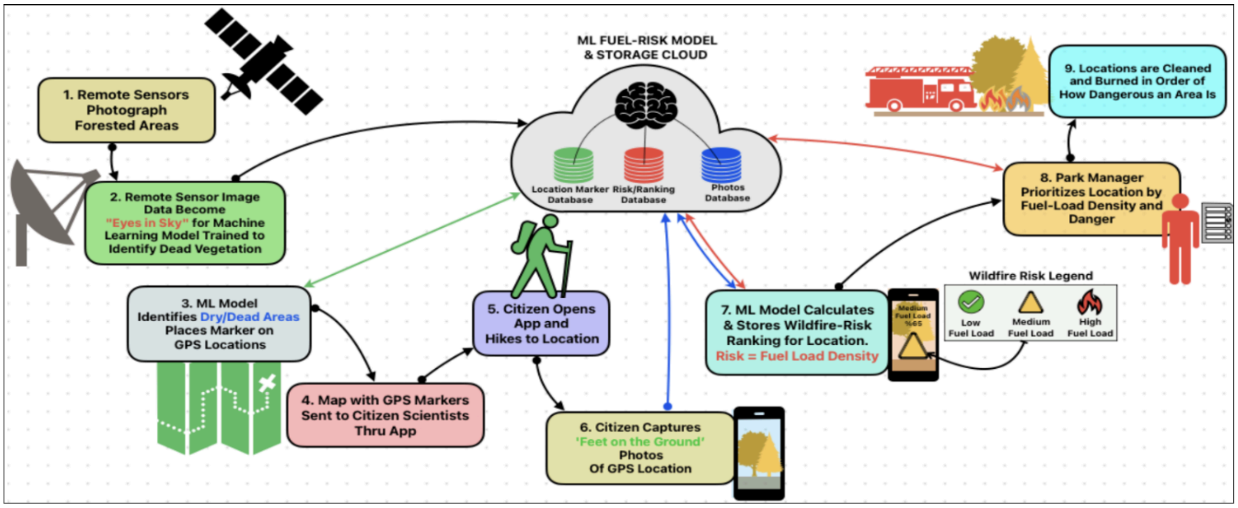


Figure 57 — Data passed into the ArcGIS QuickCapture F.L.O.R.A. mobile application as a workflow task.

Video showing how to download ArcGIS QuickCapture, login and download the FLORA Fire Index application.

Link: <https://vimeo.com/880509168?share=copy>

Video showing how to use the FLORA Fire Index application and submit your records.

Link: <https://vimeo.com/880509217?share=copy>

6.6.5.7. ArcGIS Step 6. Interoperability

The ArcGIS Disaster Hub, TerriaJS and Voyager Search have the ability to index data within the same formats which are compliant with OGC open standards such as WC3, RDF, ISO 11179, ISO 19115 and ISO 19139. This allows for effective interoperability and integration among each of the registries where ArcGIS Disaster Hub and TerriaJS along with their own indexed content can be wholly indexed through Voyager Search. The ArcGIS Disaster Registry Hub also provides a page for both Voyager Search and Terria JS that can be fully accessed and utilized.

6.6.6. D100.3 Hybrid Registry | Voyager Search

6.6.6.1. Introduction

A general barrier voiced by participants was limited, efficient resources to not only discover data but to bring together and aggregate data across geographic areas from a community of providers at different scales. In general, stakeholders also highlighted the crucial need for services that efficiently bring together authoritative data from open data catalogs and ability to access location services of SDI's. Workflows that support integration, modeling, analysis, and synthesis of transactional data during an event must be efficient, timely and provide at scale insights and intelligence to respond to stakeholder needs.

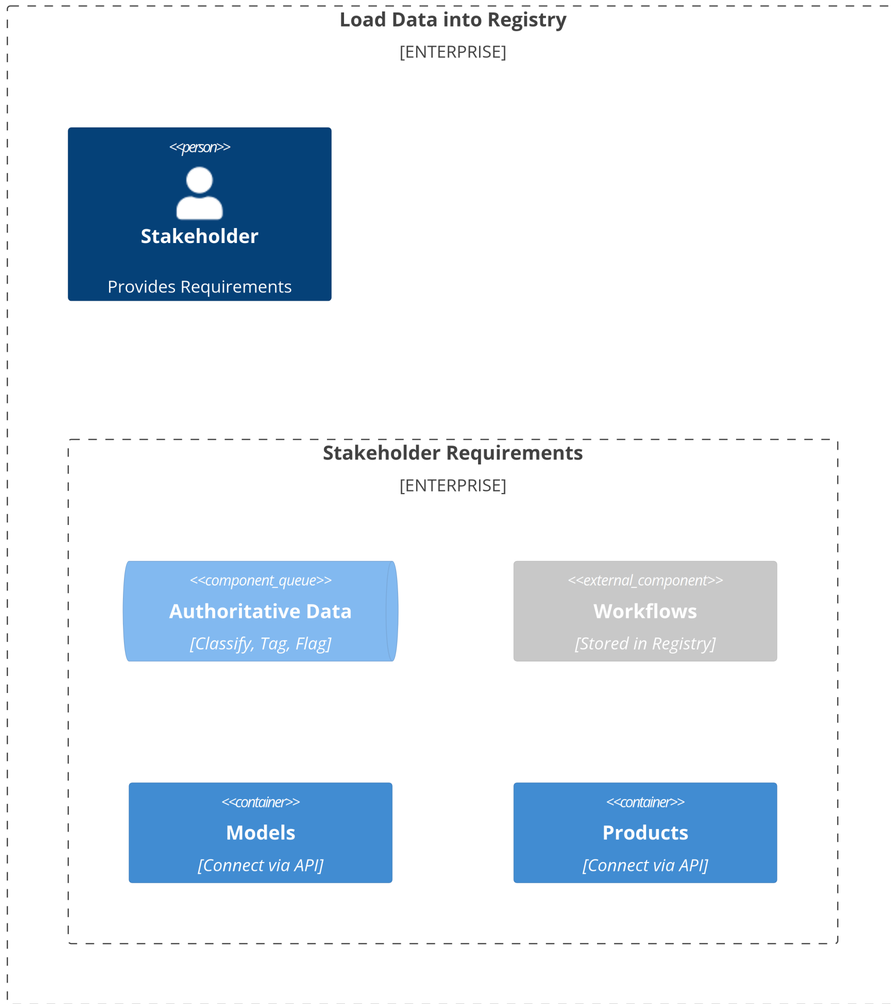


Figure 58 — Stakeholder requirements for loading data into Voyager.

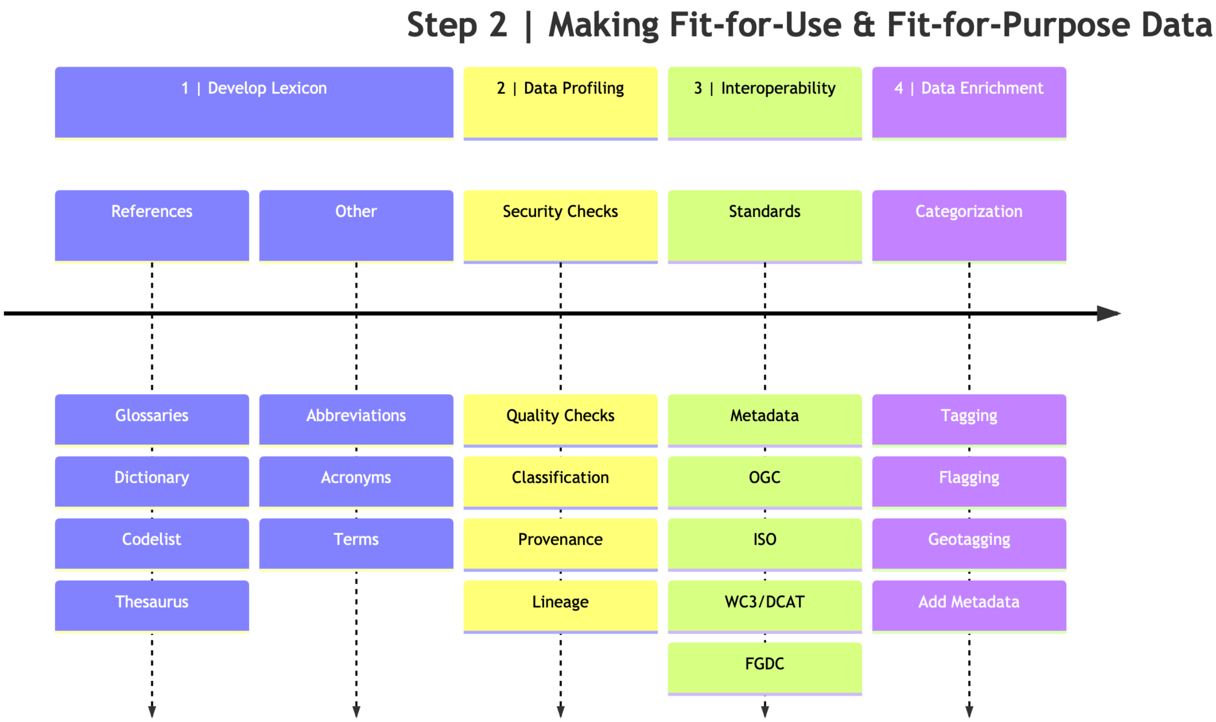


Figure 59 — Making Fit-for-Purpose & Fit-for-Use Data

A geospatial ecosystem refers to the interconnected network of technologies, data sources, tools, and stakeholders that collectively enable the collection, analysis, and visualization of geospatial data, which includes information tied to specific geographic locations on Earth. In a geospatial ecosystem, data is ubiquitously collected, processed, and analyzed to discover insights into spatial patterns, relationships, and trends. These in turn, can be used for diverse applications like urban planning, environmental monitoring, disaster management, agriculture, transportation, and more.

Collaborators worked with stakeholders and OGC member Voyager Search to research and engineer a federated data mesh architecture that employs WC3, RDF, ISO 11179, ISO 19115, ISO 19139 and other compliant registry standards. Utilzing these standards collaborators were able to efficiently connect to non-standard and standards-based APIs, ingest, discover, access, and use data, applications, models, and workflows that generated decision ready Earth insights and intelligence. Standard to documentand log ingest, generated classifications, tagging, enrichment and complete quality checks. Collaborators and stakeholders developed, tested and refined, notification and event report generation utilizing ISO 21. Stakeholders utilized the reporting, notification, and visualizations a resilience registry that sources data from standard and non-standard API connectors to index data from a variety of providers.

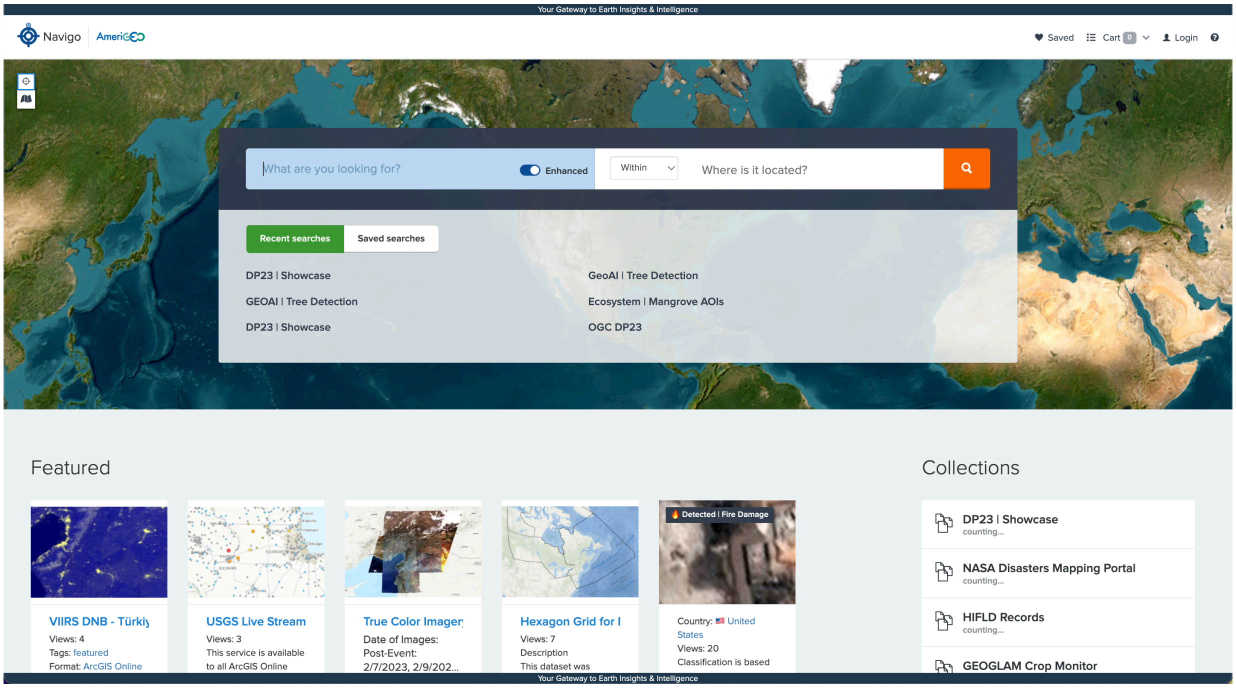


Figure 60 — Voyager Search OGC DP 2023 registry landing page.

6.6.6.2. Pilot Elements Addressed

Architecture & Engineering:

- Registries
- Catalogs
- Workflow
- Mobile Apps
- Immersive Visualization
- Connectors

Data Themes:

- Address
- Land Use
- Orthoimagery
- Transport Networks

Data Topics:

- Governance
- Authoritative
- Lifecycle Management
- Profiling
- Quality
- Provenance
- Lineage
- Reproducibility
- Analysis Ready

Topical Elements:

- Disaster Resilience
- Wildfires
- Drought
- Flood Climate
- Ecosystems Health
- National Climate Accounting

Workflow:

- Models

6.6.6.3. Voyager Step 1. Establish Repository

During a disaster, various types of authoritative data are crucial for effective disaster response, management, and recovery. These data types provide valuable insights that can help authorities, organizations, and individuals make informed decisions and coordinate their efforts. Authoritative data for disaster management and response is information that is governed, quality assured provenance and lineage, accurate, reliable, and official and is typically provided by government agencies, international organizations, and other trusted sources. This data is critical for planning for, responding to, and mitigating the impact of disasters.

In the initial implementation of the pilot, collaborators worked with stakeholders to identify data needs, sources, and methods to bring together high-value datasets and content that support disaster and climate resilience. Intergovernmental data from national and sub-national institutions, and commercial and academic data were sourced.

Bringing together disparate data involves the process of integrating or consolidating data from various sources that might be in different formats, structures, or locations. This practice is essential for gaining a comprehensive view of information and making informed decisions. Collaborators utilized the registry to connect a variety of data providers utilizing WCS, ISO, and OGC standards-based connectors. When standards-based APIs and connectors were not available the collaborators established customer connectors to ingest data utilizing open source programming languages.

Step Objectives:

1. Gather Stakeholder Requirements
2. Identify Authoritative Data
3. Inventory
4. Connect
5. Ingest and Index

Video of how to set up an OGC Standardized API Repository for Indexing.

Link: https://vimeo.com/880525461?share=copy

Setup:

- Configure Source
- Connection
- Filters
- Formats
- Pipeline Elements
- Security
- Schedule
- Task

6.6.6.4. Voyager Step 2. Data Profiling and Enrichment

The objective in profiling and enriching the data is to enhance its readiness to make it fit-for-use and fit-for-purpose.

6.6.6.4.1. Analysis and Decision Ready Data

In the context of disaster management, fit-for-use and fit-for-purpose criteria are paramount when evaluating the quality and appropriateness of geospatial information. These criteria ensure that geospatial data supports the specific needs and goals of disaster response and management. Fit-for-use in disaster management refers to the suitability of geospatial information for a particular aspect of disaster response or recovery. This involves assessing whether the data, models, workflows and services meet the accuracy, currency, and coverage requirements necessary for specific response tasks. When coordinating emergency response efforts during a natural disaster, geospatial data must be fit-for-use to create accurate evacuation routes, assess the extent of damage, or identify vulnerable populations. The data's quality and timeliness are crucial factors, as outdated or inaccurate information could hinder response efforts and potentially endanger lives.

On the other hand, fit-for-purpose in disaster management focuses on whether geospatial information is well-suited for a particular phase or function of disaster response, such as preparedness, mitigation, response, or recovery. To be considered fit-for-purpose, geospatial data should align with the specific objectives of disaster management efforts. For instance, data used for disaster preparedness and risk assessment should provide the necessary details on hazard-prone areas and vulnerability, while data used for immediate disaster response should offer real-time information about the disaster's impact and the location of affected individuals. Ensuring that geospatial data is fit-for-purpose means tailoring the information to meet the unique needs and goals of each disaster management phase.

6.6.6.4.2. Workflow Stage 1: Data profiling

The cornerstone of fit-for-use and fit-for-purpose is data profiling. Data profiling in an integral component offering a comprehensive analysis of data assets. It involves assessing data quality, structure, and content within a dataset, model, workflow or service evaluating the authenticity, accuracy and reliability. The collaborators utilized manual, algorithmic and generative workflows to complete an initial assessment to determine fit-for-use and fit-for-purpose. The registry was engineered to support quality and validation checks that can be initiated pre or post ingestion. Collaborators and stakeholders provided WC3, ISO, OGC and other metafields, to support profiling.

6.6.6.4.3. Workflow Stage 2: Organizing

In conjunction with data profiling, data classification, categorization, and tagging (CCT) play crucial roles in pre and post registry ingestion to organize content. Data classification involves assigning labels or categories to data based on predefined criteria, helping streamline data management and retrieval. Categorization, on the other hand, groups data into logical sets, making it easier to analyze and work with. Data tagging adds metadata to data elements, enriching their context and improving search and retrieval. Collaborators identified and integrated a variety of WC3, ISO, OGC, a host of socio-economic and environmental, thesaurus, glossaries, codelist, vocabularies, dictionaries, terms, acronym and other reference libraries into the registry engine to facilitate CCT and additional curation.

Data Profiling and Enrichment:

- Security Checks
- Quality Checks
- Classification
- Categorization
- Enrichment
- Tagging

Registry Library Additions:

- Abbreviations
- Acronym
- Codelist
- Dictionaries
- Glossaries
- Terms
- Thesaurus

The video link below demonstrates a source being added into Voyager and a pipeline being created that establishes workflow to enrich the data to make it more discoverable, accessible and usable by individuals and GEOAI, supporting near-real-time registration.

Video of how to build a pipeline that facilitates indexing of the data, fields and metadata of repositories.

Link: https://vimeo.com/880525406?share=copy

6.6.6.5. Voyager Step 3. Index Initial Data and Establish Automated Updates

This particular step, refers to a phase in the setup process of the Voyager Search software for establishing a pipeline that organizes the search criteria. The pipeline is then linked to the appropriate repository where Voyagers indexing agent ingests the data from the selected open data source. The initial data that will be searchable within the system is indexed, meaning it is processed and cataloged so that it can be easily queried and retrieved. Additionally, setting up automated updates, ensuring that the index is regularly refreshed with new and changed data without manual intervention, keeping the search results current and accurate. This step is crucial for maintaining an efficient and up-to-date search system.

6.6.6.6. Voyager Step 4. Search and Discovery

In the age of information overload, efficient and effective information retrieval is foundational for stakeholders, particularly in the case of disasters where timely information is crucial. The vast amount of data available online often leads to search results that are either too broad or too specific, making it challenging to pinpoint relevant information. The participants' registry employs a flexible search architecture that leverages open-source technologies and the Organic Data Science Ecosystem enabling users to narrow down their search results and discover insights and intelligence by applying the following features:

Search and Discovery Options:

1. Text Search
2. Saved Search
3. Location
4. Facets
5. Filters
6. Synonyms
7. Flagging
8. Organic Search

6.6.6.6.1. Discovery Enhancing Information Retrieval and User Experience

Once the resources were loaded into the registry collaborators and stakeholders tested the search interface to assess the useability and efficiency of search capabilities. The collaborators and stakeholders utilized the many search options and features to further refine their search to find the data they needed the most. In general, participants on average were able to discover relevant content in no more than three refinements when content was available in the registry. The below table provides the key architectural components of the participants' registry and highlights the engineering activities of the collaborators.

Table 4 — Search and Discovery Architecture

Data Search Components	Additional Information and Participant Activities
Facets Facets, also known as filters, are attributes or characteristics that allow users	Facets improve search and discovery by providing additional filters to refine search results, offering users a more streamlined and personalized experience. The collaborators in this pilot identified facets that employ code libraries from

to systematically refine search results. **Method** | *Facets are provided out of the box or curated by participants*	ISO 11179, ISO 19115, UN-GGIM, thematic and topical glossaries, and other categories identified by stakeholders. The participants identified facets that categorize content into government units, organization, data themes, location, instrument, and other topical and thematic contexts. By providing these facets, stakeholders can narrow down their search results, ensuring they find the most relevant information.
Synonyms Synonyms play a vital role in understanding user intent and expanding search results. Synonyms improve search by accounting for variations in language and terminology. **Methods** | *Code Libraries*	The participants' registry integrates synonyms that are displayed as a response along with the contextual search provided. Synonyms are generated in the participants' registry from authoritative data from governmental institutions, thematic glossaries, ISO code libraries, adjudicated open-source repositories, organizational dictionaries, and other defined code bases. In the registry, for example, synonyms ensure that a search for water also retrieves results for hydrology or hydrography By recognizing synonyms, search systems become more user-friendly and inclusive, capturing a broader range of user queries and enhancing the chances of relevant information discovery.
Tagging and Flagging Tagging involves adding descriptive keywords or labels to content, allowing users to easily locate content through keywords or phrases. **Methods** | *user-generated, algorithmic, and generative tagging*	The collaborators utilized user-generated tagging and flagging, which can provide a more dynamic and personalized approach to search and discovery. The participants' registry facilitated user-generated tags that allow the addition of keywords that resonate with their understanding of the content, leading to a folksonomy—a user-generated classification system. Tagging is particularly useful for unstructured content, such as text files, videos, photos, media content, and articles, enabling users to explore content based on their interests or specific search terms.
Location-Based Search Location-based search involves the use of standards-based parameters and methods to discover content to a geographic extent. **Methods** | *Geographic terms, spatial search alogorithms*	Location-based search enables users to find contextually relevant information, products, services, or data based on their geographical location or the location of interest.
Visual Queues Thumbnails **Methods** | *Generative, data enrichment, method*	Thumbnails

These search components play distinct but interrelated roles in improving search and discovery. They provide structure, context, and user-friendly features that empower collaborators and stakeholders to navigate vast datasets, explore content, and discover information more effectively. When integrated intelligently, these components can significantly enhance the search experience, making it more efficient and satisfying for collaborators and stakeholders.

6.6.6.6.2. Use Case #1. Aquatic Habitat at Risk

This use case provides an illustration of the crucial need for Generative Earth intelligence to monitor, forecast, and provide early warnings to improve community resilience. This Earth intelligence voyage provides a demonstration of data governance, interoperable standards, co-development of a federated architecture, and a group of dedicated collaborators and GeoPathways interns––Humanities.

Eden, an environmental engineer, is responsible for monitoring ecosystem health in the Caribbean. In the visual provided Eden is browsing the registry reviewing various search and discovery options in the search interface to assist in their quest to find insights and connected intelligence as a result of an environmental alert in the vicinity. Timely information, notification, and response could reduce the socio-economic and environmental implications of a fragile aquatic ecosystem that has been plagued by manmade and natural hazards. The registry provides the environmental engineer search results that include visual queues, sorting, view counts, and other options to improve their ability to quickly find, get, and use crucial information to monitor the health of this critical ecosystem that is vital to shipping, tourism, food and energy security and many other socio-economic benefits.

The search components of the registry architecture allow the analyst to filter using facets, textual and location-based parameters, interval-based search notifications, and other features to find responsive content. The environmental engineer has established search parameters and saved searches to automatically monitor, detect, and alert the engineer to potential threats. The registry engineers designed a federated ecosystem that connects stakeholders, providers, data, models, and services to provide monitoring, forecasting, and early warning capabilities. The registry 4D Earth intelligence engine (hereafter referred to as “the engine”) routinely scans the Organic Data Science Ecosystem harnessing high-value content to support stakeholders. The engine’s interval-based transactional generative AI provides detection-as-a-service routinely sampling incoming ortho-imagery to detect environmental threats routinely occurring in this location.

The generative service integrates deep learning algorithms and models developed by ESRI to monitor ecosystem health. The models detect harmful algae blooms, oil spills, mangroves, and other environmental hazards. The generative services integrate these models into the registry frameworks Federated Adaptive Monitoring Engine (FAME) and leveraging analysis-ready orthoimagery is able to detect, extract and generate point, imagery, and feature level data on demand using interoperable OGC API’s and open standards.

These quality-assured products are derived from governed authoritative data, models, and workflow that are built on ISO 11179, ISO 19115, OGC APIs, and standards to provide quality metadata, data, services, business rules, certified models, and workflows that are fit-for-use and fit-for-purpose.

The defined workflow quality metadata that identified orthoimagery products, against the point of detection generated at scale for assessment. Through better understanding the disaster at hand, providing notifications and alerts, and crafting recommendations and interventions that could forestall and or reduce impacts on aquatic habitats in the vicinity such as sensitive coral reefs and mangroves. The collaborators engineered a search architecture, taxonomical and domain based ontological classification and categorization business rules to provide organic facets based upon search results. The ontological architecture utilizes templates that apply business rules based on content representation, roles, data classification, security and sensitivity rules. Once the user finds the data that is most relevant to respond to their requirement they are able to add these resources to their cart being fit-for-use on their desired use case application.

Video demonstration of Voyager Search functions.

Link: https://vimeo.com/880522150?share=copy

The video linked below provides a stakeholder example of the metadata that is provided for a content item that has been indexed into the participants' registry. The content item shows the original metadata that was provided by the provider during the ingest stage and also includes categorization, classification, and tagging that occurred during the data enrichment stage. The content item shows related documents and or previous content items that were opened related to the content item in the visual provided. The content item provides the option to return to search, see a previous content item, or the next content item, or select a highlighted metadata element to see more items in the search criteria. The viewer of this content also has the ability to choose to use one of the automation, reporting, or generative detection tools to perform a task on the content item. An authorized curator has the ability to add additional information for missing metadata and add tags or flags to the content to improve search and discovery.

Video showing search and discovery of 2023 Maui Wildfire aerial images.

Link: https://vimeo.com/880522099?share=copy

Voyager Search demonstrated the ability to seamlessly consume indicator products generated through pilot workflows provided by HSR Health. These indicator products are essential for monitoring and predicting wildfire and drought conditions. Additionally, it should be able to access framework data and contextual information provided by component D100. This ensures the visualization is based on the most up-to-date and relevant data.

6.6.6.7. Voyager Step 5. Data Profiling: Classification and Tagging

List of API's:

- Geospatial Services: WMS, WFS, WCS, GeoTIFF, ESRI Shapefile, SHP, GeoJSON
- Open data APIs: CKAN, DCAT, Socrata
- Database and list formats: GDB, CSV, PDF
- Workflows and connecting those resources into modeling capacities leveraging the cloud.
- Standards, WMS, WFS, S3, Stac, API programming interfaces

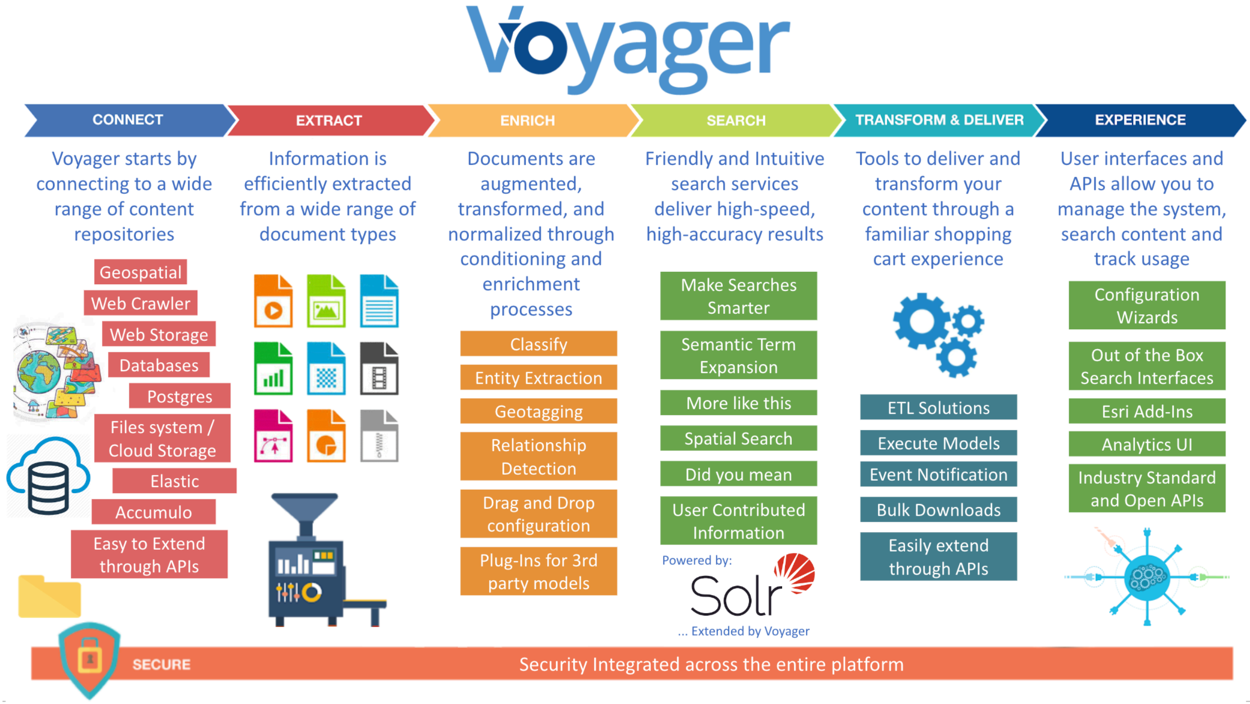


Figure 61 — Voyager Search Development and Usage Workflow.

6.6.6.8. Voyager Step 6. Workflow

Figure 62 — Workflow on how to use Voyager Search and integrate deep learning models into chosen items such as imagery.

Video showing workflow on how to task a PowerPoint presentation in Voyager Search.

Link: https://vimeo.com/880522099?share=copy

6.6.6.9. Voyager Step 7. Implementation and Reporting

During this step, which marks the full deployment and operational phase of the Voyager Search registry, the geospatial search system efficiently handles stakeholder queries and effectively connects to geospatial data lakes. It also encompasses the implementation of Voyager Search's Data Analysis mechanism that is available to stakeholders with login ability that enables the creation of charts (pie, bar and line graphs) and graphics that leverage fields, metadata, and group data. These charts and graphics can be placed together to make a comprehensive dashboard analysis of the registry's data.

These reports offer valuable insights into the registry's performance, indexing contributions, and usage statistics, shedding light on data trends, and facilitating an in-depth evaluation of the registry's efficiency and areas for potential improvement. This comprehensive approach ensures that Voyager Search not only functions seamlessly but also empowers users with dynamic visualizations for data-driven decision-making.

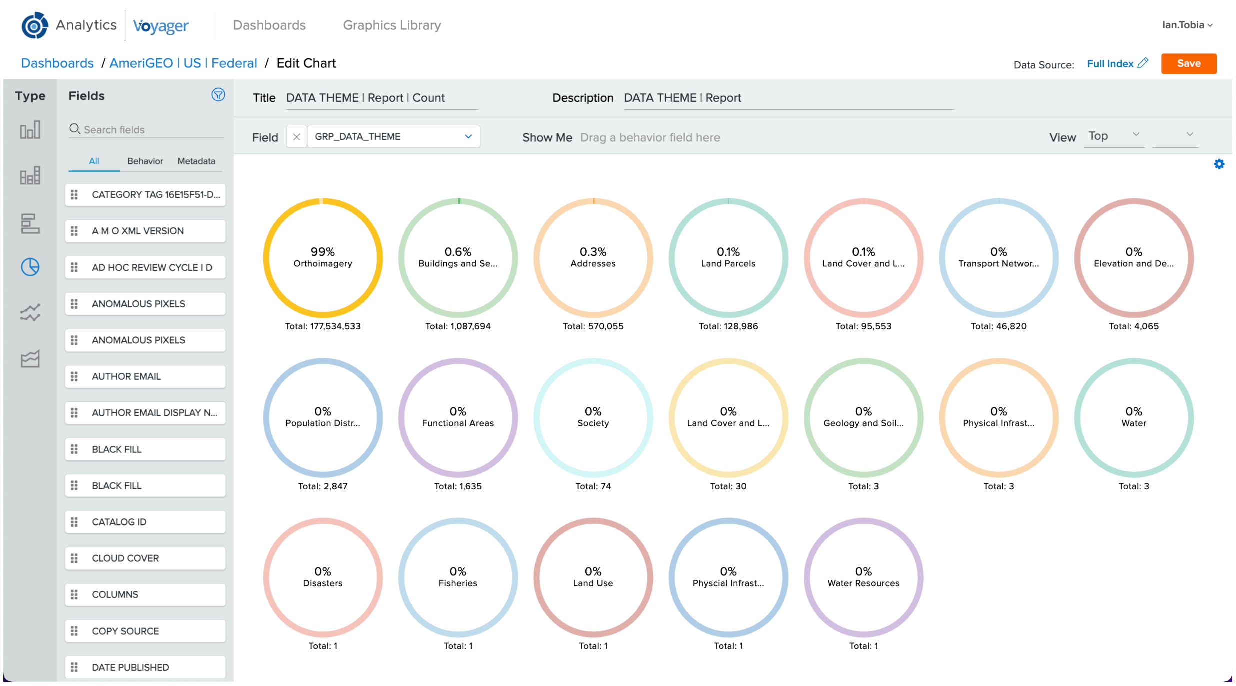


Figure 63 — The dashboard feature in Voyagers Analytics shows options for selecting available metadata in the fields pane to the left and offers graphic options for presenting analytics for the indexed data.

6.6.6.10. Results

Table 5 — Capability mapping of Registry Resources

REQUIREMENT MAPPING	TERRIAJS	ARCGIS HUB	VOYAGER SEARCH
Near-real-time registration:	Registration requires custom coding	Forms-based registration option	One-time form-based registration
Search and discovery of ARD:	Requires custom coding of resources	Requires appropriate tagging, classification of resources	Can inspect data and auto tag, classify based on requirements

REQUIREMENT MAPPING	TERRIAJS	ARCGIS HUB	VOYAGER SEARCH
DRI Workflows:	Workflows require custom coding for interoperability	Python-based workflows can be established to support DRI Workflows	Ability to integrate models to provide DRI
DRI Applications:	Requires custom coding for interoperability	Provides a variety of apps that can be used to develop DRI visualizations	Requires custom coding
Discovery of and access to geospatial framework datasets:	Requires custom coding to add framework datasets	Provides authoritative Living Atlas and government data	Provides a mechanism to offload this capability to applications that are fit for purpose
Social, crowdsourced, and volunteer observations:	Share displayed data in 3D maps, presentation feature provides narrative	Provides dashboard analytics and surveys	Can register content from social media and open mapping platforms

6.6.6.11. Challenges and lessons learned

6.6.6.11.1. D100.1 TerriaJS — Open Source

Collaborators successfully integrated 91 sources into the TerriaJs Hub through manual coding efforts to add each of the sources identified. Workflows were coded into the environment to provide access to web processing systems from providers. However, a significant challenge arose when finding suitable representations for specific data sources in server-hosted files, such as ESRI feature layers and data from other servers. A substantial portion of the existing data points within catalogs related to disaster management either had broken links or were available only for download. Initially, our list of relevant data was much more extensive, but we had to trim it down as we sought viable sources. Scouring the internet for geospatial data in TerriaJS-compatible formats proved time-consuming. As data discovery becomes more painless, it will reduce barriers to entry for users and decision-makers to utilize this open-source visualization platform.

6.6.6.11.2. D100.2 Esri ArcGIS Hub — Proprietary

The ArcGIS Hub data indexing process had challenges regarding the time taken to register individual data points. These must be manually added, including the metadata, thumbnail imagery, and source endpoints. It took extensive time to add 685 data items manually and required that we copy each item into our ArcGIS Hub's content library. Creating a duplicate of the data causes problems maintaining a data's provenance and authority. While Esri has an extensive library of authoritative data to browse online within their platform, it still suffers from the problem of new data-discovery and the time it takes to manually register new data that affects most other platforms if the data needed is not in Esri's library. The results conclude searching for new data affects all industries and data-dicovery time needs to be reduced to shorten the workflow to registering new data.

6.6.6.11.3. D100.3 Voyager Search — Hybrid

Indexing from open sources in the Voyager Search catalog and registry presented issues with a lack of data organization, enrichment and visual display where search optimization and data discovery shortcomings were present. Many of the open sources that were indexed in Voyager Search had poor spatial data infrastructure standards that included inadequate naming conventions from providers thus resulting in missing or misplaced data. In the cases where this issue was present, it negatively impacted the quality of the indexing done and the resulting search capabilities where the organization and display of data ultimately makes the discovery, acquisition and action on such data to be difficult to execute.

6.6.6.12. Updates and applications

6.6.6.12.1. D100.1 TerriaJS — Open Source

TerriaJS, with its versatile and user-friendly platform, has a wide range of applications as a data registry. It excels in facilitating data discovery, visualization, and sharing within the geospatial and geoscientific communities. Its strength lies in the ability to aggregate and harmonize diverse data sources, making it an ideal solution if an organization is seeking a centralized repository for their geospatial data.

To further enhance its capabilities as a data registry, several updates can be considered. Firstly, improving support for standard metadata formats like ISO 19115 would enhance interoperability and data sharing. Additionally, implementing advanced search and filtering options, along with user-friendly data cataloging features, could streamline the process of data registration and access.

Incorporating dynamic data update notifications and integration with real-time data sources would make TerriaJS an even more valuable tool for decision-makers in disaster management, research, and response. Furthermore, enhancing its support for citizen science data contributions and collaborative data curation would align TerriaJS with the principles of citizen science, ultimately strengthening its role in fostering community engagement and disaster resilience.

6.6.6.12.2. D100.2 Esri ArcGIS Hub — Proprietary

Esri’s ArcGIS Hub site presents a powerful platform for serving as a data registry, particularly for organizations and governments looking to centralize their geospatial information and encourage data sharing within their organization or with the public. The ArcGIS Hub content library already offers a substantial foundation for hosting various datasets, maps, and applications, but several updates can enhance its capabilities further.

Firstly, refining the content library's search and discovery features, such as advanced filtering and adding metadata support when you add new content will improve the efficiency of data search and access.

Enabling better version control and data revision tracking, along with providing users with tools for contributing their own data, would foster a more collaborative environment for data management. Furthermore, bolstering the capacity of interoperability by linking data sources with external tools, which could include: interactive web applications, dashboards would enable more dynamic and actionable data sharing, particularly when dealing with disaster management, resilience, and government to citizen engagement.

6.6.6.12.3. D100.3 Voyager Search — Hybrid

In the future, Voyager Search holds tremendous potential for further enhancements and expanded applications in the realm of geospatial and non-geospatial data management. One avenue for improvement lies in refining its search capabilities, harnessing the power of artificial intelligence to bolster their 'Enhance' search bar feature. This feature already increases data detection accuracy and facilitates more intuitive stakeholder interactions, however, moving to an AI chat bot might make searching through depths of GIS data that much faster for the stakeholder.

In possible future neural networks, Voyager's data indexing becomes more comprehensive, as ODN (Open Data Network) is now sitting at 190 Million resources and growing, it will be able to handle larger volumes of data more efficiently. In potential future neural network developments, Voyager's data indexing becomes more comprehensive.

Voyager Search does have a map widget to view some data on but the integration of advanced visualization tools would increase stakeholder interaction with the registry and help Voyager capture more client interaction time on their website.

Moreover, Voyager Search could find new applications in disaster management, where rapid and precise data detection is critical for timely response and resilience. By extending its capabilities to ingest and process real-time and near-real-time data sources, it could become an invaluable tool for monitoring, mitigating, and responding to natural/man-made disasters as-they-happen.

Furthermore, Voyager Search can play a vital role in environmental conservation, helping researchers and policymakers access geospatial information to make informed decisions regarding land use, biodiversity, and climate change. Its potential in fostering citizen science initiatives and community engagement could also be further explored, making it an essential asset in promoting data-driven decision-making and fostering collective efforts for a sustainable future.

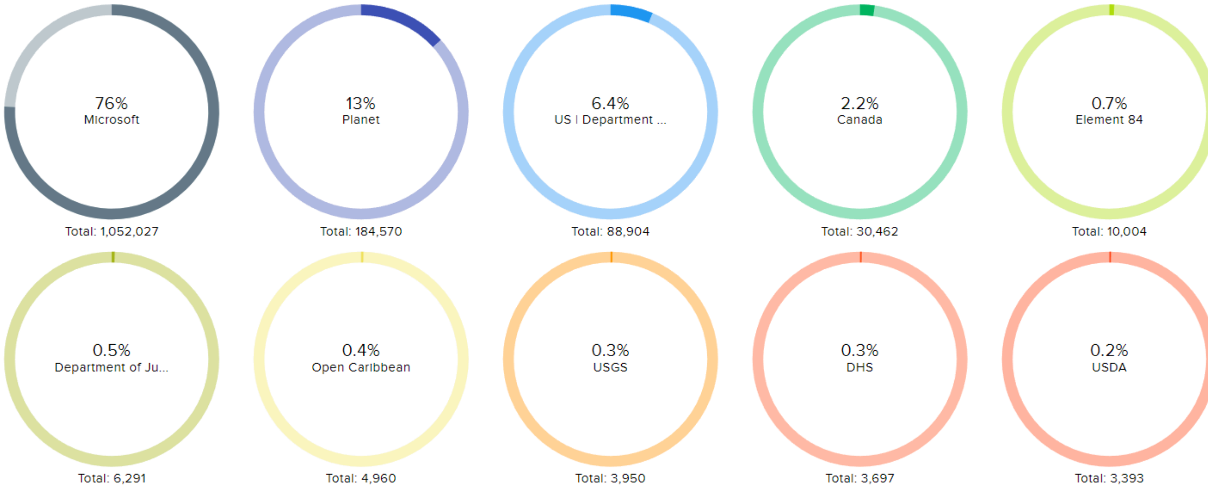


Figure 64 — Top 10 Organizational Data Indexed Within the Voyager Search DP2023 Registry.

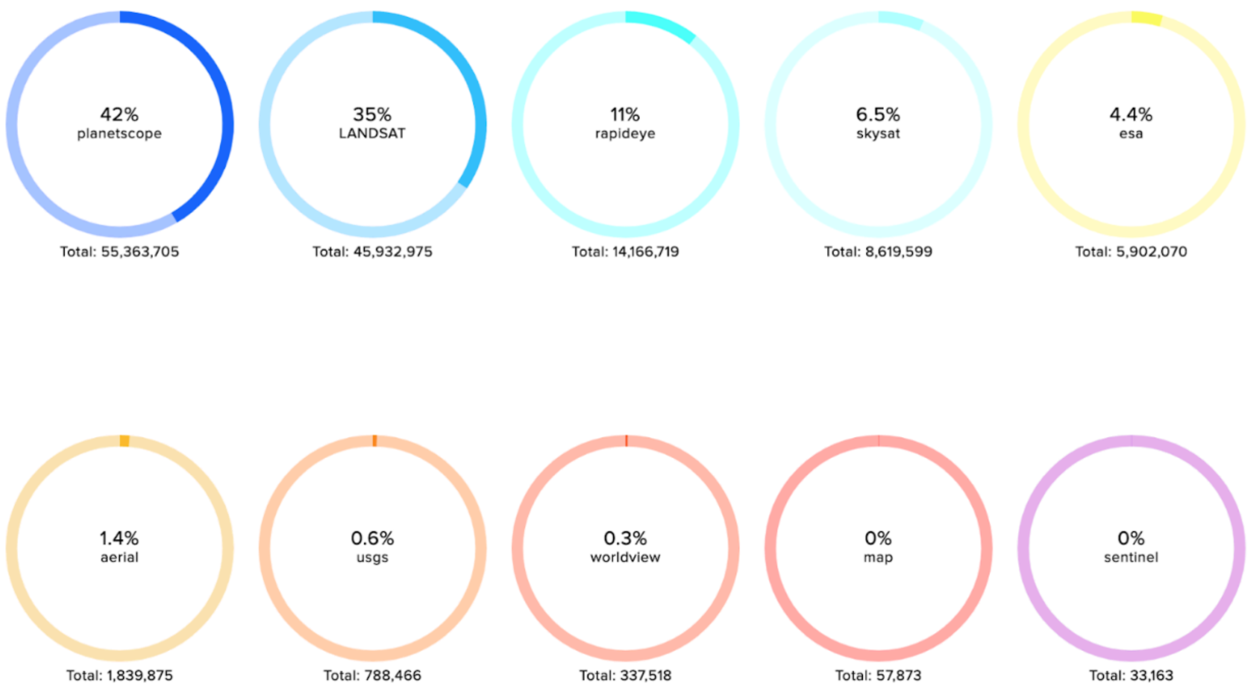


Figure 65 — Top 10 Organizational Data Indexed Within the Voyager Search ODN Registry.

6.6.6.13. Discussion and future developments

The pilot provided an opportunity to better understand stakeholder gaps and barriers in utilizing spatial data infrastructure, tools, services, models, workflows, artificial intelligence and other resources. Decision makers depend upon authoritative data from reliable sources to make effective decisions but significant improvements are needed in providing the necessary metadata that ensures provenance and lineage of content so that there is an increase in trust and better establishment of data governance to allow for fit-for-use and fit-for-purpose.

Future developments for TerriaJS, ArcGIS Online Disaster Hub and Voyager Search include incorporating new capabilities and continuing to expand above 1 billion indexed items. Further indexing of geospatial data from open sources is currently ongoing for all three registries with a primary focus on Voyager Search. As an example, open data sources for countries, academic institutions (eg. MIT, Stanford University, Oxford University), businesses (eg. Planet, Maxar, ESRI), government agencies (eg. NGA, CONIDA, NASA) and world organizations (eg. United Nations, World Health Organization) are still being collected and prepared for indexing on Voyager Search. Further UI/UX improvements will continue to be made as well as for other ease-of-use improvements that are related to data curation and search optimization. There are expectations in the near-term to scale Voyager Search into a full fledged productive system that would involve multiple indexing agents instead of the single agent that's currently present. Lastly, to improve its operability it would require additional AWS cloud-based cores that would allow for more efficient and effective near-real time processing, curation and indexing of data.

Our Collaboration

In this Disaster Pilot, GeoPathways worked with participants to research, develop prototypes, pilot, and test the ability of open source, commercial, and hybrid GIS solutions. GeoPathways and Voyager Search have joined forces to create an indexed data registry. The aim is to facilitate the development of a hybrid component registry encompassing open-source and proprietary elements. This registry will play a pivotal role in enabling the discovery and accessibility of geospatial framework datasets, contextual data related to social, political, and health aspects, integrating machine learning models with data, and incorporating crowd-sourced and volunteered observational data.

Geographic Information Systems (GIS) data has been marked by significant challenges related to industry standards and the pervasive issue of data duplication across multiple individual data holdings. In the past, the absence of coherent standards led to organizations and entities storing and managing geospatial data in their stovepiped formats and structures. This fragmentation impeded data interoperability and resulted in duplicated datasets proliferating across the internet in organizational data "hubs" or "portals."

The Open Geospatial Consortium (OGC) has played a pivotal role in mitigating these issues by championing the adoption and implementation of geospatial data standards. OGC's efforts have substantially increased the use of standardized data formats, protocols, and APIs, promoting greater consistency and compatibility among geospatial datasets. However, while OGC standards have made significant strides in harmonizing geospatial data, challenges persist in data storage, searchability, and interoperability with model workflows including AI/ML.

One of the primary challenges is the continued duplication and constant movement of data across various hosted APIs and websites. This fragmented distribution of critical geospatial information presents a substantial obstacle, especially during natural disasters where timely and accurate data is paramount. The absence of an authoritative data registry compounds the issue, leading to frustration and an operational loss among decision-makers and authoritative figures who struggle to locate the correct data needed to make informed choices, often under time-sensitive and high-stress conditions.

To address these challenges, a compelling solution emerges by enabling search and access to authoritative, comprehensive datasets. By using OGC standards to tag and index data API endpoints and providing a central search registry of indexed geospatial data, this approach promises to facilitate the easy discovery and utilization of authoritative data and models. Such a registry would serve as a one-stop source for all analysis-ready geospatial data, enhancing data analysis into decision-ready indicators. Suppose authorities can access a unified and standardized approach to searching for GIS data. In that case, authorities will be confident they can access the correct data at the right time, leading to more effective decision-making and, ultimately, preserving lives and property during natural disasters.

Our deliverable includes three distinct data registries, each centering on different technologies, capabilities, and software categories, namely open-source (TerriaJS), proprietary (Esri ArcGIS Hub), and hybrid (Voyager Search). Then integrate with numerous machine-learning workflows. We are indexing cities, counties, and states of the United States and Canada. We are also focusing on commercial GIS providers who have built base map imagery datasets; these include Maxar, Planet, and Airbus.

To address these challenges, a compelling solution emerges by enabling search and access to authoritative, comprehensive datasets. By using OGC standards to tag and index data API endpoints and providing a central search registry of indexed geospatial data, this approach promises to facilitate the easy discovery and utilization of authoritative data and models. Such a registry would serve as a one-stop source for all analysis-ready geospatial data, enhancing data analysis into decision-ready indicators. Suppose authorities can access a unified and standardized approach to searching for GIS data. In that case, leaders will be confident they can access the correct data at the right time, leading to more effective decision-making and, ultimately, preserving lives and property during natural disasters.

6.7. Drought Health Indicator Workflow (by HSR.health)

6.7.1. Introduction to the company and main activities

Based in Rockville, Maryland, HSR.health is a geospatial data analytics company that specializes in utilizing geospatial technologies, health, social, and environmental data, AI techniques, and public health models to predict the spread and severity of disease — whether infectious, chronic, or social — and assist public health and emergency response decision makers mitigate disease spread and/or allocate resources to treat the affected. The tools and information provided by HSR.health improve overall global public health.

With the goal of striving for health equity and improving global public health, this pilot project is significant because throughout the years wildfire frequency, severity, intensity, and overall effects have increased, heavily impacting public health. This project aims to find potential solutions to this public health concern.

For the Drought Health Indicator Workflow component of the 2023 Disaster Pilot, we developed a Drought Health Risk Index that identifies a-priori the underlying health and social posture of the disaster-impacted population. The goal is to provide a useful indicator of where vulnerable populations are to inform resource and personnel allocation before, during, and after the response along with informing policies to provide longer-term relief.

The Drought Health Risk Index aligns with our contribution to the Wildland Fire Health Indicator for this 2023 Disasters Pilot (DP) in addition to our Hurricane Health Risk Index (2019 DP, 2022 DP, and 2023 Federated Marine Spatial Data Infrastructure Pilot), and the Bioaccumulation Health Risk Index (2023 Federated Marine Spatial Data Infrastructure Pilot) in serving as a demonstrator over the course of a year for industry use.

6.7.2. Background and problem description

Drought is characterized by long duration, lack of identifiable onset and termination, and recurrence, impeding preparation and response efforts aimed to mitigate its adverse health effects (Smoyer-Tomic et al., 2004; Yusa et al., 2015). Understanding the community context in which droughts occur can help mitigate health effects by improving factors along disease pathways (NIDIS, n.d.). For example, a few factors influencing drought severity include

- Water needs of the population and entire ecosystem
- Level of infrastructure
- Presence of vulnerable populations

Taking measures targeting each of these factors can help prevent drought-induced disease occurrence and spread (NIDIS, n.d.; Smoyer-Tomic et al., 2004). The mechanisms described below are also depicted visually in the subsequent figure.

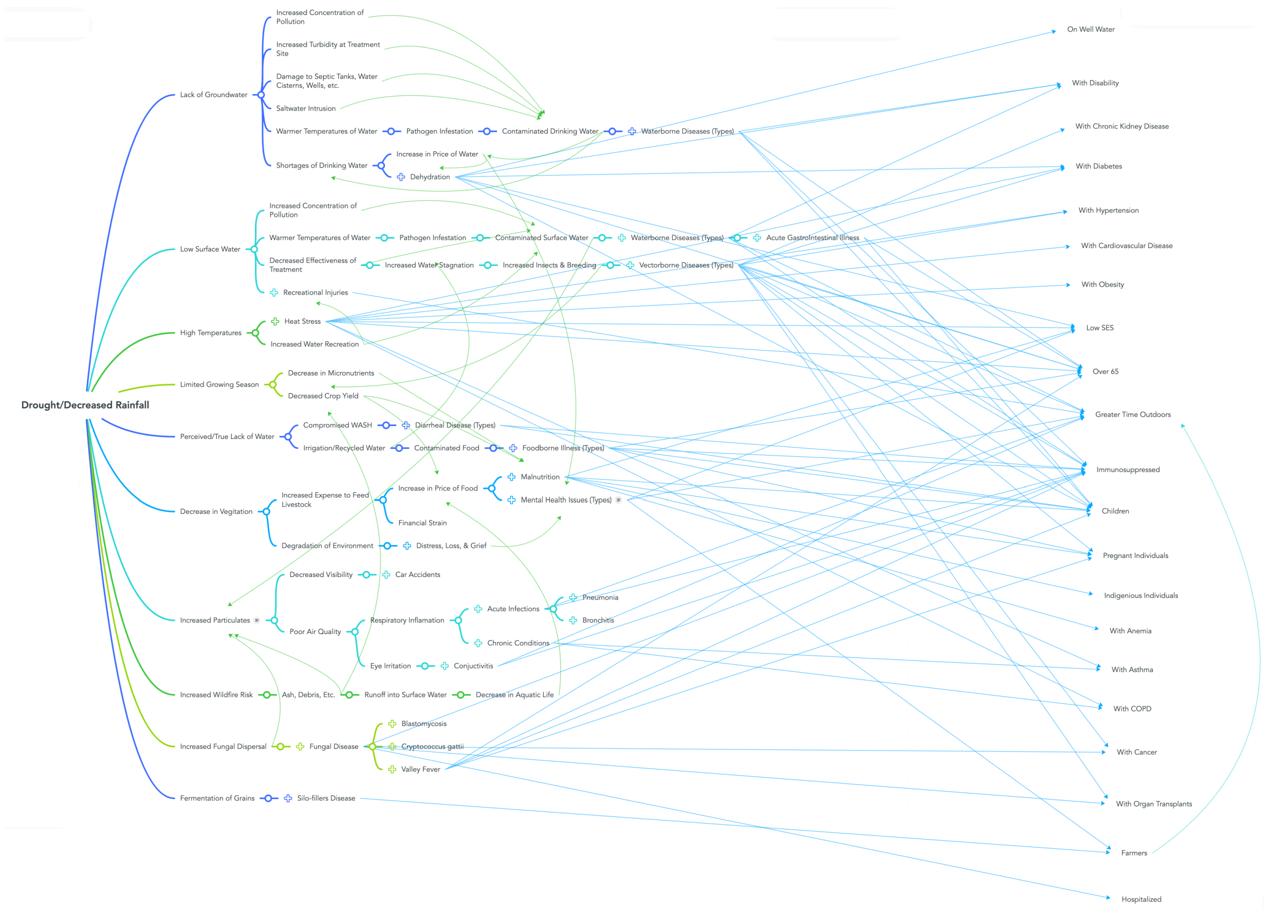


Figure 66 — Drought Health Impact Map

Health Effects of Drought

Poor or Limited Drinking Water. Through many mechanisms, individuals are at an increased risk of dehydration during drought. The lack of rainfall fails to replenish groundwater sources, including wells (CDC, 2010; CDC, 2020). Water in these sources may also become contaminated through increased (1) concentrations of pollution, (2) growth of pathogens, (3) saltwater intrusion, and (4) turbidity at water treatment sites (CDC, 2010; CDC, 2020; Yusa et al., 2015). Lack of water and contamination of existing sources can raise the price of water significantly, decreasing accessibility. The elderly, children, low-income families, those on well water, and those with disabilities or diabetes are particularly at risk (NHS, 2023; UN Environment Programme, 2019; Yusa et al., 2015). When high temperatures accompany the drought, heat stress can be exacerbated (Yusa et al., 2015). Similarly, the elderly, low-income families, and those with obesity, hypertension, diabetes, cardiovascular disease, asthma, and chronic obstructive pulmonary disease (COPD) are more vulnerable (Kenny et al., 2009).

Food Insecurity. Malnutrition and hunger result directly from drought. The limited growing season and proliferation of insects can cause crop yields to decrease by 10 to 30% (CDC, 2020; Smoyer-Tomic et al., 2004). Reduction in food supply also increases the expense of feeding livestock, as farmers are forced to buy expensive feed and water (Yusa et al., 2015). Furthermore, fish quality and quantity are impacted by contaminated water and potential runoff in the event of wildfires, the risk of which are exacerbated during droughts (CDC, 2010; Yusa et al., 2015). Together, these increase the overall price of groceries. When coupled with high prices for water, some families may not have accessible healthy options (Yusa et al., 2015). Food quality is also decreased as crops' zinc and iron content is reduced during drought (Yusa et al., 2015). Decreases in food quality have a universal impact, especially on those who are most vulnerable, including children, pregnant individuals, low-income families, and indigenous populations who may rely on fish (Yusa et al., 2015).

Infectious Disease. Several communicable diseases increase in drought conditions. Through either a true or perceived lack of water, handwashing is often compromised (CDC, 2020; Yusa et al., 2015). As such, areas with restricted water access have a higher incidence of diarrheal disease (Smoyer-Tomic et al., 2004). Globally, occurrences of diarrheal disease in children under five generally increase by 4% with each 10mm decrease in precipitation per month (Yusa et al., 2015). Waterborne diseases could also be caused by contaminated water sources (CDC, 2020; Yusa et al., 2015). When individuals drink or participate in recreational events in pathogen-infested water, Hepatitis A, campylobacteriosis, giardiasis, cryptosporidiosis, shigellosis, and more can result (Yusa et al., 2015). The elderly, immunosuppressed, pregnant, those with disabilities, those who spend much time outdoors, and certainly children are at the highest risk (Mokomane et al., 2017; UN Environment Programme, 2019; Yusa et al., 2015). Similar conditions may also be foodborne, perpetuated by food contaminated through recycled water or improperly treated municipal sewage in farming and irrigation (CDC, 2020; Yusa et al., 2015). These, too, disproportionately affect the elderly, immunosuppressed, pregnant, and children (CDC, 2022b). Drought influences the incidence of some vector-borne diseases, particularly those spread through mosquitoes. Increased stagnation and irrigation of water produce breeding sites without regular flushing of offspring out of the site (CDC, 2020; Yusa et al., 2015). At-risk populations include children, pregnant individuals, those over 60, immunosuppressed, those who spend a greater proportion of time outdoors, and those with cancer, diabetes, hypertension, chronic kidney disease (CKD), or organ transplants (CDC, 2022a; Yusa et al., 2015). Dry soil can increase fungus, spreading c. gattii, valley fever, and blastomycosis (NIDIS, n.d.; Yusa et al., 2015). Children, the elderly, pregnant persons, immunosuppressed, hospitalized, and those with cancer or organ transplants are particularly susceptible (CDC, 2021; Yusa et al., 2015). Lack of precipitation increases particulates in the air, like molds, bacteria, dust, mites, pollen, and more, which cause inflammation (Smoyer-Tomic et al., 2004). These increase the risk of conjunctivitis and acute respiratory infections, including pneumonia and bronchitis (CDC, 2020; Smoyer-Tomic et al., 2004). The immunocompromised and individuals who spend a large amount of time outdoors are at greater risk (Yusa et al., 2015).

Chronic Conditions. Poor air quality due to particulates worsens pre-existing respiratory conditions through inflammation (CDC, 2020). Asthma, emphysema, and chronic bronchitis rates are higher in areas with fires, which are more likely to occur in drought environments (Smoyer-Tomic et al., 2004). Blooms of cyanobacteria may also co-occur from the increased concentration of nutrients in water sources due to wildfire runoff and decreased water levels (Yusa et al., 2015). These organisms produce airborne pollutants that further contribute to poor air quality (CDC, 2020; Yusa et al., 2015). Those with asthma, COPD, and other chronic respiratory conditions are most susceptible. The aforementioned consequences of drought compound on individuals with other pre-existing conditions, making them more at risk for said health effects and serious complications.

Occupational Health. Decreased surface water levels can lead to injuries from recreational activities, which often increase during heat-associated droughts (CDC, 2020; Yusa et al., 2015). Car accidents may also increase due to decreased visibility in the event of dust storms

(Yusa et al., 2015). Those who spend much of their time outdoors are more at risk (Yusa et al., 2015). Silo-fillers disease, a drought-induced grain fermentation that increases nitrate levels, significantly affects those who primarily work outdoors, especially farmers (Smoyer-Tomic et al., 2004; Yusa et al., 2015).

Mental Health. Drought could increase or worsen substance abuse, domestic violence, mood disorders, and suicide (NIDIS, n.d.). Much of this is attributed to increased feelings of anxiety, depression, distress, loss, and grief associated with the degradation of the environment and the hardships brought about by low precipitation (Yusa et al., 2015). Low-income families, farmers, especially small businesses, and those with pre-existing mental health conditions are the most susceptible (Smoyer-Tomic et al., 2004; Yusa et al., 2015).

6.7.3. Objectives and role in the pilot architecture

Our goal here is to provide visibility and a demonstration of a predictive health-focused geospatial decision support application that fits into the disaster response workflow and ecosystem.

In addition, we aim to continue advancing our GeoMD Platform towards serving as a Health Data Retrieval API by adding an OGC API endpoint to improve further the accessibility of the data and geospatial insights stored on the Platform.

In collaboration with NASA, NOAA, and NRCan, we are confident that this project will create a powerful new mechanism to inform the public, local residents, disaster response organizations, the public health community, state governments, and other appropriate communities of the health and social conditions on the ground a priori to aid in their response to disaster scenarios.

6.7.4. Methodology

To analyze the vulnerable population in a drought-impacted area, we created a weighted combination of the factors influencing vulnerability to drought conditions as informed by past and current public health research and then identified the geographic areas where such populations are more prevalent, based on population demographic and health data to produce a Drought Health Risk Index.

This aligns with our goal of providing health and social information a priori to responders so that they can allocate their resources and personnel more effectively to address drought scenarios. Gaps in the availability of health data limit the accuracy of the indicator at fine granular scales. Additionally, there are some factors that we would like to include, such as people who spend a large amount of time outdoors but are unable to include them due to lack of such data.

6.7.4.1. Area of study

The Drought Health Risk Index is being produced for the province of Manitoba, Canada, in line with the target area identified by the sponsors.

6.7.4.2. Technical design

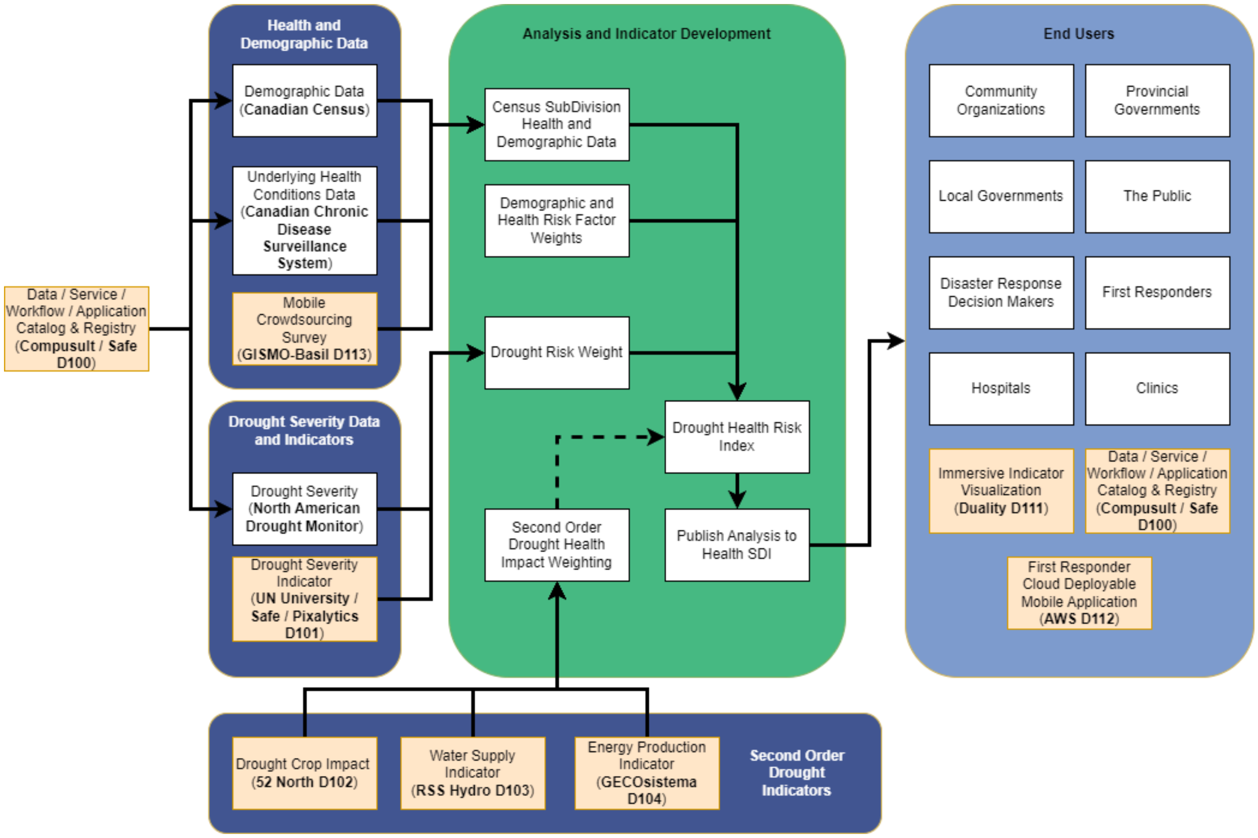


Figure 67 — Drought Health Risk Index Workflow

6.7.4.3. Data Elements

The key data elements for this project include:

- Immunosuppressed
- Children
- Over 65
- Low income
- Pregnant individuals
- With asthma
- With COPD
- With cancer

- With disability
- With CKD
- Farmers
- Unhoused
- Unemployed
- No health insurance
- Single parent families
- English fluency
- Mobile homes
- No vehicle
- No high school diploma.

6.7.4.4. Datasets and/or data sources required

- Population Characteristics — Canadian Census Bureau
- Underlying Health Conditions — Canadian Chronic Disease Surveillance System
- Drought Severity — North American Drought Monitor
  - Pilot Participants Pixalytics, Safe, and UN University are producing independent drought severity indicators that we will ingest as well.
- Mobile Crowdsourcing — GISMO-Basil Labs ===== Solution Architecture

The Drought Health Risk Index is calculated by combining demographic, health, and drought severity data to provide decision-ready information on which areas should be prioritized in drought scenario response efforts.

The primary data inputs for the Drought Health Risk Index are demographic data, health condition data, and drought extent, severity, and risk data. The demographic data comes from the Canadian Census Bureau, the health condition data comes from the Canadian Chronic Disease Surveillance System, and the initial drought extent and severity data come from the North American Drought Monitor, the authoritative government source.

Additionally, as the indicators from Mobile Crowdsourcing via GISMO-Basil Labs and indicators for drought extent and severity from UN University, Pixalytics, and Safe become available, they will be incorporated into the Risk Index to demonstrate the ability to incorporate alternative data into the Drought Health Risk Index and the overall GeoMD Platform.

The options for the use and incorporation of the independent drought severity indicators produced by fellow pilot participants include:

- Incorporating all indicators into the Drought Health Risk Index
- Allowing for the selection by the end user of the specific indicator of choice

The Drought Health Risk Index is a combination of two primary components: the health vulnerability of the underlying population and the drought extent and severity. The population vulnerability risk is a combination of health and demographic factors through a combined risk weighting analysis that provides a priori information on the specific locations and concentrations of vulnerable and at-risk populations. The weightings for each factor are determined through our analysis from our public health team and published research. The population vulnerability risk is combined with the drought risk weight based on the drought severity indicator, to produce the final Drought Health Risk Index.

6.7.4.5. Technical or health implementation

The persistent demonstrator for the Wildland Fire Health Risk Index is published on HSR_.health_'s Open GeoMD Platform (https://opengeomd.hsrhealthanalytics.org/) and GeoMD Platform (https://geomd.hsrhealthanalytics.org/), which is deployed in the AWS Cloud through both an Esri ArcGIS Enterprise Stack and a Geonode & Geoserver Open Source Stack, as well as through the Compusult catalog made available through the pilot. The data is available through OGC API (http://opengeomdapi.hsrhealthanalytics.org/), WMS, and WFS data formats and standards. Stakeholders and pilot participants can access the layer through the GeoMD Platform. The Risk Index was made available to AWS and Duality for incorporation into their mobile application and digital twin application, respectively. In addition, we collaborated with Compusult and Safe to explore and demonstrate interoperability between their data catalogs and our Health SDI.

6.7.4.6. Scenarios

The Drought Health Risk Index is being produced for the province of Manitoba, Canada, in line with the target area identified by the sponsors. The risk assessment is a current snapshot of risk based on the time this pilot effort was performed. Producing a Drought Health Risk Index that allows for historical trend analysis and forecasting across multiple years, while outside of the scope of the pilot, can provide value for long-term emergency response planning and should be explored in future work.

The Drought Health Risk Index demonstrated in this pilot, is a static indicator of risk for the identified region. Efforts to make the Risk Index dynamic and/or applicable to real-time updates should also be explored in future work — to improve its applicability during emergency response scenarios greatly.

6.7.5. Results

The Drought Health Risk Indicator layers can be accessed from the following links:

- Open GeoMD Drought Health Risk Index Layer- https://opengeomd.hsrhealthanalytics.org/catalogue/#/dataset/22
- GeoMD Drought Health Risk Index Dashboard — https://hsr.maps.arcgis.com/apps/dashboards/3b35b4d997f249c1864a3456b68ee02c

Figure 68 — GeoMD Platform Drought Health Risk Index Persistent Demonstrator Dashboard

6.7.5.1. Challenges and lessons learned

The largest issue for the project is the lack of data availability and granularity on certain at-risk populations. It's understood through research that these groups are more significantly impacted by drought, yet quantifying the individuals affected and to what extent is not currently possible. This issue, unfortunately, cannot be mitigated. For data that was available, much was not standardized for tabular usage. The data was cleaned before ingesting it into the model to address this issue, but further development of standards for tabular data will ease this process going forward.

6.7.5.2. Updates and applications

There are options for the use and incorporation of the independent drought severity indicators (Drought Crop Impact, Water Supply Indicator, and Energy Production Indicator) produced by fellow pilot participants, which include:

- Incorporating all indicators into the Drought Health Risk Index
- Allowing for the selection by the end user of the specific indicator of choice to be included in the Drought Health Risk Index

6.7.6. Discussion and future developments

In future pilot efforts, we would like to incorporate the predicted changes to drought extent and severity from climate change to create a future-looking health risk index. Additionally, we would like to explore further interoperability through technical interoperability experiments among pilot participants and stakeholders to demonstrate collaboration and interoperability.

6.8. Water Supply Indicator Workflow (by RSS-Hydro)

6.8.1. About RSS-Hydro

RSS-Hydro is a geospatial solutions and service company focusing its R&D and commercial products on water risks, particularly the SDGs. RSS-Hydro has been part of several successful OGC testbeds, including the DP 21 to which this pilot is linked, not only in terms of ARD and IRD but also in terms of use cases. In this pilot, RSS-Hydro's main contribution is the lead of the Engineering report. In terms of technical contributions to various other OGC testbeds and pilots, RSS-Hydro is creating digestible OGC data types and formats for specific partner use cases, in particular, producing ARD from publically available EO and model data, including hydrological model output as well as climate projections. These ARDs will feed into all use cases for all participants, primarily use cases proposed for Floods, Heat, Drought, and Health Impacts by other participants in the pilot. The created ARD in various OGC interoperable formats will create digestible dataflows for the proposed OGC Use Cases. Specifically, RSS-Hydro can provide access to the following satellite and climate projection data:

- General processing and interoperability enabling satellite Earth observation data, focusing on water risks and disaster management
- Climate Projection data (NetCDF, etc., daily downscaled possible): air temp (10 m above ground). Rainfall, possibly wind direction, as well
- Satellite-derived Discharge Data to look at Droughts/Floods, etc., by basin or other scales.
- Hydrological and hydraulic (flood) model simulation outputs at (sub)basin scale.

6.8.2. Background and problem description:

Droughts can significantly impact water availability. Identifying droughts at an early stage makes it possible to anticipate better the availability of freshwater resources and how best to utilize them. Given limited time and resources, improving interoperability on critical connections is important, where a lack of interoperability is particularly likely to derail data sharing. Disaster management frequently encounters key challenges in sharing and collaborating over data that make present awareness solutions more complex, slower, and less effective than they could be. Specifically in the context of indicators of drought impact on freshwater availability, the following problems pose significant challenges:

- Data, particularly timely EO-derived variables, can be unavailable, hard to find, complicated to share, challenging to access and slow to be processed into common forms suitable for analysis and integration.
- Many data sources are derived from models, whether primarily predictive or interpretive, functional or machine learning-based, and may require special treatment to correctly represent their uncertainties, sensitivities, biases, dependencies, and domains of validity in end-user information products.
- Information products, even when available, often overwhelm in volume and frequency the connectivity and tools available to responders and relief organizations in impacted regions and the time and attention these stakeholders can apply to ingesting that information. To effectively track droughts, it's necessary to analyze various indicators and indices that gauge changes in the hydrological pattern of a specific region. These markers, utilized to define drought conditions, encompass factors like rainfall, temperature, river flow, groundwater and reservoir levels, soil moisture, and snowpack depth. Obtaining reliable data or comprehensive derived indicators is relatively straightforward for certain factors. However, other factors necessitate the establishment of an extensive observation network to gather a continuous series of data points that can later be condensed into meaningful indicators. Deploying and sustaining such observation networks can be financially demanding, particularly when expanding to meet the requirements of an entire country or continent. Alternatively, existing data representing several of these factors can be leveraged to create composite indicators.

6.8.3. Objectives and role in the pilot architecture

This Pilot aims to explore and advance geospatial standards-based awareness and collaboration solutions for improving disaster management. This is to be accomplished through prototypical implementation of components and services that utilize modern cloud architecture and next-generation technologies to optimize collaborative workflows that can rapidly and scalable provision ARD and DRI products, services, and applications.

In line with the CFP, RSS-Hydro's water availability indicator activity will address the following critical components of a geospatial information flow for the Water Science and Watershed Management Branch of Manitoba:

- **Timely, Directed Data-to-Decision Workflows:** Instantly deployable, adaptable, and scalable discovery, access, and processing of geospatial ARD from satellite- and model-based water flow availability at daily updates.
- **Decision Ready Indicators:** Analysis, visualization, and collaboration development processes enable transformation at the appropriate stakeholder organization by providing

near real-time automated DRI capabilities to monitor water availability at a sub-basin scale.

- **Decision Support:** On-demand and event-driven dissemination of DRI to responders, decision-makers, and other disaster stakeholders through cloud-supported, quickly configurable mobile applications.

- **Volunteered and Crowd-sourced Observation:** Collection, validation, curation, and integration of situation-specific information reported by local sources and gleaned from local activities.

- **Shared Perspective:** effective visualization and communication of indicator products and immersive visualization environment within which indicator products can be shared with practitioners. So, our goal is to establish a workflow to create a drought indicator that assesses the impact of freshwater availability. To achieve this, we will deploy virtual monitoring stations, called RiverWatch stations, which will use satellite data and microwave sensors (such as AMSR-E, AMSR-2, TRMM, and GPM) on various satellites. These RiverWatch stations will generate daily time series data on water discharge. They serve as drought indicators for freshwater availability. Using approximately 25 years of daily records, we can determine whether water discharge increases or decreases over specific intervals (e.g., week, month, season, or year). This indicator can then be correlated with temperature (T) and precipitation (PPT) data, allowing us to incorporate climate model projections for T and PPT. Consequently, we can estimate future water anomalies, giving the drought indicator a predictive capability.

6.8.4. Methodology

6.8.4.1. Area of Interest

Manitoba is a Canadian province in the country's central part. It is Canada's fifth most populous province, with a population of approximately 1.3 million as of 2021. The area boasts a diverse landscape, ranging from arctic tundra and the Hudson Bay coastline in the north to dense boreal forests, large freshwater lakes, and prairie grasslands in the central and southern regions. Manitoba's climate is characterized by its harsh nature, making it susceptible to various natural disasters such as droughts, floods, wildfires, and winter storms. Floods are the most prevalent, leading to fatalities, injuries, and significant socioeconomic damage. However, Manitoba is also known for its droughts, especially in the southern part, which is more populated.

Over the past century, the prairies of Manitoba have witnessed several instances of drought. These occurred in the late 1880s and early 1890s, in 1910 and 1914, between 1917 and 1920, in 1924 and 1929, and throughout the 1930s. Manitoba also faced similar droughts in 1961, 1967, 1976, 1979, 1980, 1984, 1988, and 1989. Furthermore, a severe, multi-year drought from 1999 to the mid-2000s affected a substantial portion of the Canadian Prairies. In 2012, Manitoba experienced rapid drought development following widespread flooding in 2011. 2015 brought drought conditions characterized by warm temperatures and increased winds, leading to an elevated risk of wildland fires across western Canada. In 2017, moderate drought conditions affected Manitoba after an early spring surge resulted in above-normal streamflow conditions in most southern and northern Manitoba. Nevertheless, after months of below-average precipitation during the growing season, nearly all Manitoba grappled with moderate to severe drought conditions by July and August. Consequently, there is considerable interest in what happens to aquifers during a drought and how reliable is the water supply from Manitoba's aquifers.

Similar difficult-to-predict drought conditions have been reported for the White River, Indiana. The White River (Figure 69), located in east central and southern Indiana, USA, is a typical river of the Midwest that flows through mostly farmlands. Over the past few decades, the watershed has encountered significant drought challenges during the periods when crops are cultivated. These issues are attributed to the diminishing groundwater levels, which are a consequence of climate change and extensive usage. It is anticipated that this strain will persist in the foreseeable future. We'll use the White River watershed as an analog to demonstrate how a monitoring system for water availability can be utilized by using a satellite data–modeling–informed workflow.

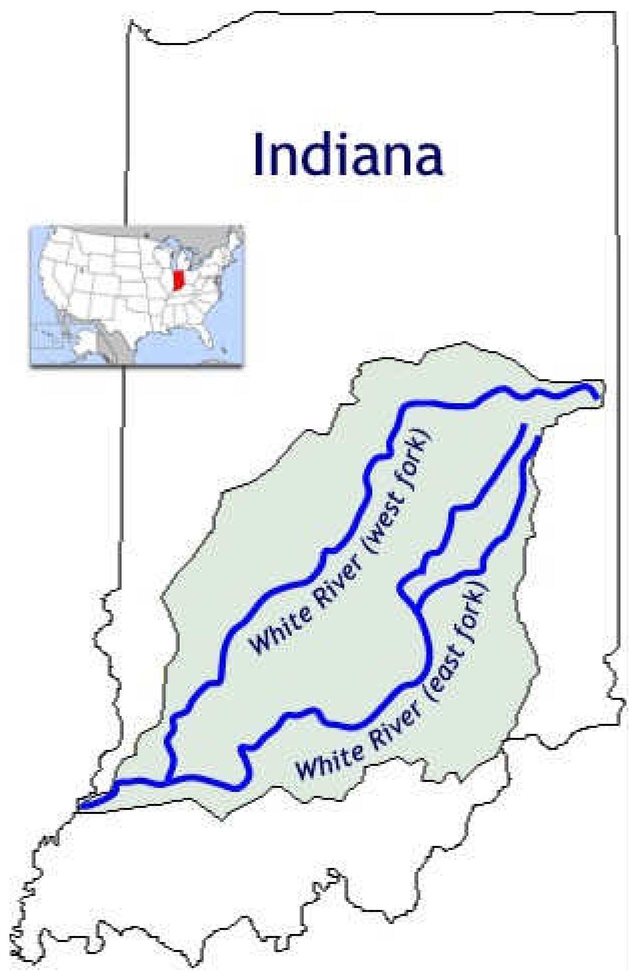


Figure 69 — White River, Indiana (courtesy of David Speakman).

6.8.4.2. Technical design

Since 1998, passive microwave sensors on satellites have consistently provided global coverage of the Earth's land surface. These sensors, including AMSR-E, AMSR-2, TRMM, and GPM, operate at specific wavelengths, allowing them to collect data even when cloud cover is present. They are capable of tracking changes in river discharge by measuring radiation.

As rivers experience rising water levels and increased discharge, the water area within a designated "gauging reach," typically a single 10 km x 10 km pixel, expands. This gauging reach encompasses water areas (with low radiation emissions) and land areas (with significantly higher emissions). As the proportion of water area within this reach increases, the overall emitted radiation decreases. This microwave signal is, therefore, sensitive to variations in flow area and discharge.

In instances where there is no recorded discharge, DFO — Flood Observatory utilizes the Water Balance Model, WBM (Wisser et al., 2008), to generate independent estimates of discharge at a particular discharge measurement site. These estimates are then compared to the contemporaneous and geographically matched satellite-observed water area estimate. Initially, the microwave ratio signal used by the DFO undergoes processing (daily) via the Global Flood Detection System at the Joint Research Centre, JRC, of the European Commission (De Groeve, 2010). Subsequently, this signal is smoothed using a 4-day running mean to address sporadic gaps and minimize signal noise (Kettner et al., 2021).

Consequently, these sensors have enabled the continuous monitoring of freshwater availability since 1998, which can help improve flood forecasting and water management. This functionality allows for identifying and monitoring water resource status, encompassing conditions ranging from droughts to flooding events as they happen. It involves the creation of a water availability index by contrasting present freshwater levels with data from the past 25 years. When contemporary freshwater levels surpass the historical average for the same timeframe, it indicates greater water availability, whereas if they fall below the historical average, it signifies reduced water availability.

This information can be directly compared to measured precipitation, infiltration, and evapotranspiration to understand the water cycle better. The River Watch system can also determine the variability in daily, weekly, monthly, and annual watershed runoff.

In this pilot, this technology is used to build the DRI workflow for water availability time series and drought impact indicators, which is valuable in but not limited to the following scenarios:

- A water manager in a drought-prone region can use the developed indicator to monitor the water availability in their area and identify areas at risk of drought. They can also use the indicator to assess drought conditions' severity and develop drought mitigation strategies.
- Study the impacts of drought on vegetation and develop new methods for drought monitoring and forecasting. In summary, water availability time series and drought impact indicators are valuable tools for managing water resources and mitigating drought impacts.

6.8.4.3. Technical implementation

DFO – Flood Observatory is an extensive repository of historical records detailing river discharge and significant flood event runoff data for multiple rivers worldwide. These datasets encompass the period from 1998 till now. DFO has developed a method to utilize satellite data in combination with a hydrological model to monitor water availability and, as such, provides access to daily satellite-based water discharge from 1998 onwards. This can be implemented for Manitoba, Canada, and similarly for the White River. Daily discharges are displayed such that users can easily identify if values are above or below a seasonal low flow threshold, the 1.5-year flood, the 10-year flood, or the 25-year flood frequency.

6.8.5. Results

Measurements of the flow of rivers and the runoff from surrounding areas are crucial for managing water resources, optimizing the generation of hydropower, making accurate predictions and taking control measures for floods, monitoring the severity and duration of droughts, and enhancing our understanding of the global water cycle. The river discharge at a particular location represents a comprehensive reflection of the various processes within the water cycle across the area upstream, often exhibiting significant fluctuations over short periods. Although significant efforts have been directed toward enhancing the global availability of ground-based discharge data, the sharing of hydrological data among nations remains limited, and the existing network of ground stations worldwide is insufficient. Satellites can be employed to monitor river discharge daily. These methods have been implemented for the White River, serving as a model for the Manitoba province of Canada.

Here, we highlight some key results, but the entire daily discharge dataset and the derived drought indicator are available here. For comparison purposes, a reference 20th percentile of the measured discharge for each day of the period 2003-2010 is provided for each day and provides a low flow threshold (green line, Figure 70); also, values of the 1.5, 10, and 25 yr recurrence flood discharge is calculated using the annual maximum floods and the Log Pearson III distribution: these provide useful thresholds for evaluating past or present flood magnitudes. The drainage area is drought if daily discharge values drop below the low flow threshold. As shown in Figure 70, during much of the summer of 2023, the White River drainage basin was in a drought condition.

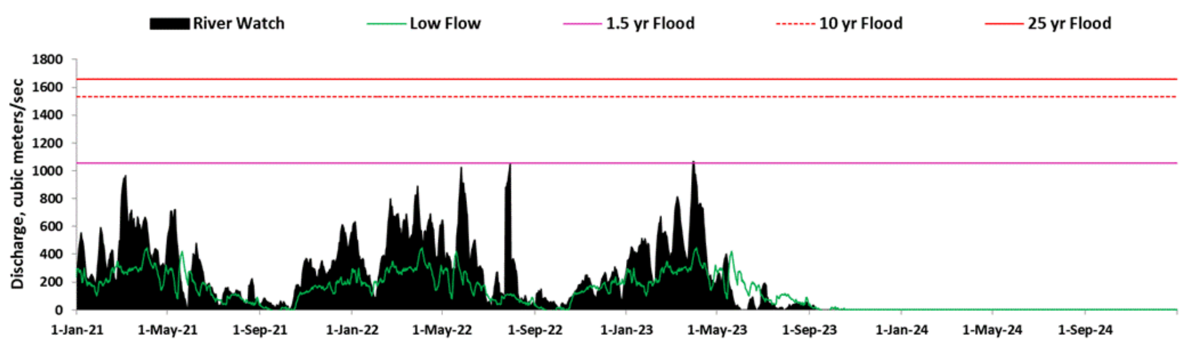


Figure 70

Discharge in Figure 70 was obtained utilizing satellite data. The daily discharge using satellite data is in black, and a 7-day forward weighted moving average is applied. The low flow is the 20th percentile discharge derived from the daily data of 2003-2010. The various flood intervals are purple and two red lines; exceeding that threshold by the daily discharge means the river is in flood.

A more historical view is provided in Figure 71, where the entire daily discharge time series is provided. This provides the capability to identify how unique it is for the catchment to be in drought conditions. As shown in Figure 71, there are no large durations of drought conditions observed except for the late summer and early fall of 2008 and the summer of 2023. More detailed information on the actual discharge can be obtained through the associate data web page. Once obtained, this data can be further examined for higher resolution at low flow (so drought) conditions.

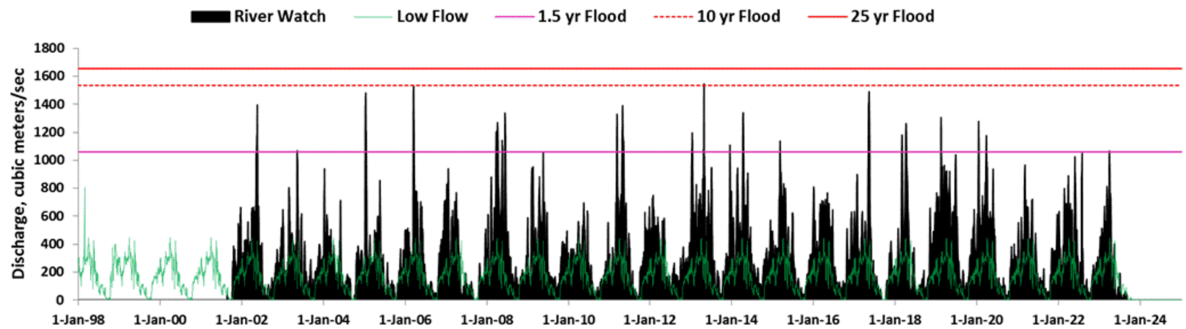


Figure 71 — Similar to Figure 70, but now showing the entire time series of water discharge using satellite data (2002 → now).

The satellite sensor for this site started obtaining data from 2002, not from 1998 onwards, as is the case for most other sites.

This satellite-based discharge monitoring system is implemented for over several hundred sites worldwide. Access to the discharge data for each monitoring site is provided through the web. The stations are represented by colors, indicating the flow status of that station, where yellow represents low flow conditions, blue normal flow, purple moderate flooding, and red major flooding (Figure 72).

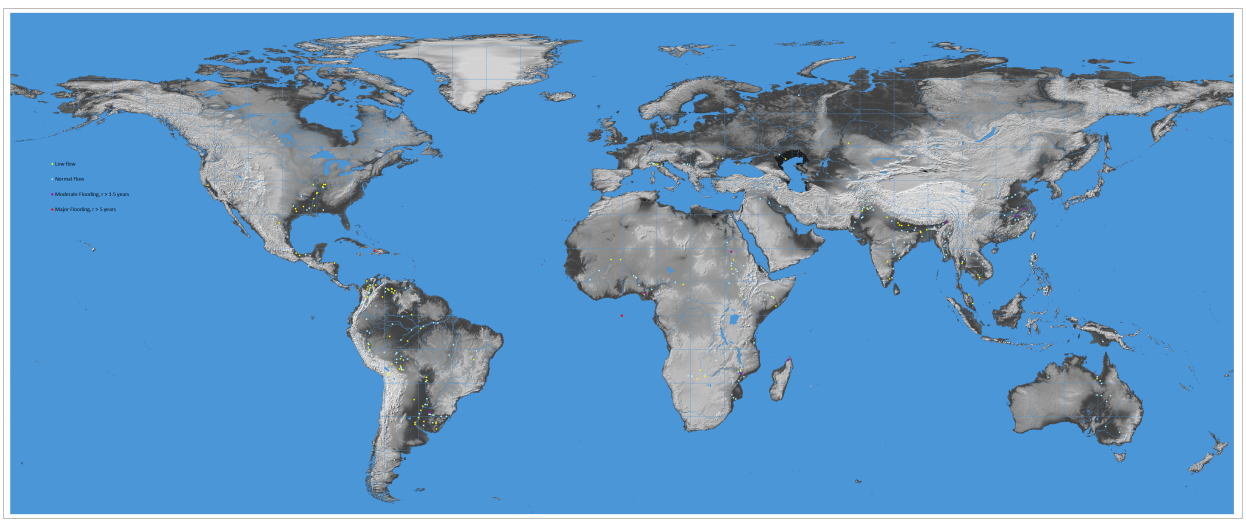


Figure 72

6.8.6. Discussion and future developments

Passive microwave radiometry is a powerful tool for monitoring changes in river discharge, has demonstrated a remarkable ability to provide accurate data over several decades, and has the potential to continue. This capability was unforeseen when designing sensors like AMSR-E, AMSR-2, and GMI on various satellites, including TRMM, AQUA, GCOM-W, and GPM (Brakenridge et al., 2022). Such monitoring is critical for comprehending the scale of river floods and droughts and improving future drought risk assessments. The maintenance of pre-1998 Ka-band microwave records in data archives, alongside new processing techniques, allows for the extension of consistent watershed runoff observational records back in time by at least another decade. This capability can be integrated into future missions like the Copernicus Imaging Microwave Radiometer (CIMR), which aims to provide observations up to 2040 using radiometers from L to Ka bands. Orbital microwave sensors are well-suited for identifying long-term drought and flood anomalies along rivers, given their ability to distinguish abnormal events from normal seasonal variability. Additionally, their high spatial resolution is not critical, and they experience relatively minimal interference from cloud cover.

Previous research conducted by Brakenridge et al. in 2007 suggests that an underlying cause of error in the daily data derived from this remote sensing method is the absence of precise synchronization between the discharge data obtained from the station and the remote sensing system. To illustrate, instances have been observed where the maximum flood discharge, as observed by surface gauging stations, occurs 1 to 2 days before the peak recorded by the remote sensing method, which assesses the flow area along the entire stretch of the river. Such delays result in a negative discrepancy (remote sensing value – station value) when the peak flow passes the station, and the reach area progressively experiences flooding. Consequently, a positive error emerges several days later as the water level is already receding at the station, partly due to the overflow. As a result, although the ground-based stage and satellite-based flow area techniques might accurately capture the peak discharge value, the disparity in timing could significantly elevate the average daily measurement error. We anticipate further reducing the signal error by applying ML methods to derive a more accurate discharge product.

6.9. Drought Severity Workflow (by Pixalytics Ltd, Safe Software, and University of Prince Edward Island (UPEI))

6.9.1. Introduction to the company and main activities

Pixalytics

Pixalytics Ltd. is an independent consultancy company specializing in Earth Observation (EO). We combine cutting-edge scientific knowledge with satellite and airborne data to provide answers to questions about our planet's resources and behavior. The underlying work includes developing algorithms and software, including EO quality control and end-user-focused applications.

Safe Software

Safe Software has been a leader in supporting geospatial interoperability and automation for more than 25 years as the creator of the FME Platform. A central goal is to promote FAIR principles, including data sharing across barriers and silos, with unparalleled support for both vendor-specific formats and open standards. Within this platform, Safe Software provides various tools to support the design, deployment, and automation of interoperability workflows, both on-premise and in the cloud.

Open standards have always been a core strategy for Safe Software to support data sharing. The FME platform can be seen as a bridge between the many supported vendor protocols and open standards. Safe has collaborated extensively with the open standards community, including OGC, ISO, BSI, and EU INSPIRE. Safe has participated in many OGC initiatives, including Maritime Limits and Boundaries, IndoorGML pilots, and most recently, the 2021 Disaster and 2023 Climate Resilience Pilots. Safe also actively participates in a number Domain and Standards working groups (CityGML, MUDDI, EDM, IndoorGML and Climate Resilience, to name a few).

6.9.2. Background and Problem Description

Despite the lower geographical spread, the U.S. drought in 2022 accounted for USD $ 22 billion in economic losses. Droughts are geographic events that occur in a specific location and impact the people, economy, and society in that and the surrounding areas — often tens or hundreds of miles away. For this reason, geospatial information is effective in supporting both the understanding of and response to disaster scenarios. According to the WHO report, the death toll from the weather, climate, and water extremes has fallen significantly over the last 50 years due to the introduction of early warning systems, including geospatial information.

Geospatial tools and applications have the potential to save lives and limit damage, and the world is becoming better at using these resources. Unfortunately, the ability to share, use, and reuse geospatial information and applications across and between organizations within disaster and emergency communities, both governmental and non-governmental, requires the right partnerships, policies, standards, architecture, and technologies to be in place before the disaster strikes.

For this pilot, one focus area for drought impact indicators was southern Manitoba. This area, has historically not tended to experience as much drought as other regions of the prairies to the west. However, more recently with the effects of climate change, this area has shown increasing drought stress which has implications for the need to manage and model drought more closely. Both the Manitoba Drought Monitor and the Canadian Drought Monitor shown below actively track on-going droughts in the region.

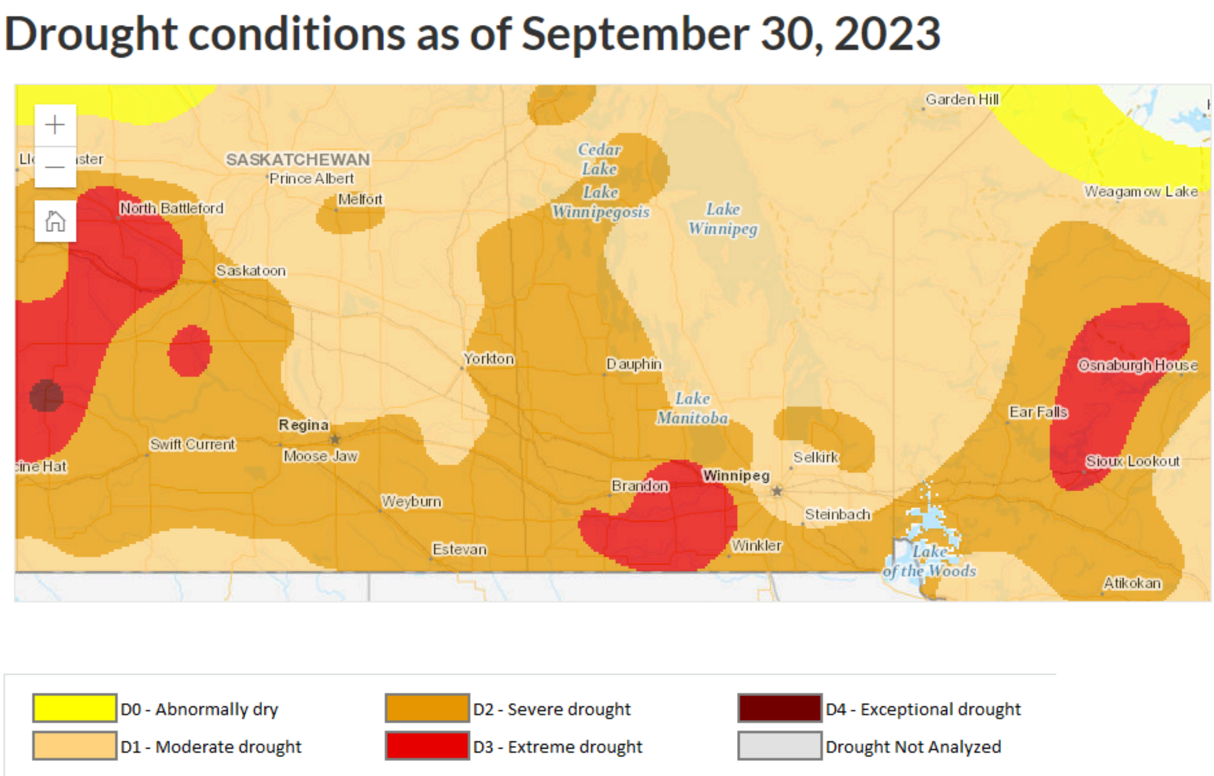


Figure 73 — Canadian drought monitor showing areas of the eastern prairies experiencing various degrees of drought as of September 2023 (Agriculture Canada).

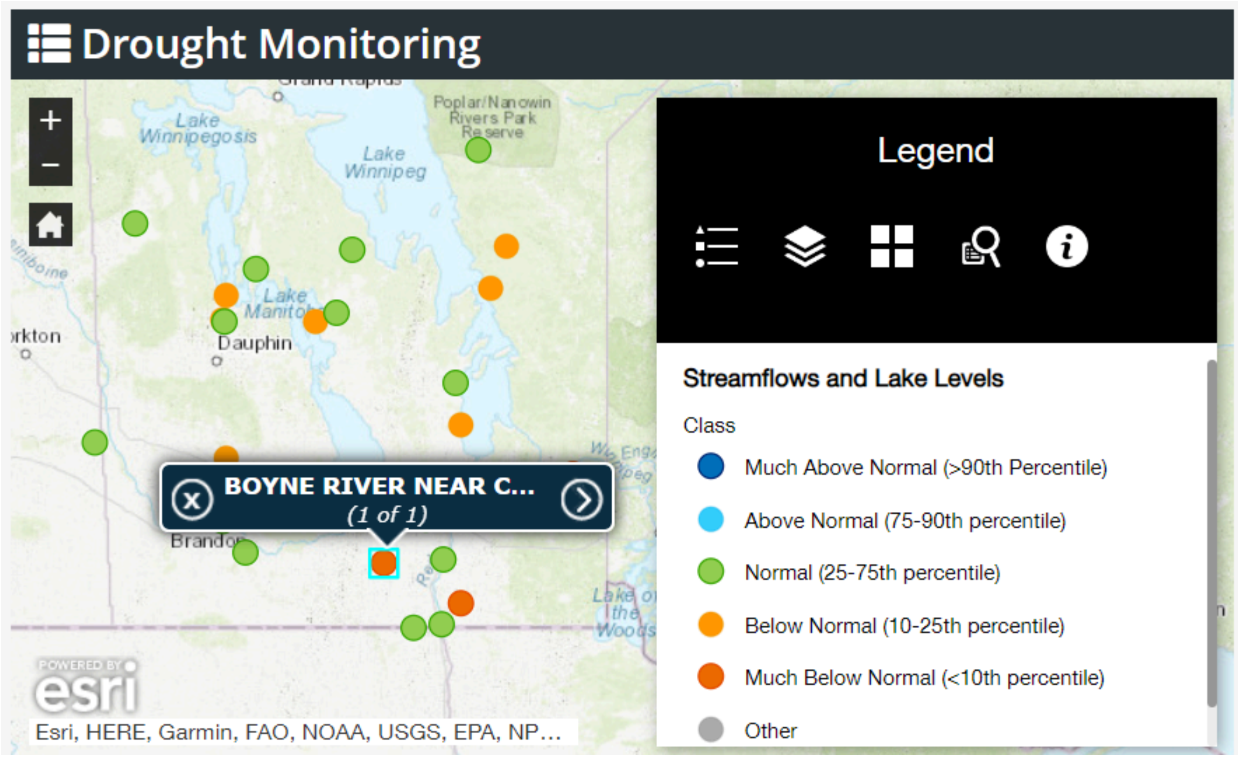


Figure 74 — Manitoba drought monitor showing degrees of drought for lakes and rivers in Manitoba, fall 2023 (Manitoba Environment).

6.9.3. Objectives and role in the pilot architecture

Disaster Pilot 23 (DP23) is the latest in a series of initiatives. Its focus is to:

- Develop flexible, scaleable, timely, and resilient information workflows to support critical disaster management decisions, enabling stakeholder collaboration, and
- Provide applications and visualization tools to promote a wider understanding of how geospatial data can support emergency and disaster communities. The Disaster Pilot 2023 call stated that D101, the Drought Severity Indicator Workflow, should be an implemented workflow to produce one or more indicators of drought severity. It is hoped that this workflow help save more lives and reduce the impact of disasters on communities.

6.9.4. Methodology

The three participants have focused on different aspects of workflow development:

- Pixalytics’ Drought Severity Workflow (DSW) was begun in the Climate Resilience Pilot, then updated and further developed in Disaster Pilot 2023, alongside creating a permanent demonstrator. It involved implementing and testing a workflow based on Sepulcre-Canto *et al.* (2012) in which the authors developed a Combined Drought Indicator (CDI) that encompasses precipitation, soil moisture, and the vegetation’s response to drought. The workflow is accessed via a Web Processing Services (WPS) API where the user provides the location and time extent, with the extracted CDI returned.

- Safe Software's primary focus in both the Climate Resilience Pilot and this Disaster Pilot has been to support the extraction of data from climate projection services to provide a future perspective on risk indicators and natural hazards of interest, such as drought. Our workflow transforms climate services data into ARD — analysis-ready data — more easily consumable by GIS applications, via publication of this via OGC API Feature services.
- The School of Climate Change and Adaptation at the University of Prince Edward Island (UPEI), Canada, studied the general requirements to ensure interoperability of the systems for drought severity and vulnerability analyses. Drought severity workflow knowledge encompasses several aspects of environmental (e.g., precipitation), economic (e.g., income level), and social data (e.g., health and chronic condition data). Here, we reviewed how adequate data helps make fair, efficient, and informed decisions about drought risk and severity.

6.9.4.1. Area of Study

Pixalytics

For the Pixalytics DSW, it can run anywhere in the world. Still for Disaster Pilot 23, the focus has been on Canada and the U.S although it still works for any land-mass in the world.

Safe Software

For Safe Software, this pilot's primary area of study has been southern Manitoba. More specifically, the data extent used was approximately longitude/latitude: 102W, 49N to 95W, 52N. The time range of the output data is from 2020 to 2060. Still, as with Pixalytics, Safe Software's climate ARD service and drought indicator can be configured to run anywhere as climate model data is available globally.

UPEI

UPEI's approach can be applied anywhere, but focused on the province of Manitoba in Canada.

6.9.4.2. Technical design

Pixalytics

The Pixalytics DSW is used to create a decision-ready CDI output. The structure includes the workflow shown in Figure 75, with a user calling the Application Programming Interface (API). Then the back-end undertaking the processing and output generation passed to the API.

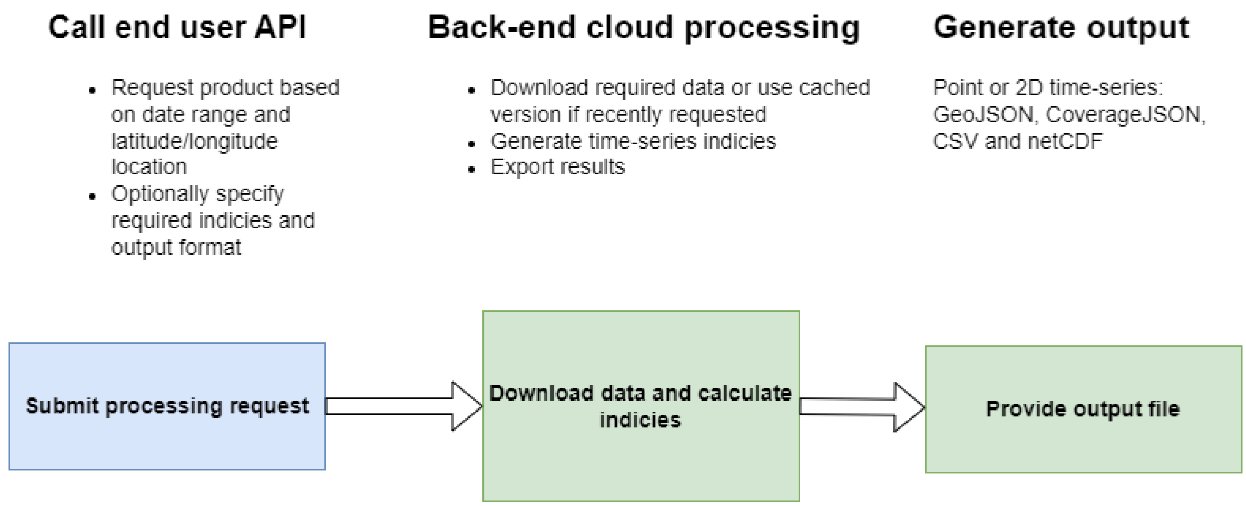


Figure 75 — Drought Severity Workflow architecture

Its components are:

- *Input:* The input data are a combination of modeled and/or Earth Observation (EO) derived products that can act as drought indicators. Within the CDI, the user selects the indicators they are most interested in, and the inputs used vary according to what is chosen and include precipitation, soil moisture, and the Fraction of absorbed light by the plants (FAPAR). These parameters are retrieved from multiple sources that may be combined or used individually:
  - Copernicus Climate Change Service (C3S) through the Climate Data Store (CDS),
  - Copernicus Global Drought Observatory (GDO),
  - NOAA through their Climate Climate Environmental Data Retrieval (EDR) API or
  - Safe Software provides access via an OGC API Features server.
- *Processing:* Individual drought indicators are calculated for the three chosen input parameters: for precipitation, the Standardized Precipitation Index (SPI) is calculated; for soil moisture, it's the Soil Moisture Anomaly (SMA); and for vegetation health, FAPAR is used. These drought indicators can also be downloaded in a pre-calculated form from the GDO. The three individual indicators are combined to generate the Combined Drought Indicator (CDI); the detailed methodology behind this is described by Sepulcre-Canto *et al.* (2012).

During the Disaster Pilot, the aim is to develop further combined indicators for other scenarios, such as health and wildfire, as CDI is primarily used for vegetation health.

- *Output Type and Format:* The data is provided through an API. The API can provide a point or 2D time-series extraction in CSV, GeoJSON, CoverageJSON,

- or NetCDF format. The API access has been set up following the Building Blocks for Climate Services WPS approach. The front-end API is supported by Nginx, which is an open-source web server, and Certbox for HTTPS certification.
- *Running the Indicator:* The code is currently held within several GitHub repositories. So, to make it easier to install, it will be transitioned to a Docker container. At the moment, the API runs on a web server owned by Pixalytics, with the intention of transitioning it to a permanent demonstrator before the end of the pilot. Currently accessed via: https://api.pixalytics.com/climate/wps?request=GetCapabilities&service=wps&identifier=drought

Safe Software

The Drought Severity Indicator developed by Safe Software supports the modeling and analysis of drought risk estimation in southern Manitoba. This component takes the climate environmental variable ARD (Analysis Ready Data) from Safe Software's Data Service component and applies the service to estimating relative drought risk. This is accomplished by using appropriate queries and business rules related to drought impact to estimate relative drought risk over time based on selected climate scenarios.

Safe Software began component development in the Climate Resilience Pilot and then extended this in the Disaster Pilot. Safe Software's primary focus in both Pilots has been to support the extraction of data from climate projection services to provide a future perspective on risk indicators and natural hazards of interest, such as drought. Component workflows transform climate services data to a form of ARD — analysis-ready data — more easily consumable by GIS. In particular, it uses the FME platform to consume regional climate model results in data cubes and generate FAIR analysis-ready datasets for downstream analysis and decision support using OGC API services.

Managing and mitigating climate change's effects poses difficulties for spatial and temporal data integration. One challenge is translating the outputs of global climate models into specific impacts at the local level. Central to this is the identification of key drought risk impact indicators required by decision makers and the business rules and datasets needed to drive them. The workflow includes data aggregation and statistical analysis of precipitation over time, taking into account deviation from historical norms and cumulative impacts by time period. This may be useful as a starting point for the assessment of drought risk by region and time. It also represents an important example of how global and regional climate model outputs can be used to support disaster and climate resilience planning at the regional and local scales, by translating scenario model outputs into specific natural hazard risks and impacts at local levels.

This component was implemented on the FME, a spatial data integration and automation platform produced by Safe Software that can bridge the gaps between disparate systems using its support for hundreds of different spatial and nonspatial data formats. FME is ideally suited to help explore options for bridging this gap, given its ability to read datasets produced by climate models such as NetCDF or OGC WCS and then filter, aggregate, interpolate, and transform them as needed. FME can also inter-relate climate data with higher resolution local data and then output it to whatever format or service is most appropriate for a given application domain or user community. This component supports the consumption of climate model output data cubes such as NetCDF or ZARR. It also has the capacity to consume earth observation (EO) data and the base map datasets necessary for downstream workflows, though given time and resource constraints during this phase, we did not pursue consumption of other data types besides climate data.

In terms of processing, this component takes the climate scenario model data cube results from climate data services and transforms them into analysis-ready data (ARD). Making this data available via commonly accessible open standards is seen as key to making this crucial data more widely accessible and usable by those who are likely to be affected by potential impacts. In this case, the data is first converted into a relational form and stored in a spatial database — a geopackage. Then a spatial database to GeoSON workflow is used to make the data available via an easily accessible GeoJSON web service using OGC API Features. See the data cube to database and spatial database to GeoJSON FME workflows shown below. For the selected climate scenarios, this supports the analysis of estimated drought risk impacts over time via simple feature queries that can be translated to SQL queries on the underlying spatial database. It also feeds drought-related environmental factors to other pilot indicator components such as Pixalytics drought model for more refined drought risk analysis.

For the purposes of this pilot, it was recognized that more complex indicators, such as drought, are likely driven by multiple environmental and physical factors. As such, the initial goal was to select and provide primary climate variable data useful for deriving drought risks in combination with other inputs. Given that the primary input to drought models is precipitation or lack thereof, a data flow was developed that extracted total precipitation per month and made this available both as time series GeoJSON datasets as well as OGC API features time series points. This climate scenario primary drought data was provided for the province of Manitoba study area and was the dataset consumed by the Pixalytics drought model component.

Input

The climate model data used in this pilot was obtained from the climate data services published by Environment and Climate Change Canada.

The following climate model scenario was selected for the purposes of this pilot:

Manitoba Regional Climate Model (RCM) Details

Spatial Extent: Lat 49 N to 52 N, 102W to 95W

Temporal Extent: 2020-2060

Model generation: CMIP5

Model scenario: RCP45

Downscale approach: bias-corrected and spatially downscaled *NetCDF version 4 using NetCDF conventions CF v1.4

Model summary:

Future total monthly precipitation and mean temp from RCP45 CMIP5 for 2020-2100 Statistically downscaled climate scenarios from Environment Canada Climate Data Portal (BCSD: bias-corrected and spatially downscaled) RCP4.5: 'Business as usual'. The downloaded climate data had 960 bands representing monthly time steps.

RCP 4.5 is the most probable baseline scenario (no climate policies) taking into account the exhaustible character of non-renewable fuels. CMIP5 describes the RPC run version or generation (Phase 5 2012-2014), and BCSD is a statistical term about the method of downscaling used (bias-corrected and spatially downscaled). CMIP5 and BCSD are technical terms that won't be that meaningful to readers not familiar with climate models, but they are necessary parameters if you want to get the same results. For more information on climate model parameters, see: https://en.wikipedia.org/wiki/Coupled_Model_Intercomparison_Project

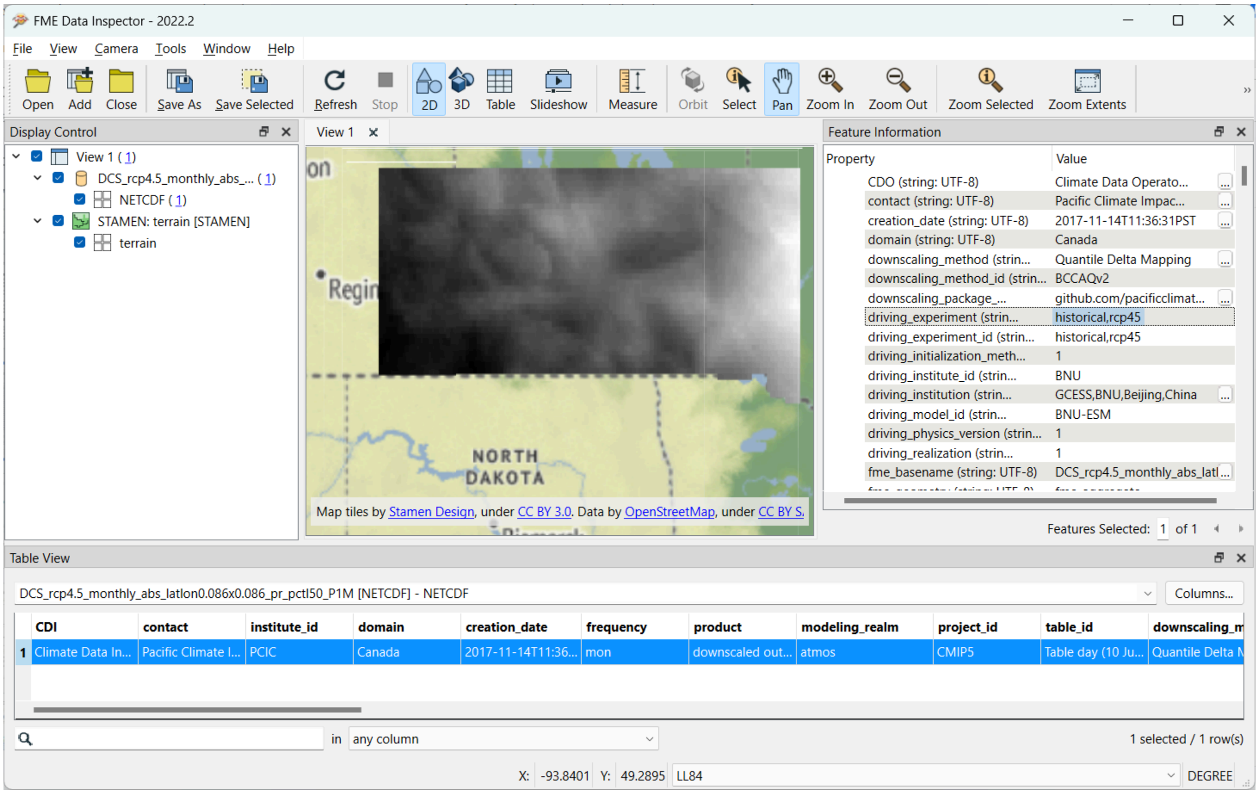


Figure 76 — Source NetCDF data cube from Environment Canada's climate data extraction tool shown in FME Data Inspector.

Processing

The workflow involved developing a transformation workflow on the FME platform to extract, transform, and load climate model results from data cubes into a relational spatial database and then provide OGC API services to deliver GeoJSON to end-client applications. Safe Software's ARD component generates climate model outputs as an OGC API Features service, delivering GeoJSON point features with associated climate properties. In particular, properties include monthly mean temperature, total precipitation, and change in precipitation compared to the historical baseline (mean precipitation from 1950 to 1980 for that same location). This allows the end user to develop business rules that define climate scenario based drought impacts by submitting the appropriate queries to the ARD climate variable service. So in a very real sense, the drought model is essentially a set of queries submitted to Safe's climate ARD component that ask for a set of time series points that pass a combination of drought related environmental variables business rules. The output of this is the same as that of the climate ARD component, but applied to drought risk estimation.

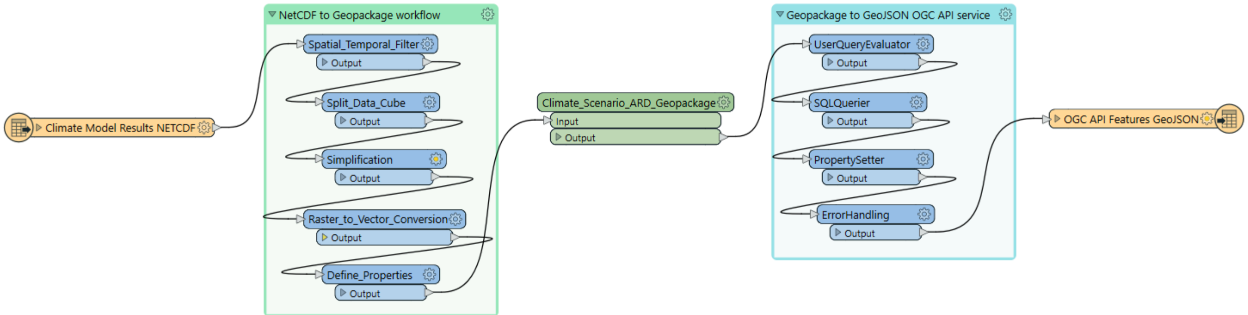


Figure 77 — High-level component FME workflow from climate data cube NetCDF to spatial database geopackage to OGC API Feature service GeoJSON.

The basic workflow for precipitation and temperature:

1. Download and read the data cube for the selected climate scenario and environmental variable type of interest
2. Split the data cube into separate grids for each time step
3. Set timestep parameters
4. Compute timestep stats by band
5. Convert grids to vector points
6. Map geometry and feature properties and load features to a relational database data model in Geopackage
7. Upload the geopackage staging database to the FME cloud instance
8. Publish the client feature query workflow to the FME cloud-hosted OGC API Feature Service, which extracts features as GeoJSON layers for the environmental variables of interest (precipitation, precipitation delta, and temperature).

For the precipitation delta drought proxy indicator, the following steps were also performed:

1. Read data cube for selected climate scenario environmental variable types of interest
2. Split the data cube into separate grids for each time step
3. Set timestep parameters
4. Compute timestep stats by a band
5. Combine bands for each environmental variable type into a multiband raster for each time step

6. Convert grids to vector points, preserving environmental properties for each point including precipitation total, precipitation delta, and temperature mean.

7. Map geometry and feature properties and load features to a relational database data model in Geopackage

8. Upload the package staging database to the FME cloud instance

9. Publish the client feature query workflow to the FME cloud-hosted OGC API Feature Service, which extracts features as GeoJSON layers for the environmental variables of interest (precipitation, precipitation delta, and temperature).

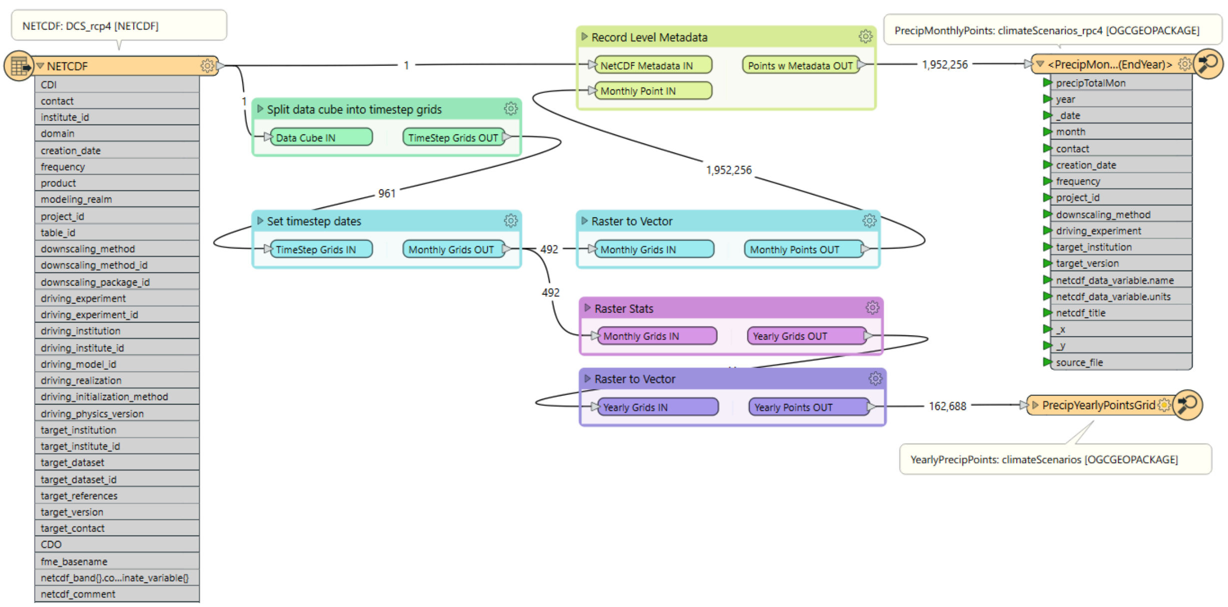


Figure 78 — Climate service data FME transformation workflow from NetCDF data cube to Geopackage relational database.

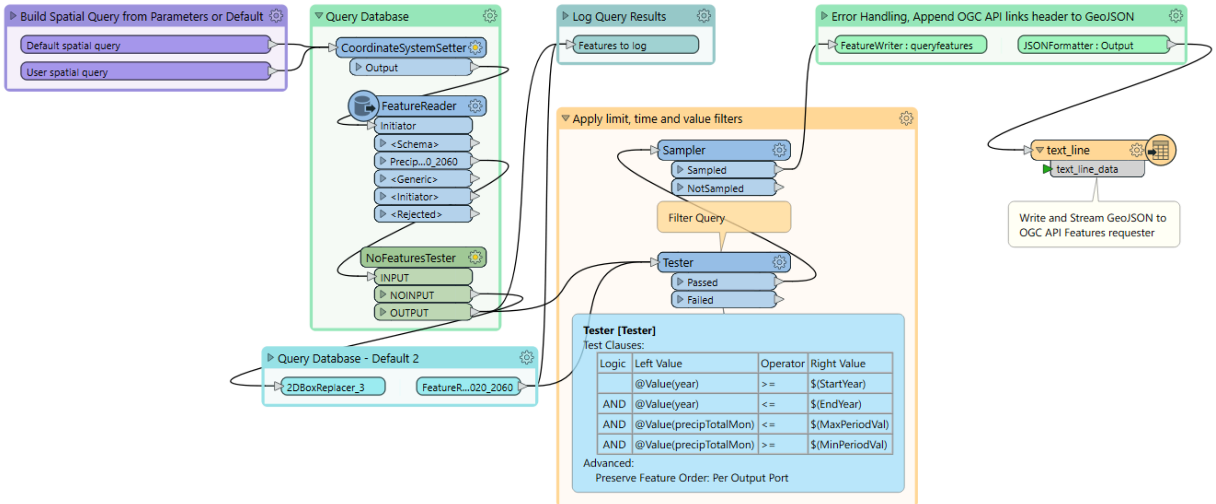


Figure 79 — OGC API Feature Querier: Geopackage to GeoJSON.

In order to provide a more broadly usable drought risk estimate, a proxy drought risk indicator was refined by normalizing the difference between precipitation from the past vs. future climate scenarios. Calculations were made by dividing the time series grids of projected precipitation by historical grids of mean precipitation per month per cell. The goal was to provide a value between 0 and 1 where 1 = 100% of past mean precipitation for that month. Naturally, this approach can generate values that exceed the range of 1 if the projected precipitation values exceed the historic mean. The goal was not so much to predict future absolute precipitation values but rather to generate an estimate for precipitation trends, given the influence of climate change. For example, this approach can help answer the question — in 30 years for a given location, compared to historical norms, by what percentage do we expect precipitation to increase or decrease? See Output below for some example queries and results.

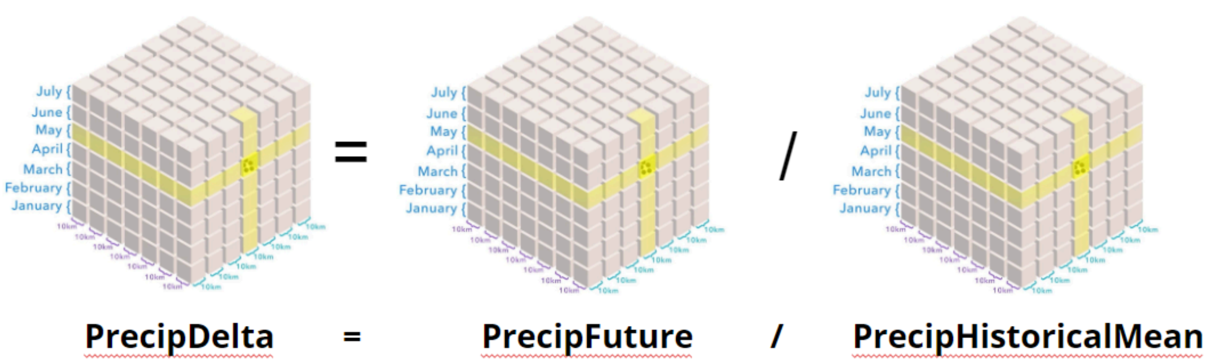


Figure 80 — Calculation of precipitation delta by dividing future projected precipitation by historical for each point in the time series.

Safe Software's climate scenario drought impact component is essentially a set of queries submitted to Safe's climate ARD component that ask for a set of time series points that pass a combination of drought related environmental variables business rules. The output of this is the same as that of the climate ARD component, but applied to drought risk estimation. So the drought model is ultimately a drought targeted OGC API Feature request and the output is the associated OGC API Features GeoJSON response that specifies the time series points along with their environmental variables that meet the conditions of the drought query.

The service response data can then be used as a rough estimate of general drought risk, or to drive downstream drought analysis. For example, Pixalytics submitted a query for precipitation estimates for a specific location and time range, and fed that into their near future drought model runs. In this way, they were able to develop a continuous summary of observed and projected drought severity for specific locations from approximately 2020 to 2024.

For the selected climate scenarios, this supports the analysis of estimated drought risk impacts over time via simple feature queries that can be translated to SQL queries on the underlying spatial database. The OGC API Features service then generates a response as GeoJSON point features with associated climate properties. In particular, properties include monthly mean temperature, total precipitation, and change in precipitation compared to the historical baseline (mean precipitation from 1950 to 1980 for that same location). This allows any end user to submit queries to the climate drought variable service. This data can then be used to drive downstream drought analysis or as a rough estimate of general drought risk. For example, in the case of Pixalytics, they could query for precipitation estimates for specific locations and feed that into their near future drought model runs. In this way, they could have a close, continuous summary of observed and projected drought severity for specific locations from approximately 2020 to 2024.

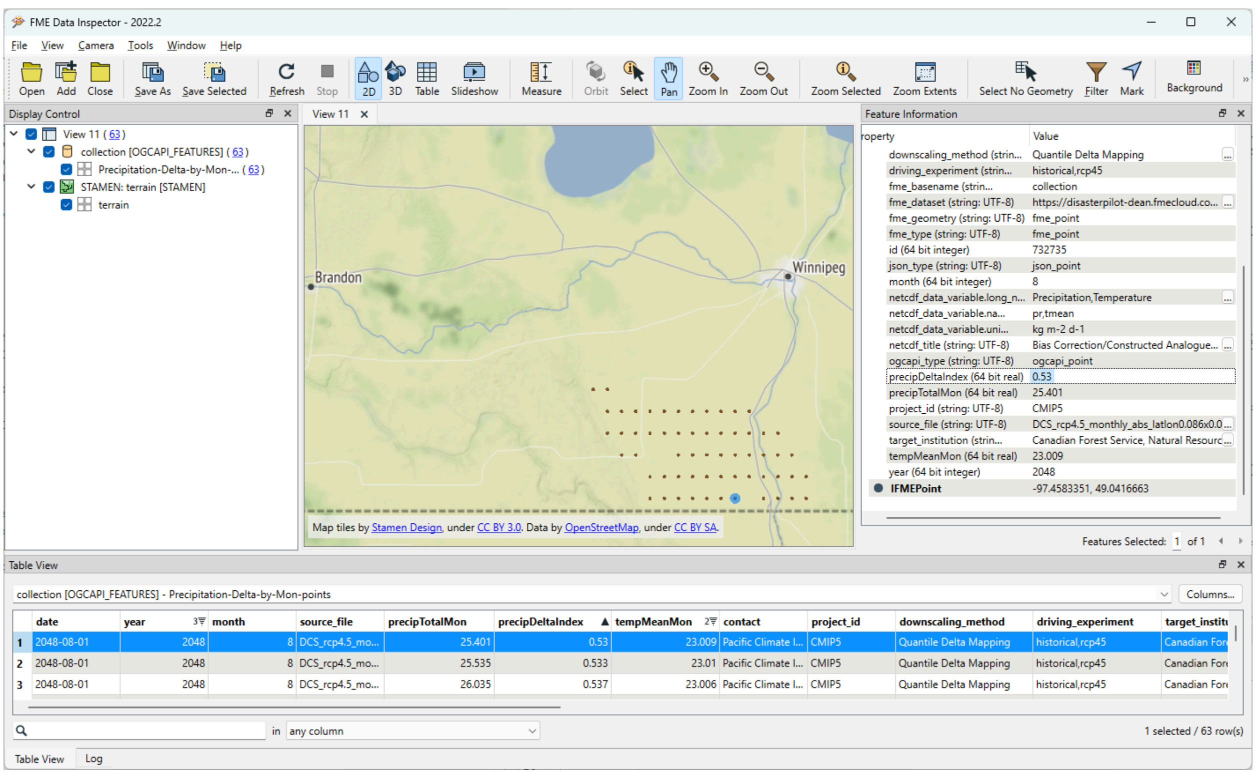


Figure 81 — FME OGC API Feature Service response as displayed in Data Inspector. Results show the response to the query below highlighting an area south of Winnipeg near the US border from August 2048 and 2058. This answers the question, “Where and when can we expect to see a drop in precipitation of more than 25% and mean monthly temperatures > 23C for the current climate scenario?

```
bbox=-100.0,49.0,-96.0,51.0, StartYear=2020, EndYear=2060
```

```
MaxPeriodVal=0.75, MinPeriodVal=0, MinTemp=23
```

Figure 82 — Query:

Result: Points as above for the timesteps Aug 2048 and Aug 2058

This data is displayed in Safe Software's Data Inspector client using the OGC API Features reader. This result shows climate model points derived from the RCP4.5 business as usual scenario that result from the query above. That is, these points represent the hot and dry areas and times (August 2048 and 2058) that satisfy the query above and could constitute increased drought and fire risk. This illustrates one approach for making climate model outputs more accessible in a form and structure easy to consume by those used to working with GIS tools.

UPEI

```
The summary of steps for interoperability assessments includes:
```

Figure 83

1. Bringing experts in environmental, economic, and social impacts of drought together. Supply them with adequate data relevant to interoperability capacity.
2. Assessing drought direct and indirect impacts and then ranking impacts.
3. Assessing vulnerability.
4. Developing a "to-do" list and identifying actions. **Input data**

Table 6 shows an example of how to set up a table to prioritize the impacts of drought severity relevant to the Manitoba location.

Table 6 — Prioritizing the impacts of drought severity for Manitoba, as an example.

RANK	IMPACT	COST	AREA EXTENT	TRENDS OVER TIME	PUBLIC PRIORITY?
1	Manitoba Hydro exports				
2	Farming and crops				
3	Wildfires fighting				

Output data

The output from the drought impact assessment from Table 6 establishes that mitigating and adaptation strategies for agriculture and crop damages are a priority, Table 7 can identify the underlying conditions. The logic behind vulnerability assessment is finding key entry points and adaptation strategies to mitigate the impact of drought in a region. Many agricultural regions in the world can be adversely impacted by drought, but not all impacts are equal. Therefore, finding the root causes of the impacts is a step toward recovering from its assessed severity.

Table 7 — Example of vulnerability assessment template.

IMPACT OF DROUGHT	UNDERLYING CAUSES	POSSIBLE ACTIONS	MITIGATION (M), RESPONSE ®, ACCEPTED RISK (AR)	FEASIBLE?	COST	TO DO?
Crop failure	Variable climate	Weather modification	M			
		Weather Monitoring	M			
	No irrigation	Haul water during a drought	R			
		Provide government assistance for irrigation projects	M			
	Expensive seeds	Subsidize sales	M			
	Farmers preference to plant specific seeds	Conduct workshops	M			
		Conduct research	M			
		Enhance communication	M			
	Government preference to plant specific seeds	Lobby for new incentives	M			
	No drought warning	Provide weather monitoring	M			
	High cost of crop insurance	Government Subsidies	R			
	Laco of research on the efficiency of drought relief efforts	Identify target groups and conflicting relief programs	M			
	Lack of drought relief program coordination	Streamline relief application on funding	M			

Source: University of Nebraska-Lincoln (1998).

6.9.4.3. Technical or health implementation

The aim of the Pixalytics DSW is to support an understanding of whether a location is suffering from drought and what the indication of drought is referring to, i.e., is it a lack of rain, lack of soil moisture, or stressed vegetation? Multiple individual indicators can also be triggered, and there will be a temporal dependency on this. An example of the multi-parameter inputs to the CDI is shown in Figure 84. The top plot shows the SPI, the middle plot SMA, and the bottom plot FAPAR. The colored (yellow to orange) vertical bars then show the CDI moving from watch to warning when one of the indicators is triggered. When the CDI moves to alert, there will be a *redish* bar with Alert 1 showing two indicators are triggered while Alert 2 is all three individual indicators triggered.

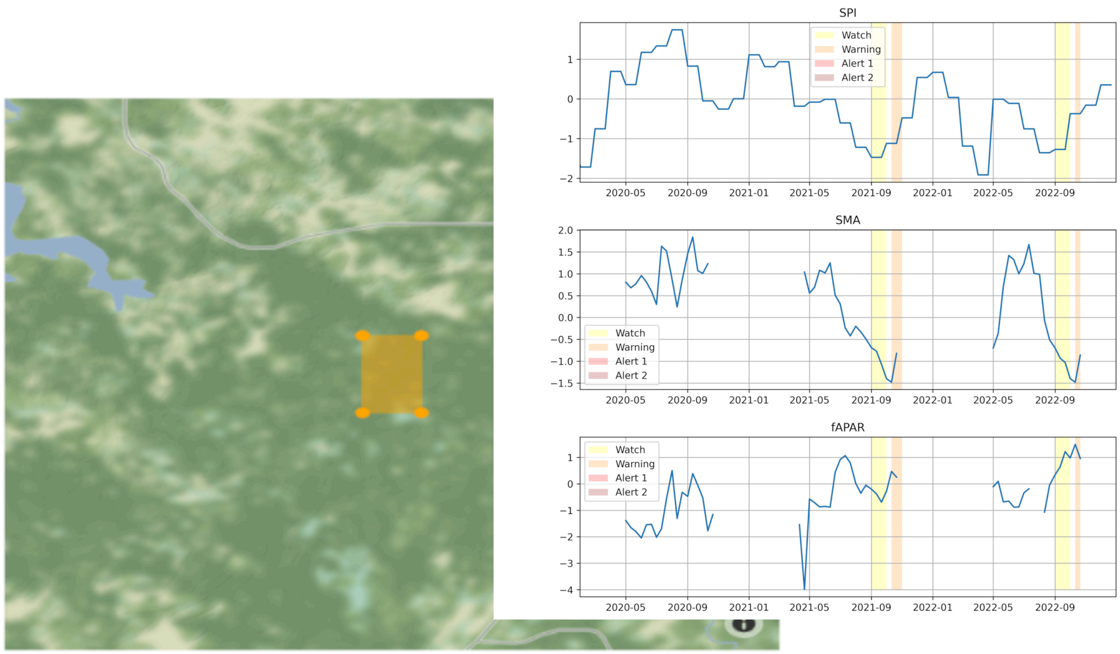


Figure 84 — Example of the Combined Drought Indicator being run for a location within Canada.

The job roles that would be supported include a Decision Ready Indicator (DRI) Analyst and a DRI Decision Maker. The individual indicators and CDI will indicate whether drought is occurring and the current impact. It will be helpful for farmers if there is a lack of soil moisture identified, then irrigation or early crop harvesting might be appropriate actions, especially when the vegetation indicator is also triggered. We are expanding the indicators to be suitable for forested areas and include health effects on the population through temperature.

There are collaborations with ECMWF, NOAA, and Safe Software regarding the input datasets (carried over from the Climate Resilience Pilot). Also, HSR.Health uses the DSW as an indicator ingested into their Health Impact Indicator for which updates are occurring.

Safe Software

To support future drought risk estimates for Manitoba, we provided a precipitation forecast time series to Pixalytics as input to their drought analytics and DRI component. Their component offers a much more sophisticated indicator of drought probability since, in addition to precipitation, it also takes into account soil moisture and vegetation. The goal was to extract precipitation totals per time step from Manitoba's downscaled regional climate model (RCM) climate variable outputs based on CMIP5 (Coupled Model Intercomparison Project Phase 5) model results obtained from Environment Canada. For this use case, the grids have a spatial resolution of roughly 10km and a temporal resolution of a monthly time step. Pixalytics then ran their drought model based on these precipitation estimates to assess potential future drought risk in southern Manitoba. The data was provided to Pixalytics initially as an OGC API Feature service GeoJSON feed of 2D points derived from the data cube cells with precipitation totals per cell.

6.9.4.4. Scenarios

A scenario investigated was combining the input projection data from Safe Software with the historical/current data extracted by Pixalytics so that the precipitation drought indicator could be shown from the past into the future. A location within Canada was chosen, where data was available from the Safe Software OGC API Feature service. Figure 85 shows the precipitation and derived drought index (SPI) for a location near Winnipeg.

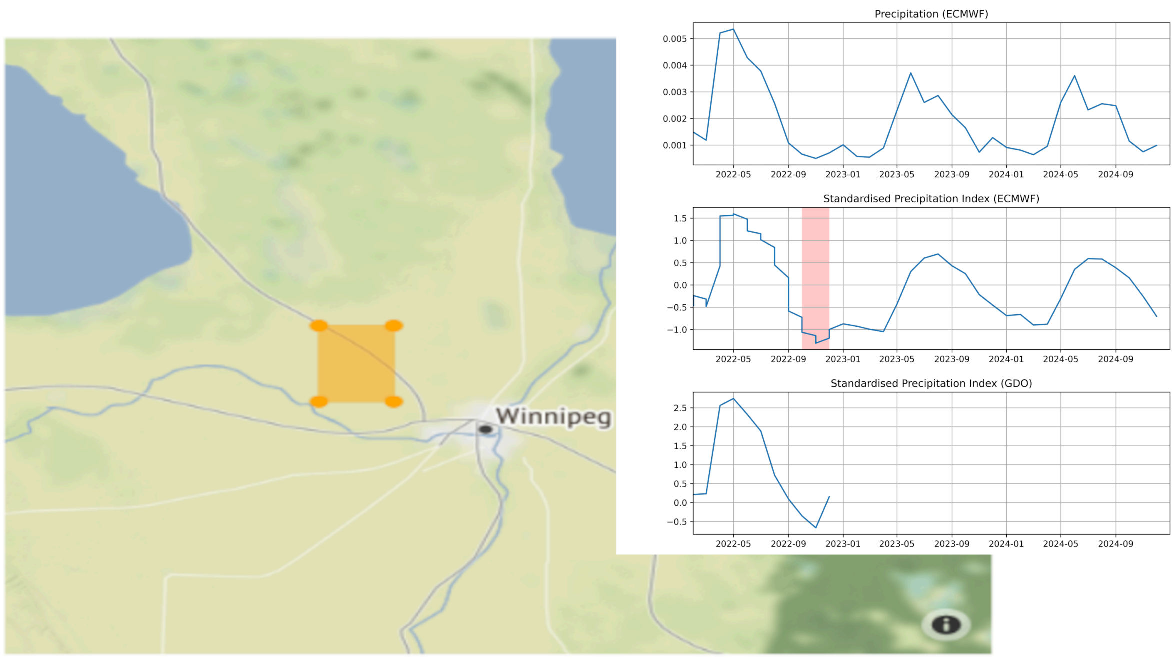


Figure 85 — Precipitation and the associated drought index (SPI) extracted over a location in Canada near Winnipeg, using historical data from ERA5 and statistically downscaled projected data from RCP45 CMIP5.

6.9.5. Results

Pixalytics

The results were a combination of the outputs derived, and the process undertaken to develop, deploy, and allow others to use the WPS front-end, including HSR.Health. Approaches to calling the front-end were tested, including Python code, and a QGIS plugin called WPS Client has been updated to be able to perform a request and view the outputted JSON file, with a second QGIS plugin called Data Ploty used to visualize the time-series data; see Figure 86.

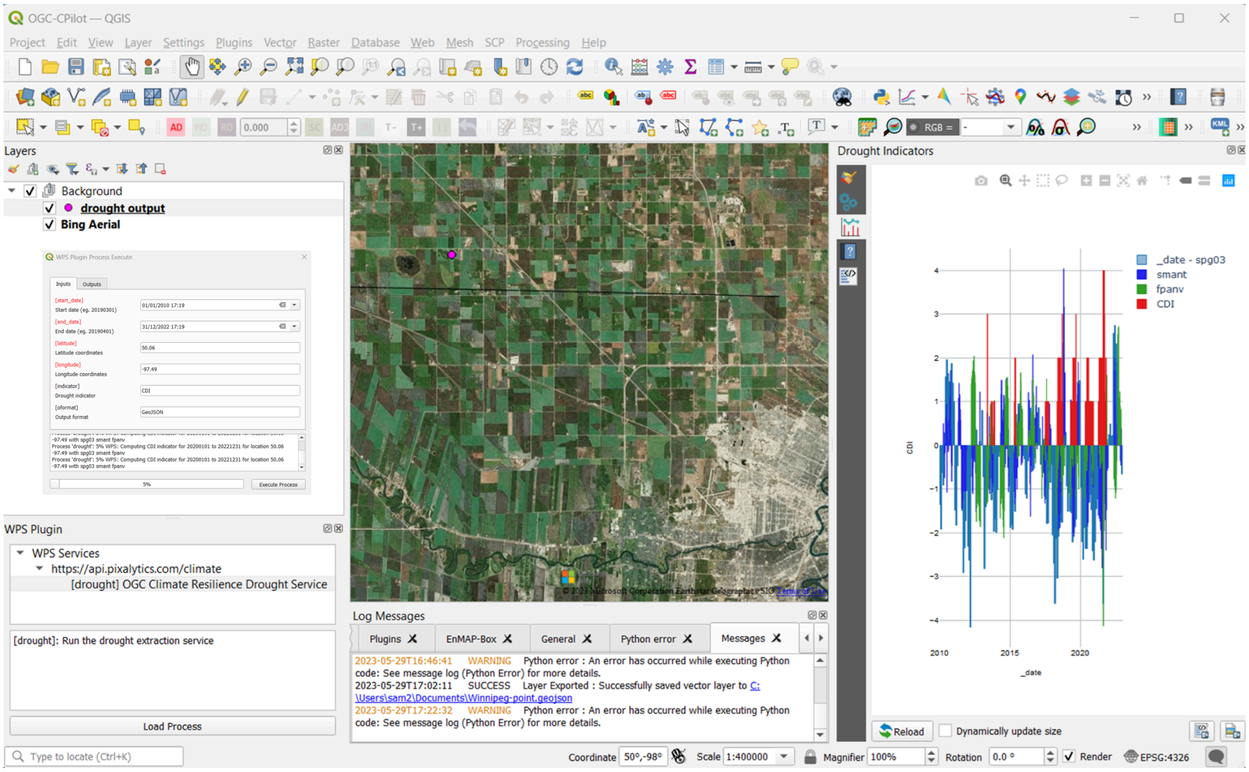


Figure 86 — View of WPS Client plugin and extracted CDI and plotted within QGIS.

Safe Software

Safe Software's drought feature service was able to reveal areas and times where future projections indicated relatively high temperatures coinciding with a drop in precipitation relative to historical norms, as based on the source climate scenario data. In the query and results example shown above, the drought indicator query asked for all the locations and times where the monthly mean temperature was projected to be > 23 C and where precipitation was projected to drop more than 25%. Even though this query was applied to the entire southern third of Manitoba over the next 40 years, the only areas and times that resulted from the query was the area directly south of Winnipeg in the Red River valley near the US border, for the periods of August 2048 and August 2058. Depending on other drought risk factors in that region, such projections might indicate the justification for further modeling and analysis of climate and drought projections for those areas, perhaps leading to some long-term drought mitigation measures.

It is important to underline that this particular indicator is more of an interactive service than one meant to yield one specific result or prediction. As such, it is up to the end user, whether they be drought domain experts or local farmers or administrators, to develop the business rules for drought that they deem most appropriate. This indicator service provides a means of interacting with the relevant environmental variables from the climate model projections, such as precipitation and temperature, to see when and where problems might occur. What is defined as problematic will naturally differ depending on whether the end user is concerned about a specific agricultural crop, water supply for a city or hydroelectric power for the province. This drought indicator service then provides an access point where end users can explore the climate scenario data as it relates to southern Manitoba. The cases shown here are just examples and are only meant to serve as a starting point for further testing and exploration.

6.9.5.1. Challenges and Lessons Learned

Pixalytics

The approach of using a WPS front-end to the CDI download/processing/extraction provided a simple-to-use front-end with a back-end that can extract the inputs from a range of sources that included APIs and downloaded NetCDF files. This back-end complexity of formats/standards is hidden from the user. Still, when the data provider changes inputs, it can impact the robustness of the front-end delivery if updates are not made to the underlying code. By connecting to APIs rather than downloading files, it is hoped that the connection to the input datasets will be more robust and should not change unexpectedly, but this will vary according to the input source and its operational state. The aim within the code is that the default output generation relies on operational sources so that this is more robust.

Safe Software

During our participation in the pilot we made several observations about the characteristics of data structures and properties that are useful when converting model data to ARD. Disaster Pilot 2021 involved extraction from data cubes from a flood model to vector area polygons that represented flood contours. When we applied this process in the Climate Resilience Pilot to climate environmental variables, we found that the temperature and precipitation contours were too coarse to be usable as drought risk metrics. Therefore, in the Climate Resilience Pilot, we made the change to produce location time step points rather than contours.

In this pilot, we also found it useful to merge multiple environmental variables into the individual location time step points in the relational database rather than having a separate table for each environmental variable. This allows us to make combined queries for various environmental variables. For example, we can now query for a specific temperature and precipitation range rather than having to do separate queries and then somehow combine the results afterward. This involves more preprocessing ahead of time and generates a larger database but reduces the work required downstream by client applications.

The benefits of this workflow can help disaster management and planners evaluate the resilience of their plans against a range of possible future climate scenarios. By making climate model outputs, such as NetCDF data cubes, more accessible to common analytics platforms typically used by planners, such as GIS, this indicator component helps shed light on what local trends to expect in the future based on various climate model scenarios. This should help the stakeholders responsible for managing disaster and climate impacts more easily access and interpret the potential risks associated with climate change in their local context.

From a planning perspective, it can be expensive to build comprehensive drought models, either at the local scale or across an entire province. So it may be useful to make basic environmental variable projections available such as precipitation over time. It is usually not obvious to a non-domain expert how much precipitation is enough, excessive or inadequate. There are many factors that come into this both in terms of the type of impact involved. On the other hand, a simple normalization of changes or trends in key environmental variables is a good first step in looking for regions and times where drought or flood risk may be increasing. For example, knowing where and when precipitation is 20% lower or higher over a given time period might warrant an investigation in the resilience of those areas for drought or flood respectively. Naturally these trends need to be examined in the context of existing drought risk factors and historical drought. Different impact types such as agricultural, drinking water, recreation or hydropower will all have different thresholds of concern. Still, the general trends can at least serve as a first step in terms of locating those of areas and times of interest for closer management and more thorough investigation.

In a similar vein, another important benefit of this drought primary indicator is that it can be used to support downstream analysis. This indicator is a rough proxy for drought risk since at present it only includes values for precipitation, change in precipitation from historical baseline, and temperature. On the other hand, more sophisticated drought models such as that developed by Pixalytics can use the precipitation and temperature values as inputs to drive their more refined models. Future forecast scenarios for precipitation and temperature can be combined with localized detailed models that include other drought risk factors like soil type, geology, hydrology, land use and vegetation. In this way, climate projection data can allow the more sophisticated drought models to make projections about possible future drought risk which neither model or indicator could do on its own. This type of indicator synthesis is crucial in order to build comprehensive views of disaster and climate risks over time at the regional and local scale. Also, the concept of primary indicators that can be used to drive secondary indicators is also important in that it allows a wider range of indicators to be developed without each indicator recipe having to build the entire analytical workflow on their own.

UPEI

In designing drought severity workflow, it is essential to differentiate between the impacts of drought severity vs. the underlying reasons (i.e., vulnerability) for drought. The impacts of drought are usually associated with reduced crop yields, livestock losses, and reservoir depletion. Drought impacts can also be traced to social consequences such as the forced sale of household assets or lands or physical and motivational malfunctions. Understanding the underlying drought severity differs from the direct and indirect drought impacts. It is also essential to evaluate what drought impacts will recur in a region under climate change and population and water demand changes.

6.9.6. Discussion and future developments

Pixalytics

The approach has been further developed since the Climate Resilience Pilot with the incorporation of the Safe Software OGC API Feature service rather than a provided GeoJSON file. Also, the DSW has been packaged into a Docker container, so the deployment as a demonstrator is straightforward.

Work needs to continue on the robustness of the code so that when input data is unexpectedly unavailable, it fails ‘nicely.’ There is already caching of intermediate files so that when the same data is requested more than once, the download/processing doesn’t need to occur again, speeding up the API call when large requests are made subsequently.

Work is also ongoing on expanding the drought indicator output from its original combined form of precipitation/soil moisture/vegetation to include other parameters such as air and/or land surface temperature.

Safe Software

Perhaps the next step may be to explore other back-end storage options that may be more scalable, such as cloud-native formats. For example, at this point, our data is stored in monthly time steps. If we moved towards weekly or daily timesteps, the amount of data would increase by one or more orders of magnitude. In that case, performance would likely degrade to the extent that it would limit the service's usability. It is felt that it would be useful to explore the use of cloud-native data stores such as Geoparquet or ZARR as the backend storage for this data. Caching approaches should also be explored for any production system.

The availability of accessible climate data services using open standard APIs such as OGC APIs means a much wider range of applications can now access this data. That said, considerable work remains to be done on developing business rules relevant to specific applications. For example, related to long-term future drought risk, what are some of the environmental variables, statistics, thresholds and ranges that may be associated with increased risk? What other business rules might be developed to better model other related natural hazards risk such as flood and fire? How useful are comparisons to past historic trends vs. looking at absolute environmental variable thresholds such as temperature or precipitation min, mean or max? What local data can be incorporated to reflect local conditions better and improve the local accuracy of any projection? This could include surface models (high-resolution DEMs), hydrology, vegetation, land use, and earth observation data.

It will be essential to summarize water budgets by watershed or catch basin and location in the future. This could help assess water budgets for various applications, whether fisheries, agriculture, drinking water, or hydroelectric power. It could also be helpful for multiple impacts, including flood and fire risk and drought.

It would also be helpful to assess cumulative rainfall over time using a sliding time window, for example, total rainfall within a 72-hour period. For example, this could be used to determine spikes in precipitation events that could cause flash floods. Building rules based on consecutive months with total precipitation less than a certain threshold could also drive drought indicators.

Given resource constraints, we needed more time to integrate other environmental drought factors such as hydrology, vegetation, geology, soils, land use, surface permeability, or other watershed or base map data such as high-resolution DEMs. It would be interesting to explore how to improve the spatial and temporal accuracy of drought, flood, and other forecasts. This may be achieved using a pan sharpening approach by combining lower resolution climate projections for relevant environmental variables (10 km grid) with higher precision datasets representing local factors (1 — 10 m accuracy). For example, a precipitation projection of a 10% increase could be combined with a high-resolution DEM to estimate very localized changes to flood risk.

Safe Software's climate ARD services were only available later in the pilot. It is hoped that in future pilots, these types of data services will be made available earlier so that more participants can incorporate the resulting climate scenario environmental variables into their richer impact models to provide a more accurate projection of potential future natural hazard risk. This would also allow for more experiments with indicator chaining.

Workflows developed for Manitoba drought impact analysis were designed in such a way that they can be readily transposed to other contexts and scenarios, given adequate provision of equivalent source data. The process recipes were implemented using Safe Software's FME platform, which is a no-code, model based, rapid prototyping environment that supports data integration and automation with a special focus on spatial data support (more than 500 formats and services supported). With this model driven approach it is relatively easy to rerun or automate the same dataflow based on new inputs. In this way new results can be generated based on different climate scenarios such as those based on low, medium or high emissions.

For further information on Safe Software's pilot components and associated persistent demos, see Safe Software's contributions to OGC Disaster and Climate Pilots.

UPEI

In this workflow study, we highlight how a collaborative drought severity workflow can identify vulnerable populations in drought-affected areas. The benefits of UPEI's contribution are a workflow for prioritizing impacts and vulnerabilities relevant to a particular region or activity and supporting scientific researchers, policymakers, and the public.

6.10. Drought Crop Impact Indicator Workflow (by 52°North)

6.10.1. Introduction to the company and main activities

The 52°North Spatial Information Research GmbH was founded in 2006 as a German company limited by shares ("Gesellschaft mit beschränkter Haftung — GmbH") that act as a non-profit organization based on its shareholders' agreement. Shareholders receive neither profit shares nor other payments from company funds. 52°North coordinates activities of partners from research, industry, and public administration. Its mission is to foster the development of new concepts and technologies in Geoinformatics, Sensor Web, Web-based Geoprocessing, Earth Observation, and Spatio-Temporal Data Science.

The company has a long and outstanding record in the Geo-IT domain and contributes significantly to developing international standards (e.g., OGC, European INSPIRE directive). The proactive innovation strategy of 52°North is apparent in European and national research projects and the company's involvement in OGC's Collaborative Solutions and Innovation Program (COSI). This is complemented by consulting and software development projects helping customers to integrate up-to-date technological developments into their operational infrastructures.

52°North fosters open science by promoting and using open data and developing open-source software. Regarding solution strategies for climate change adaptation and disaster risk management, 52°North is co-developing spatial infrastructures for the projects I-CISK and DIRECTED, funded by the European Union.

6.10.2. Background and problem description

Due to the increasing probability of severe heat periods in the context of climate change, the risk for extended drought periods is rising worldwide. One sector that is heavily impacted by droughts is the agricultural sector, where the estimation of the effect of water scarcity on crop well-being is of great importance for ensuring food security. In this respect, data on damages caused by droughts play an essential role in adapting to the new environmental conditions: the availability of comprehensive forecast data on drought periods enables responsible personnel to plan actions that assure plant health, e.g., by adjusting irrigation schedules or cultivating more resistant species.

6.10.3. Objectives and role in the pilot architecture

In the context of the deliverable D102 of the Disaster Pilote, a framework has been developed to provide crop suitability maps (Peter et al., 2020) for the study area of Manitoba. Crop suitability maps summarize information on whether the geographical areas' environmental conditions meet the long-term crop production requirements. In this sense, the geographical areas are categorized according to the suitability of the respective environmental conditions. The framework's final output is a map highlighting geographical regions of colors depending on their suitability categories.

The framework is implemented using only open-source components such that the final product is open-source. The implementation follows the well-established OGC standards by implementing an OGC API Processes. All parts are designed in a modular way such that the modeling tool, as well as the different data sources, can be extended and replaced easily.

6.10.4. Methodology

The workflow can be sketched as follows:

- precipitation and temperature data is retrieved from the Meteorological Service of Canada (MSC)
- environmental data is then been combined with crop information databases by the Food and Agriculture Organisation (FOA) of the United Nations on crop needs, and based on the level of agreement between datasets, land categories are defined
- the final maps and data are made available via *API Processes* using pygeoapi
- the output is provided as a GeoJSON file and as netCDF file that contains one variable for every land category
- the infrastructure is embedded in a Docker container and deployed in a cloud
- the workflow will be implemented for the Manitoba region as a pilot test (current bounding box: min_lat = 49.0, min_lon = -102.0, max_lat = 60.0, max_lon = -88.9)

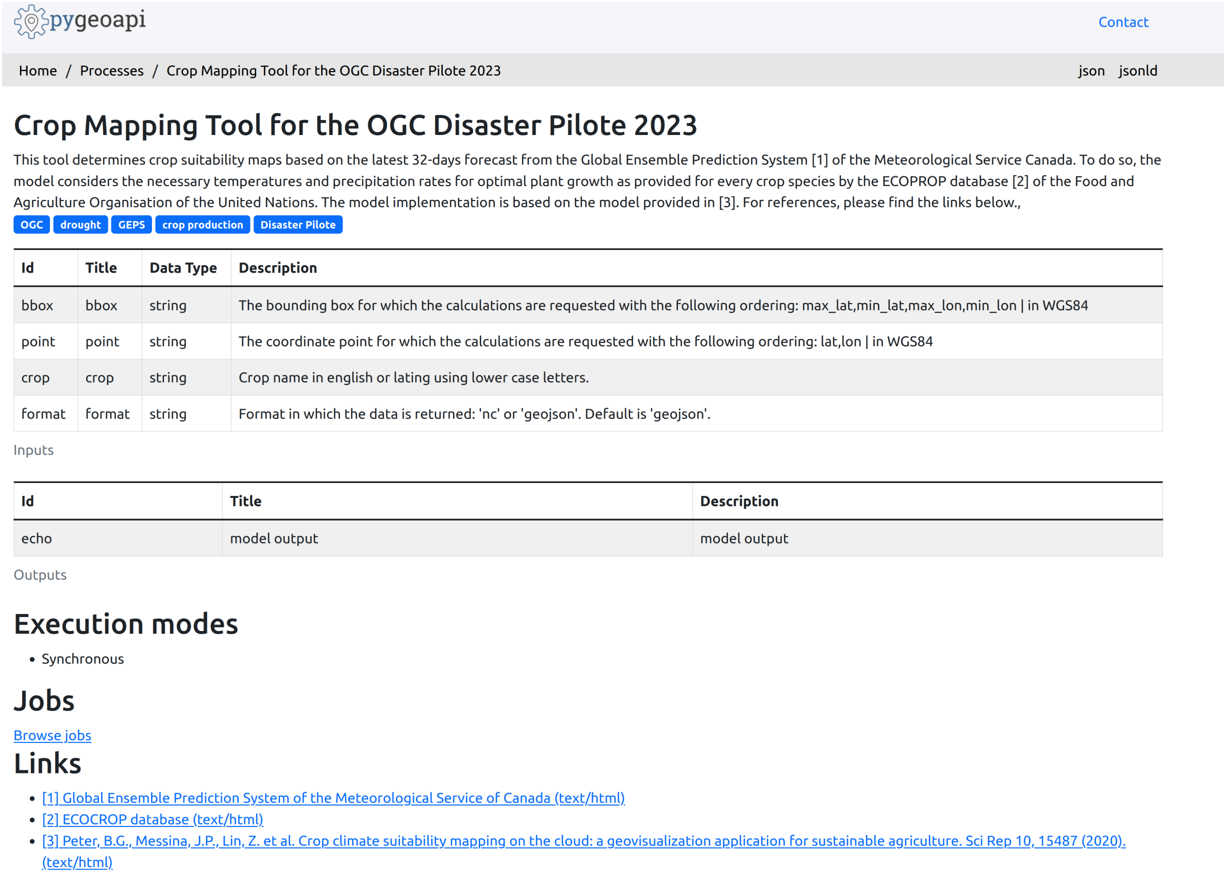
6.10.4.1. Area of study

The study area of D102 is Manitoba, Canada. The bounding box that is investigated is reaching from 49.0°N 102.0°S to 60.0°N -88.9°S.

6.10.4.2. Technical design

The central component of the framework is the Crop Mapping Tool, which reads the environmental data and calculates the crop suitability categories. The implementation of this model is done in Python and is based on the concept described in this link (Peter et al., 2020). It separates five suitability categories, referred to as 'optimal,' 'suitable,' 'marginal,' 'unsuitable,' and 'pessimal' (ordered so crop suitability decreases). The categorization considers the forecasted temperature and precipitation for the coming month. The forecast data is correlated with the requirements of a particular plant species.

The environmental data utilized for the categorization is read in as grib2 data from the Global Ensemble Prediction System (GEPS) of the Meteorological Service Canada (MSC). For the precipitation, the ensemble mean of the product 'APCP_SFC_0' and for the temperature, the ensemble mean of the product 'TMP_TGL_2m' has been used. The information about the crop requirements has been taken from the ECOPROP database of the Food and Agriculture Organisation (FOA).


pygeoapi Contact

Home / Processes / Crop Mapping Tool for the OGC Disaster Pilote 2023 json jsonld

Crop Mapping Tool for the OGC Disaster Pilote 2023

This tool determines crop suitability maps based on the latest 32-days forecast from the Global Ensemble Prediction System [1] of the Meteorological Service Canada. To do so, the model considers the necessary temperatures and precipitation rates for optimal plant growth as provided for every crop species by the ECOPROP database [2] of the Food and Agriculture Organisation of the United Nations. The model implementation is based on the model provided in [3]. For references, please find the links below.,

OGC drought GEPS crop production Disaster Pilote

Id	Title	Data Type	Description
bbox	bbox	string	The bounding box for which the calculations are requested with the following ordering: max_lat,min_lat,max_lon,min_lon | in WGS84
point	point	string	The coordinate point for which the calculations are requested with the following ordering: lat,lon | in WGS84
crop	crop	string	Crop name in english or lating using lower case letters.
format	format	string	Format in which the data is returned: 'nc' or 'geojson'. Default is 'geojson'.

Inputs

Id	Title	Description
echo	model output	model output

Outputs

Execution modes

- Synchronous

Jobs

Browse jobs

Links

- [1] Global Ensemble Prediction System of the Meteorological Service of Canada (text/html)
- [2] ECOCROP database (text/html)
- [3] Peter, B.G., Messina, J.P., Lin, Z. et al. Crop climate suitability mapping on the cloud: a geovisualization application for sustainable agriculture. Sci Rep 10, 15487 (2020). (text/html)

Figure 87 — The API description of the Crop Mapping Tool implemented via pygeoapi.

The services of the framework can be accessed via an *API Processes* implemented by the Python server implementation pygeoapi. These services include

- The provision of a GeoJSON file that stores the regions with a similar crop suitability category for a particular bounding box as Polygons;
- The provision of a netCDF file in which the individual crop suitability categories for a certain bounding box are stored as separate variables; and
- The provision of a GeoJSON file that provides the crop suitability category for a certain coordinate pair as title of a Point geometry.

All components run in a docker container and are deployed in an Open Telekom Cloud. Since the implementation of this workflow is meant as a proof of concept, test data from the MSC is loaded directly into the docker container. Automatic download of the data could easily be realized by a kubernetes CronJob.

6.10.5. Results

Exemplary output by the Crop Mapping Tool are shown in the following Figures.

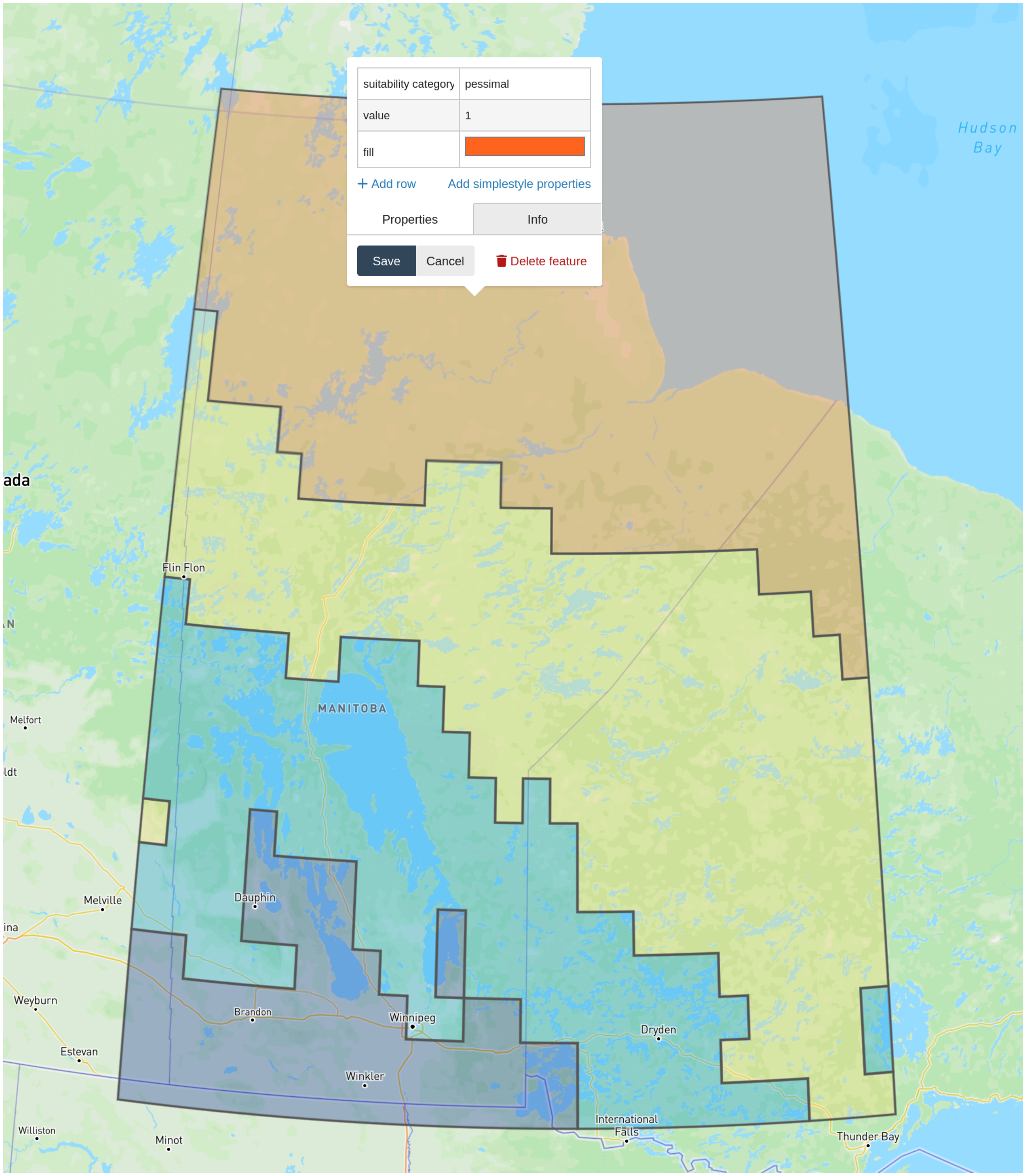


Figure 88 — Examplary crop suitability map which is returned if calculations for a certain bounding box are requested, here for the test region inManitoba. The suitability of the enviromental conditions is decreasing from suitable (blue) to pessimal (red). This figure has been generated with the help of geojson.io.

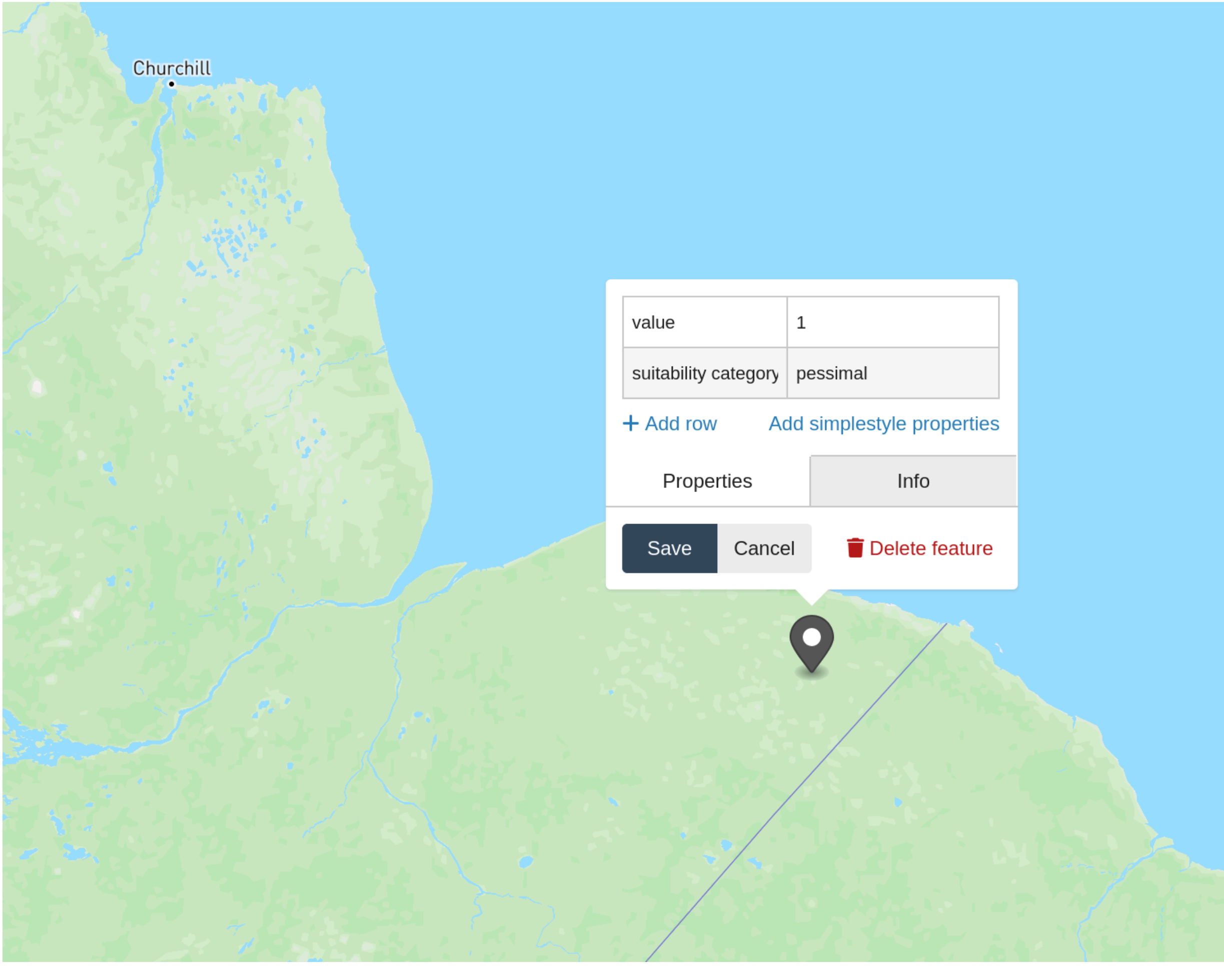


Figure 89 — Example visualisation for a requests with a specified coordinate pair. The crop suitability is provided along with the Point geometry. This figure has been generated with the help of geojson.io.

```json
{
    "type": "FeatureCollection",
    "features": [
        {
            "id": "0",
            "type": "Feature",
            "properties": {
                "value": 1.0,
                "suitability category": "pessimal"
            },
            "geometry": {
                "type": "Point",
                "coordinates": [
                    -89.89,
                    56.67
                ]
            }
        }
    ]
}
```


Figure 90 — Example GeoJSON output for a requests with a specified coordinate pair.

6.10.5.1. Challenges and lessons learned

One critical ingredient for the forecast of crop suitability maps is the availability of long-term predictions for precipitation and temperature. To our knowledge, respective data are only available at the time of writing for the study area for one month in advance. On the other hand, most plant species' growth period spans several months. Since the product developed for this deliverable shall only serve as a proof of concept, monthly forecasts have been utilized as a basis for the land classification. For future applications, replace these data with respective long-term forecasts. Scenario-based climate prediction ensembles could be downscaled, bias-corrected, and fed into, e.g., stochastic weather generators providing the necessary data inputs. However, this would require additional modeling expertise and resources. Furthermore, a thorough treatment of uncertainty in modeling and presenting the results would be necessary.

A further challenge constitutes the complexity of processes that determine the response of plants to severe environmental conditions.

6.10.5.2. Updates and applications

The provided crop suitability maps support farmers' decisions for crop cultivation's short-term and long-term planning. Regarding short-term planning, crop suitability maps help to adjust irrigation schedules based on the forecasted environmental conditions. In long-term planning, comparing the suitability of environmental conditions for different plant species can facilitate the selection of appropriate plant species.

The framework that has been developed in the context of this deliverable serves as valuable input for the EU projects I-CISK and DIRECTED.

6.10.6. Discussion and future developments

The realistic modeling of plant health and growth requires that not only climatic conditions but also, e.g., soil properties or the ability of the plant to absorb water are considered. Since the objective of this deliverable was to develop a technical workflow to provide crop suitability maps, only a simple model based on precipitation and temperature has been utilized. Nevertheless, this simple model can easily be extended to consider more parameters important for plant growth. Modularly implementing the different components enables experienced users to replace the crop modeling tool with a more complex model.

To further support the decision-making processes of the user, it would be favorable to provide information about the statistical uncertainties along with the modeling results. Determining the uncertainties would require the propagation of the uncertainties on the predictions for the environmental data through the model calculation. The latter was beyond this project's scope but is suggested for future developments in this respect.

6.11. Development of the Emergency Location and Language Application (Ella) (by Basil Labs, GISMO, Natural Resources Canada, and Manitoba Emergency Management Organization)

6.11.1. Introduction to the company and main activities

A team composed of members of the NYC Geospatial Information Systems and Mapping Organization (NYC GISMO) and Basil Labs, a private, spatially oriented technology company, was given funding to develop a citizen science application to address citizen data interactions during droughts and wildfires. The GISMO/Basil team focused on developing a survey design on a smartphone platform to document the effects of drought on the Manitoba business community.

However, this application was designed for other information needs to deal with disaster events in different locales. The application has been named the Emergency Location and Language Application (Ella).

6.11.2. Background and problem description

Description of Manitoba Ella (M-Ella):

- M-Ella survey target: The Manitoba Team wished to use a first version of M-Ella for capturing information about businesses that were affected by drought, with a specific interest in understanding the effects of drought on business revenue and employment.
- The draft M-Ella Drought survey can be examined in detail using https://app.ellasurveys.com/survey/c5bbfb37-231e-c0ae-1969-d5cdd5445d08
- See Question 1: At the request of Team Manitoba, in the interest of keeping the identity of the business private, respondents were asked to choose their location by choosing one of a list of Forward Sortation
- Photo(s) were requested of natural areas that were important to the business being surveyed.
- Voice responses were requested relating to:
    - Factors contributing to changes in revenue noted in previous structured questions
    - Explanation of the importance of natural water to business Postal Areas instead of using the GPS capabilities of the smartphone.
    - Description of business changes due to drought
- Use of voice translation and AI: As explained above, voice responses would be translated into English and converted into text. They would then be analyzed by AI for common words and themes, which could be grouped by business type, postal location, and other factors.
- Artificial Intelligence: Ella's use of A.I. capabilities is a game changer. Since Ella seeks to keep tabs on and interact with potentially thousands of individuals and dozens of response teams in real time, it needs to rapidly covert voiced communications into a standardized useable form, analyze it, and automatically route intelligence to the intended target audiences. When dealing with so many potential users, this can only be done by A.I.'s ability to interpret, categorize, route, and even prioritize communications. More generally, given the complexity and volume of information generated by a disaster, A.I. capabilities will be essential to properly sort information and integrate all types of information to ensure it gets into the right hand at a speed impossible to replicate manually.

6.11.3. Objectives and role in the pilot architecture

Team Manitoba directed Team Ella to develop a survey application that would capture information about the effects of drought on the business community. Team Manitoba wanted to be able to demonstrate how drought affected business revenue, number of visitors, and jobs, which had been difficult in the past to quantify. Improved numbers would give Manitoba officials a better idea of drought effects and would be helpful for policy decisions. While Ella was being tested for this purpose, it was also being evaluated for future use in other aspects of the disaster lifecycle, including preparedness, response, and recovery.

6.11.4. Methodology

The design of the Ella tool to support the survey needs of the Manitoba community depended on the Ella Team working closely with Canadian partners. There were at least five interviews and consultation sessions between Team Manitoba and Team Ella at which survey objectives were identified, and survey questions were proposed, selected, and reviewed. Survey technical architecture was also intensively discussed. The Ella team was sensitive to the desire not to use Ella for direct emergency response as a first application. The Ella team was also sensitive to user requirements for locational and personal privacy, security, and using a local data storage platform.

6.11.4.1. Area of study

The Area of Study is the Canadian Province of Manitoba. The Manitoba Team intends to make the Ella survey available to businesses in the Province to gather information about the effect of drought on business operations, revenues, and staff.

6.11.4.2. Technical design

Identify Smartphone Capability Options:

The Ella Team identified all the different ways that a smartphone platform could be used to collect data, knowing that the Manitoba Team would then select those features they thought to be most useful. Those features included:

- Types of structured questions:
  - Choice of number and date range categories
  - Sentiment, strength of feelings, opinion
  - Pull down:
  - Simple Yes/No:

    - Fill in:

- Location Capture:
    - Smartphone GPS via satellite and/or cell tower triangulation
    - Selection or Fill-in of Postal Zone, Municipal Boundary Area, etc.
    - Placing point on a map display
    - Automatically poll the location of everyone within an area of interest to determine those at continuing risk

- Photo and/or video capture to highlight input (can be multiples)
- Voice Capture and Analytics
    - Transcribe voice into written text in the language spoken
    - Translate text into a common language
    - Apply A.I. tools to identify keywords and common themes
    - Apply A.I. to identify levels of urgency if utilized when 9-1-1 systems are overloaded or unavailable

- Other Analytics (examples)
    - Creating maps of collected data and identifying patterns (e.g. heat maps, distribution maps)
    - Tabulating responses and comparing responses between different areas
    - Creating quantitative charts of responses
    - Showing trends over time if multiple survey iterations are sent out

○ User-friendly dashboard of key information: Trends, common operating picture (COP), situation awareness (SA)

- Future Options
    - Sensor connections for environmental data (temperature, air quality, water quality, ground moisture)
    - Personal health data (body temperature, respiration, heartbeat)
    - Use of specialized websites to identify features captured in photos such as building damage, street conditions, type of fauna, crop conditions, wildfire fuel load. Note that the USGS DP-23 Team is developing a citizen science application for DP-23 that links smartphone photos to an AI-based fauna identification application.

```
*Special Operational capabilities that can be designed into
Ella*
```

Figure 91

- Rapid survey design using application template: Ella can be designed so that non-programmers can rapidly modify a survey or quickly create wholly new surveys through simple pull-down menus.
- Capacity to collect information and intelligence from people within a disaster zone or other area of interest
- Ability to re-issue surveys as the situation on the ground changes or when a data refresh is desired.
- Support communications between first responders in the field, disaster response managers, and people caught within a disaster zone: Ella can allow response managers to transmit guidance to all those within a disaster area or to specialized groups such as those evacuating using vehicles or those identified to be in immediate danger.
- Support communications between different teams of responders dispatched to the same or adjoining areas for improved coordination.

Constraints and Considerations

● **Persistent Communications:** For Ella to be effective in collecting data from individuals within a disaster area through the use of smartphones, it will be essential that wireless communications be maintained across a disaster zone, often in the face of significant damage to telecommunications infrastructure. The Ella team has not studied this problem. Still, it feels that there are solutions that can be deployed to maintain wireless communications, including mobile cellphone towers placed amid a disaster zone and the use of aerial assets, whether satellites, helicopters, fixed-wing aircraft, drones, or balloons that can acquire and transmit smartphone signals.

● **Smartphone Battery Life:** Disasters can evolve and extend for many days, and access to electric power to recharge smartphones may not be readily available. The Ella team has not yet studied this challenge but believes some solutions might include Hand-crank and other forms of mechanical chargers, the use of backup generators, and the use of pre-charged backup chargers/batteries.

● **Standardized Smartphone Capabilities:** It would be important to ensure that all smartphones adhere to standards that would ensure that the data collected, regardless of smartphone brand or operating system, would be compatible and easily integrated for analysis.

6.11.4.3. Technical or health implementationTechnical

Data Availability

The platform survey responses are accessible via REST API for individuals who wish to view and explore the data on other platforms. For individuals not interested in external viewing, all data is viewable in the "Summary" tab of the platform, allowing individuals to explore responses in real-time without external software quickly.

Input data, processing, and output data Data is inputted via users filling out surveys that administrators have created. Administrators can add text, voice, dot placement on maps, and geolocation questions. Voice questions are transcribed and translated into English, and all responses are viewable in charts and maps on the platform in the "Summary" section. If the administrator wishes, they can create topic word bins to classify text and voice responses into specific categories. Administrators can export data in CSV format and generate API keys to access data via REST API. Regarding geolocation, administrators can select one of two options: collecting the general geolocation via the IP address of the respondent's device or precise geolocation via mobile phone geolocation access.

Technical standards and infrastructure requirements

To access the survey creation page (administrators) as well as the surveys themselves (respondents), internet access is required. Surveys are mobile responsive and can be accessed via desktop or mobile. All user information and data are housed in Firebase (the exception is the pilot in Canada, in which the data is housed on a server instance geographically located in Canada).

Server Location within Canada:

Team Ella is currently using a Google Firebase server in Montreal: "northamerica-northeast1" Cloud Firestore locations | Firebase (google.com)

Security

Google has built around these requirements (details in the same link as above) — "..Data in a regional location is replicated in multiple zones within a region. All regional locations are separated from other regional locations by at least 100 miles. Another contingency we can add to the above is to automatically email a database backup every x number of days.

Self-hosting flexibility

While the functionality isn't currently built out, for a multi-province project, we can build this functionality if each province, for example, would like to host its version.

Access Tiers

We have not needed to set up elevated user levels in the past but can easily set up custom permissions for user accounts based on your specifications. e.g.:

- One administrator account (full read/write/user creation/deletion/grant database access, etc.)
- Editor accounts (read/write access to relevant parts of the database that the administrator grants)
- Viewer accounts (read access to parts of the database granted by admin/editors) **Libraries and APIs employed to depict the pipeline and transformation of data.**

```
*Google Speech-to-Text APIs* are used for voice-to-text
transcription: Ella has an option for survey administrators
to save the original voice recordings and the text
transcriptions OR to only house the text transcription in
the database (while the audio file is never uploaded to the
database) -- depending on the survey admin's preferences re:
data privacy
```

Figure 92

```
*Google Cloud Translation APIs* are used for translation.
Currently, while 100+ languages can be used to answer
surveys, all analytics the admin plays with use responses in
English or translated into English.
```

Figure 93

- **Rake is used for keyword identification**, and we are currently considering employing ChatGPT for auto-topic classification Keyword Extraction using RAKE – CodeLingo (wordpress.com)
- **Geolocation** is accessed in two ways, depending on the survey administrator's preference:
- **IP address geolocation** — less precise but does not require an explicit question prompting the user to give geolocation access.
- **Device geolocation** — more precise but requires a question popup where the user gives access for precise geolocation. **GIS Software:** ESRI software dominates across Canadian provinces. Theo stated that Ella does not use Esri's services, but users of Ella can integrate their data into an operations dashboard or map easily via our Rest API

Database: Basil is using Mungo DB. Some basic information about Mungo and any options that might be considered would be useful MongoDB-Wikipedia

Analytic Options: There should be a listing with a brief description of the analytic and display functions of Ella, for example:

- Word cloud
- Voiced themes and word categories (can message urgency be identified (sentiment) and ranked)
- Heat maps and other mapping analytics
- Charts (pie, bar, etc.) reflecting answers to each structured question.

Health Implications

The use of Ella for the gathering of citizen information and information from first responders in the field has several potential health benefits. Because Ella is designed to be flexible and can be quickly adapted so that as many surveys as necessary can be issued to keep track of a disaster event.

- **Preparedness/Pre-Disaster:** Ella can be used to ask citizens within a threatened community about their level of preparedness and about vulnerabilities needed to alert the response community in case rescue or special resources might be needed. Depending upon citizen consent, personal health, and location information can be solicited to pinpoint needs, develop community needs maps, and organize evacuation or assistance delivery efforts.
- **Disaster Response:** Once a disaster is imminent or has struck, Ella can be used to ascertain real-time conditions of citizens trapped within the disaster area so long as persistent cell phone communications can be maintained. This information can help direct the actions of the response community to target search and rescue operations where they are most needed. If the response community uses Ella, it can give the Emergency Operations Center real-time information about the status of the disaster event, enhancing situational awareness. As information about the disaster event is gathered, it can be used to give both citizens and the response community protective guidance. For example, evacuation routes are safe to take and actions that can be taken to increase safety.
- **Disaster Recovery:** Once the most violent aspects of a disaster have passed, Ella can be used to maintain situational awareness of the health of citizens across the disaster area. Citizens can also keep the response community informed about situations on the ground. Ella could be an effective tool to locate missing citizens and responders. In the ways described above, Ella can help save lives and reduce dangerous health threats by keeping the response community informed of conditions in the disaster area.

6.11.4.4. Scenarios

RatApp: Testing Ella in New York City

As the Manitoba Team discussed their application needs with the Ella team, the Ella team went forward with a test of the Basil Labs survey application to determine if it could be adapted to use other than customer survey assessment. At the time, there was a great deal of coverage in NYC about its rat problem, with the appointment of a new Rat Czar and the rollout of strategies to reduce the presence of plastic garbage bags on the street containing food waste that attracted rats. RatApp was designed to enable citizens to easily and quickly document a rat sighting on the street or within a building, provide a precise location, and supply a photo of the area where the rat was observed. About forty records were collected by volunteer testers, each requiring about one minute to enter into a smartphone. This contrasted with the more than five minutes it took to call NYC’s 3-1-1 system to report a rat sighting — which did not include a photo or a precise location. Based on the lessons learned from this pilot, the Ella team was in a good position to develop the application desired by Manitoba. The RatApp slide deck can be viewed here: https://docs.google.com/presentation/d/1ZlumnuXHU09OXalLJ6rTpttQvsATQeic/edit#slide=id.p1

Wildfire Scenario

As Team Manitoba discussed how they wished to deploy the survey application, the Ella Team thought through using Ella to respond to a wildfire and developed the following scenario.

- Within a community at risk of wildfire, citizens would be offered access to the Ella basic application, perhaps as part of a pre-event exercise or the issuance of a more routine survey of defensible spaces. Basic individual information, including home location, vulnerabilities, number of occupants, and mobility, could be pre-installed.
- When conditions favorable to wildfire occurrence exist, emergency responders can issue alerts and request any information about smoke or fire conditions being experienced or observed.
- When a wildfire breaks out, is geolocated, and the fire's direction, speed, and spread are determined, those in the threatened areas can be identified and notified. Safe evacuation routes can be identified as places for shelter. Depending on defensive capabilities, individuals can be advised to shelter in place. Updates about fire movement would be sent regularly.
- First responders would be put into direct communication with individuals needing assistance to evacuate.
- Those able to evacuate by vehicle or by foot would be given updates based on their current location about the safety of their escape routes and provided with better alternatives if necessary.
- Resources and safety equipment could be sent to areas where people are collecting based on smartphone location tracking.
- Fire suppression and rescue activities could be focused on specific locations and areas where people are directly threatened and on areas where fire suppression activities are likely to have the greatest impact.
- Citizen reports of health conditions and fire locations can be reported at frequent intervals until the crisis ends. Voiced responses can be translated into common text, analyzed, and mapped to provide situational awareness to the responder community.

As described in the scenario above, there are many ways of using an Ella-type application to track individuals and groups of citizens threatened by a disaster event and leverage response teams and resources to protect them, whether they remain at home, have traveled to a safe place, or are still on the road. Information can be regularly re-calibrated if there is a significant shift in fire direction and speed of spread. Other newly arising conditions impacting safety can also be included.

```
All individuals within the disaster zone, responding to the disaster
or managing the disaster, can make use of the information and
communications enabled by an Ella-type application. Conducting pre-
event exercises will ensure that Ella can be used with maximum
effectiveness. Separate Ella groups can be formed among specialized
teams of responders, including medical personnel, firefighters, and
those responsible for coordinating the evacuation.
```

Figure 94

During and after disasters, there can be many individuals who go missing. A smartphone application can make it easier for the response community to verify the location of those who escaped harm and can also be used to locate those who are seriously injured and those who did not survive. In the recent Maui fire, were still 800 persons missing ten days after the fire burned itself out.

6.11.5. Results

Current Status of the Manitoba Drought Survey: In its draft form, the survey has been made available to Team Manitoba for testing purposes. The dashboard and other analytic, mapping, and presentation capabilities are now available or will soon be completed. Team Manitoba is expected to request modifications to the application through August, with this phase of project completion expected in mid-to-late August. We hope that upon taking final possession of M-Ella, Team Manitoba will be able to modify the Drought Survey and design other surveys with minimal support. Incorporating new and additional capabilities is a subject open for future discussion.

6.11.5.1. Challenges and lessons learned

Through the Ella development process the Ella team learned about the importance of regularly checking in with Team Manitoba to ensure survey creation met their needs, and satisfied their security and safety concerns. Once a strong working relationship was established, Team Ella and Team Manitoba made rapid progress on a satisfactory design.

6.11.6. Discussion and future developments

The Ella pilot gives Team Manitoba a survey application to help determine the business effects of drought within the Province. The application was developed so that without technical training, the Manitoba user community could use Ella to design other survey forms for distribution. The Ella team will continue to work with Manitoba to ensure that they are comfortable adapting Ella to their needs and will be available to discuss new capabilities that can be added to Ella, such as the use of sensors for temperature, humidity, air quality, and the monitoring of health conditions. etc.

6.12. Data Service and Catalog Component Workflow (by Safe Software)

6.12.1. Introduction to the company and main activities

Safe Software has been a leader in supporting geospatial interoperability and automation for more than 25 years as the creator of the FME platform. A central goal is to promote FAIR principles, including data sharing across barriers and silos, with unparalleled support for vendor-specific formats and open standards. Within this platform, Safe Software provides various tools to support the design, deployment, and automation of interoperability workflows, both on-premise and in the cloud.

Open standards have always been a core strategy for Safe to support data sharing. The FME platform can be seen as a bridge between the many supported vendor protocols and open standards. Safe has collaborated extensively with the open standards community, including OGC, ISO, BSI, and INSPIRE. We have participated in many OGC initiatives, including Maritime Limits and Boundaries, IndoorGML pilots, and the 2021 Disaster and 2023 Climate Resilience Pilots. Safe also actively participates in several Domain and Standards working groups (CityGML, MUDDI, EDM, and Climate Resilience, to name a few).

6.12.2. Background and problem description

Safe Software's Data Service Catalog & Registry component is implemented using the FME platform to support cataloging, referencing and access to climate model data, and related web services & metadata. The service also makes climate model data cubes available as FAIR Analysis Ready datasets (ARD) for search, access, downstream analysis and decision support. In addition the service has the capacity to incorporate base map, earth observation, and a wide range of other datasets.

Whatever the type of natural disaster, whether fire, flood, drought, or other hazards, increasingly the severity of natural disasters is exacerbated by the effects of climate change. Managing and mitigating climate change's effects poses difficulties for spatial and temporal data integration. One challenge is translating the outputs of global climate models into specific impacts at the local level.

The FME platform can help explore options for bridging this gap given its ability to read datasets produced by climate models and then filter, aggregate, interpolate and transform it as needed. FME is a spatial data integration and automation platform produced by Safe Software. It is configured using no code data transformation models that can bridge the gaps between disparate systems using its support for hundreds of different spatial and nonspatial data formats and services. This includes the capacity to consume climate model outputs such as NetCDF data cubes or OGC WCS time series, and then filter, aggregate, interpolate, and transform them as needed. FME can also inter-relate climate model data with higher resolution local data and then output it to whatever format or service is most appropriate for a given application domain or user community. This component supports the consumption of climate model output data cubes such as NetCDF or ZARR, transformation into a relational spatial database and made available by OGC API services.

Safe Software's pilot components built on lessons learned from the Climate Resilience Pilot and previous Disaster Pilots to ensure continual improvement in our ability to integrate with the other components of the pilot and make a wide range of user types and needs scalable. Our initial intent was to make a pilot contribution through an enhanced ARD component, building on lessons learned from past pilot ARD development. Such a component seems crucial for the pilot's data value chain to feed DRI (decision-ready indicators) and its overall success. However, since no such component was specifically solicited, we decided to contribute a data service component that includes both elements of data service and ARD data enhancement and provision. Also, our component emphasizes incorporating and serving climate model output ARD, which we believe is essential to support disaster management in our changing world.

While ARD has traditionally been applied in the context of earth observation data, we believe that ARD approaches can be equally applied to developing data products related to climate scenario time series data to make them easier to consume for a wider range of applications and users.

Our data service component also explored approaches to support data search and cataloging to address the initial design considerations for data services. The metadata harvest component allows users to provide a dataset as a URL or uploaded file. The service then auto-generates spatial metadata based on this, which can be used to support cataloging. We also implemented a basic OGC Records API, which provides a metadata catalog of our climate ARD services and lists the various items available via our services.

6.12.3. Objectives and role in the pilot architecture

One challenge Safe Software's data service component addressed was to take climate model results and feed them to forecast and impact models related to the hazards of interest, such as drought, fire, or flood. Our workflow transforms climate services data cubes (NetCDF) to a form of ARD (analysis-ready data) more easily consumable by GIS applications, via publication of this via vector themes on OGC API Feature services. The underlying goal related to the wider pilot architecture is to feed the data value chain from raw source data — in this case, climate model data cubes, through to ARD to feed decision and impact indicator (DRI) workflows. In this way the climate model source data is made available using OGC standard processes (OGC APIs), which is key to making the data more widely accessible and usable by those likely to be affected by its potential impacts. Another challenge that was addressed is making data services more easily discoverable and searchable. The metadata harvest service and OGC API Records service were both designed to improve our ability to make our services more discoverable and integrate better with other pilot catalogs.

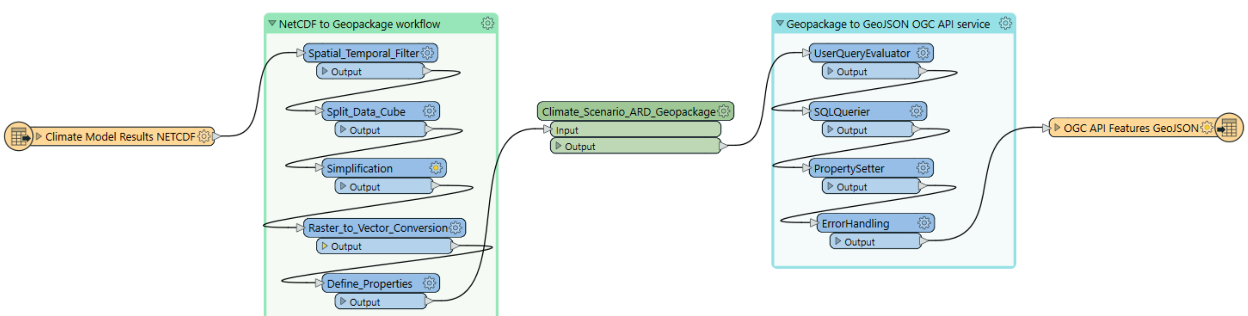


Figure 95 — High-level component FME workflow from climate data cube NetCDF to spatial database geopackage to OGC API Feature service GeoJSON.

6.12.4. Methodology

6.12.4.1. Area of study

The primary area of study for this pilot component has been southern Manitoba. More specifically, our data extents are approximately in the longitude/latitude range of 102W, 49N to 95W, 52N. The time range of our output data is from 2020 to 2060.

6.12.4.2. Technical design

Climate Variable ARD

In terms of input, processing, and output, this component takes the climate scenario model results from climate data services and transforms this into analysis-ready data (ARD). Making this crucial data available via commonly accessible open standards is key to making it data more widely accessible and usable by those likely to be affected by potential impacts. The data is first converted into a relational form and stored in a spatial database — in this case, OGC Geopackage. See the FME workflow NetCDF to Geopackage workflow shown below. Then a spatial database to GeoSON workflow is used to make the data available via an easily accessible GeoJSON web service using OGC API Features. See the spatial database to GeoJSON workflow shown below.

Note that the Geopackage to GeoJSON workflow is published to FME Flow / FME Server which in turn is hosted on the FME Hosted environment (FME Cloud) that runs on AWS — Amazon Web Services. This allows a workflow developed on the desktop using FME Form to run as a continuously accessible web service — in this case configured to support the OGC API Features protocol. One key aspect is parsing the OGC API feature requests and translating the parameters into database queries. This ensures that the feature queries only process the data needed to fulfill the request and helps keep performance scalable, given that the database stores several million records of point data.

Data Inputs

Environment Canada:

The climate model data cube was downloaded from Environment Canada's climate data extraction tool.

https://climate-scenarios.canada.ca/?page=statistical-downscaling

https://climate-change.canada.ca/climate-data/#/downscaled-data

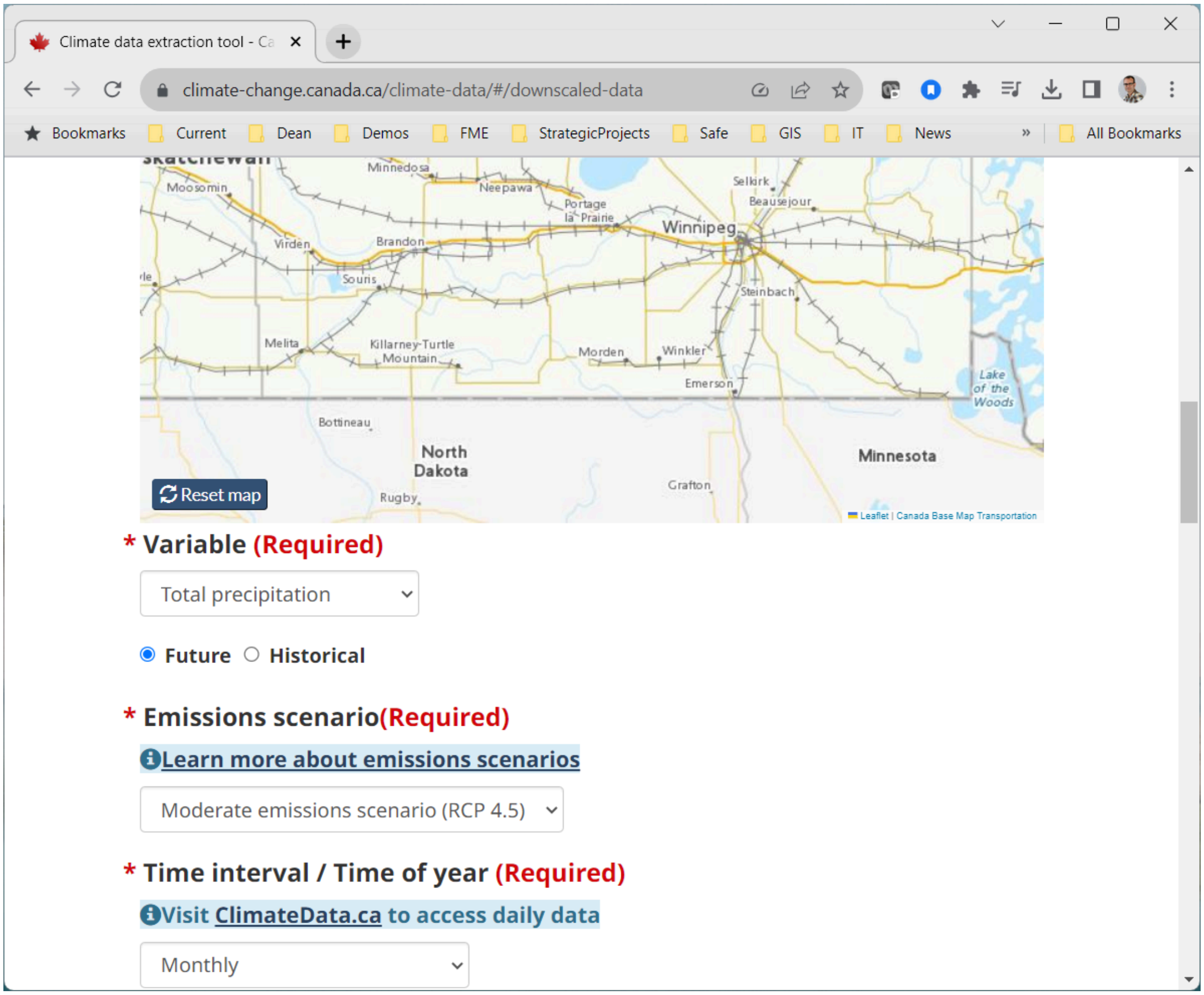


Figure 96 — Environment and Climate Change Canada Climate Data Extraction Tool.

The downloaded climate data used NetCDF v4 using NetCDF conventions CF v1.4 with 960 bands representing monthly time steps. The model generation, scenario and downscale approach were CMIP5, RCP45 and BCSD respectively. For more details on the climate scenario and environmental variables used see the section on Drought Severity Workflow.

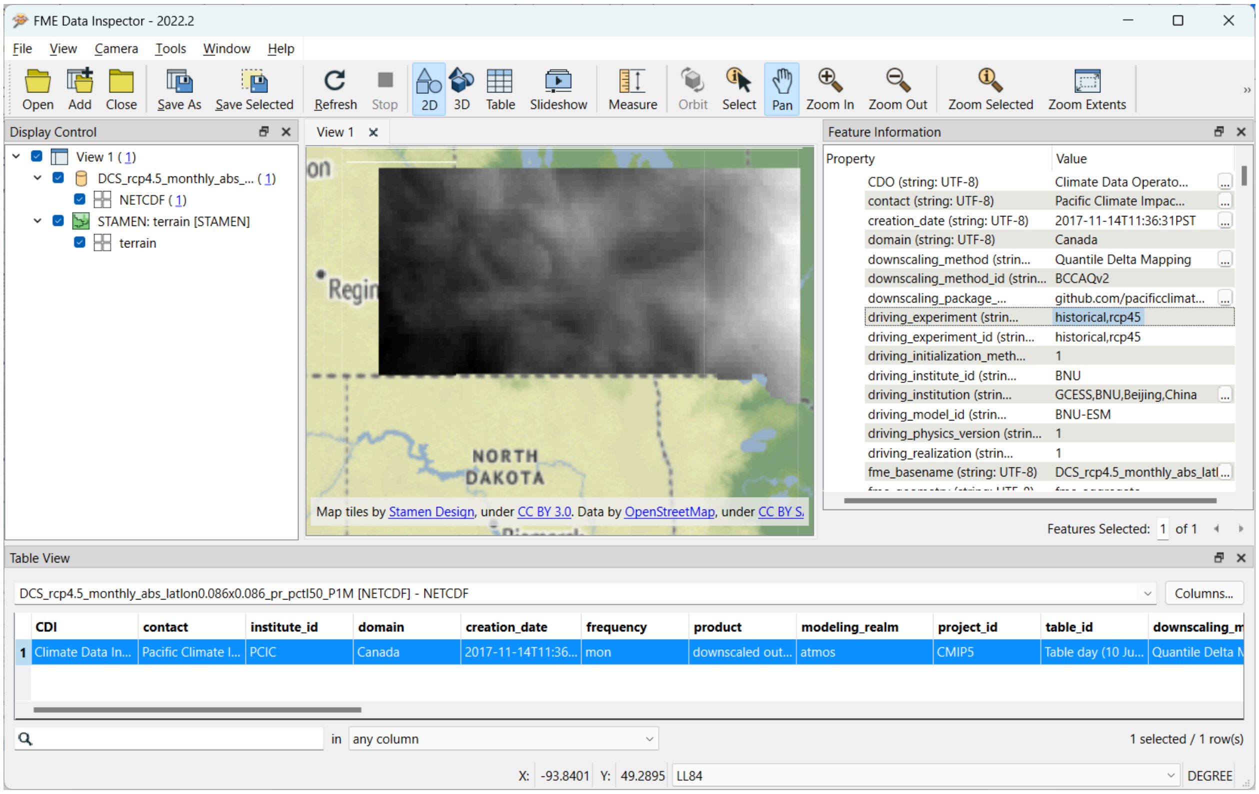


Figure 97 — Source NetCDF data cube from Environment Canada's climate data extraction tool shown in FME Data Inspector.

Processing: Data Cubes to ARD:

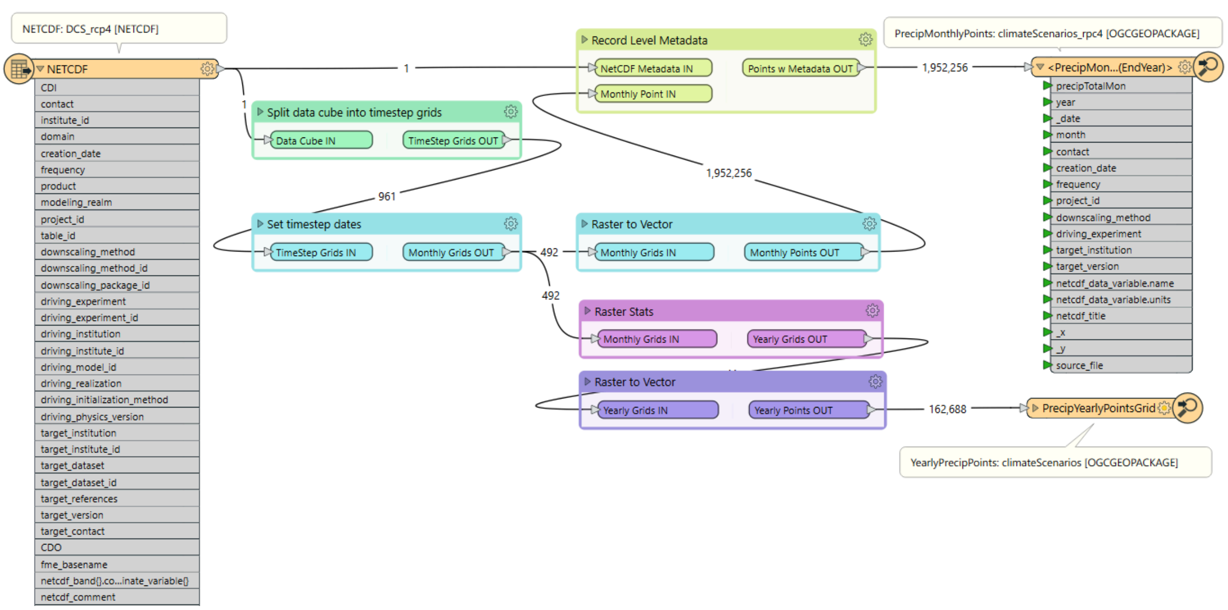


Figure 98 — Climate service data FME transformation workflow from NetCDF data cube to Geopackage relational database.

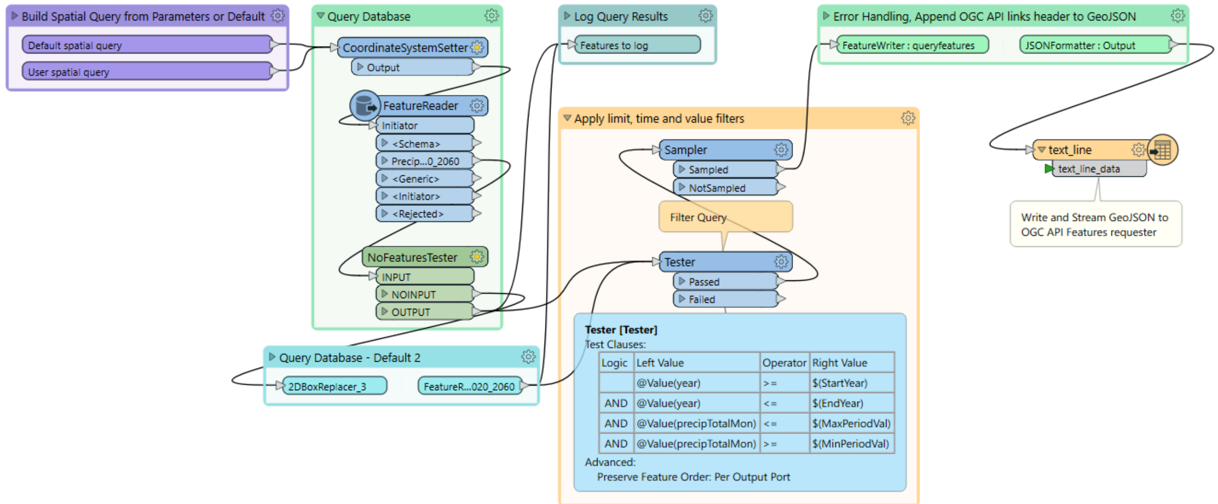


Figure 99 — Geopackage spatial database to GeoJSON delivered via OGC API Features, published to FME Flow Hosted (FME Server hosted on FME Cloud /Amazon Web Services)

Note that the Geopackage to GeoJSON workflow is published to FME Flow / FME Server which in turn is hosted on the FME Hosted environment (FME Cloud) that runs on AWS — Amazon Web Services. This allows a workflow developed on the desktop using FME Form to run as a continuously accessible web service — in this case configured to support the OGC API Features protocol. One key aspect of this is parsing the OGC API feature requests and translating the parameters from them into database queries. This ensures that the feature queries only process the data actually needed to fulfill the request and is key to scaling performance given that the database stores several million records of point data.

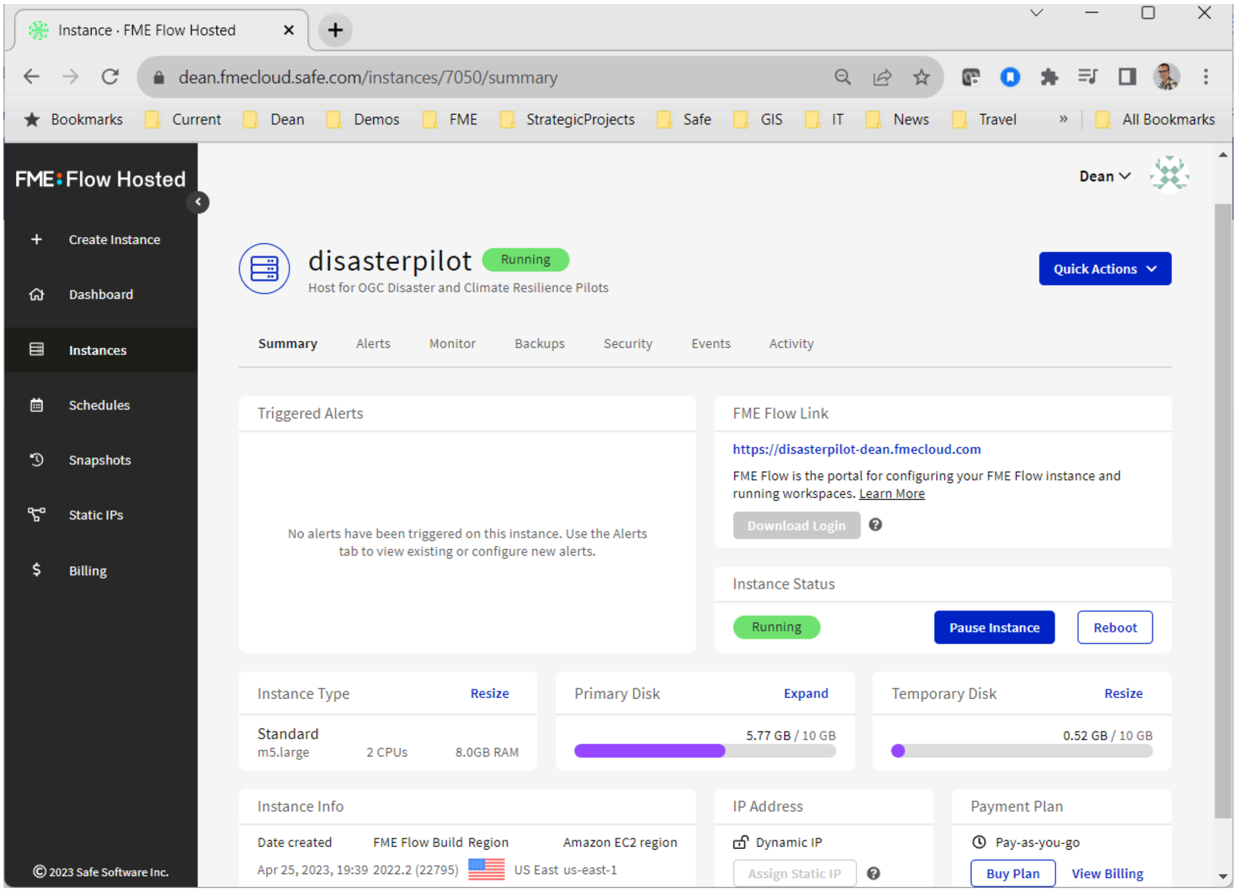


Figure 100 — FME Flow Hosted - the FME Server environment hosted on Amazon AWS that hosts the OGC API Feature and Records services

For the selected climate scenarios, this supports the analysis of estimated drought risk impacts over time via simple feature queries that can be translated to SQL queries on the underlying spatial database. It also feeds drought-related environmental factors to other pilot indicator components such as the Pixalytics drought model for more refined drought risk analysis. For this pilot, it was recognized that more complex indicators, such as drought risk, are likely driven by multiple environmental and physical factors. As such, the initial goal was to select and provide primary climate variable data, such as precipitation and temperature, that would be useful for deriving drought risks in combination with other inputs. Our ARD data flow extracts total precipitation and mean temperature per month, making this available as OGC API features of time series points streamed as GeoJSON. This climate scenario primary drought data was provided for the province of Manitoba study area and was the dataset consumed by the Pixalytics drought model component. For more information on this, refer to the drought impact and indicator components described under section D101.

ARD Data Output and Example

As mentioned above, data service allows end users to use an OGC API client to access the climate data using queries and retrieve the environmental variables and statistics for their specific geographic extent and time period of interest. The service itself supports a range of query parameters which can allow users to explore various value ranges and extremes inherent in the climate scenario projections. Multiple environmental variables such as temperature, precipitation and change in precipitation relative to historic are available on the time series points. Users can then ask questions to look for times and places of concern relative to specific natural hazards such as drought, fire, heat or flood. As example, the following request can be made to the service: “Find all time step points over the next 40 years for southern Manitoba where projections indicate > 25% dryer and mean monthly temperature > 23C.”

OGC API Features client request example: “Find all time step points over the next 40 years for southern Manitoba where projections indicate > 25% dryer and mean monthly temperature > 23C.”

OGC API Features Query Parameters:

Start Year: 2020 End Year: 2060 BBox: -100.0,49.0,-96.0,50.5 Limit: 2,000,000 MinPeriodValue: 0 (PrecipDelta) MaxPeriodValue: 0.75 (PrecipDelta) MinTemp: 23C (Min Mean Monthly Temp)

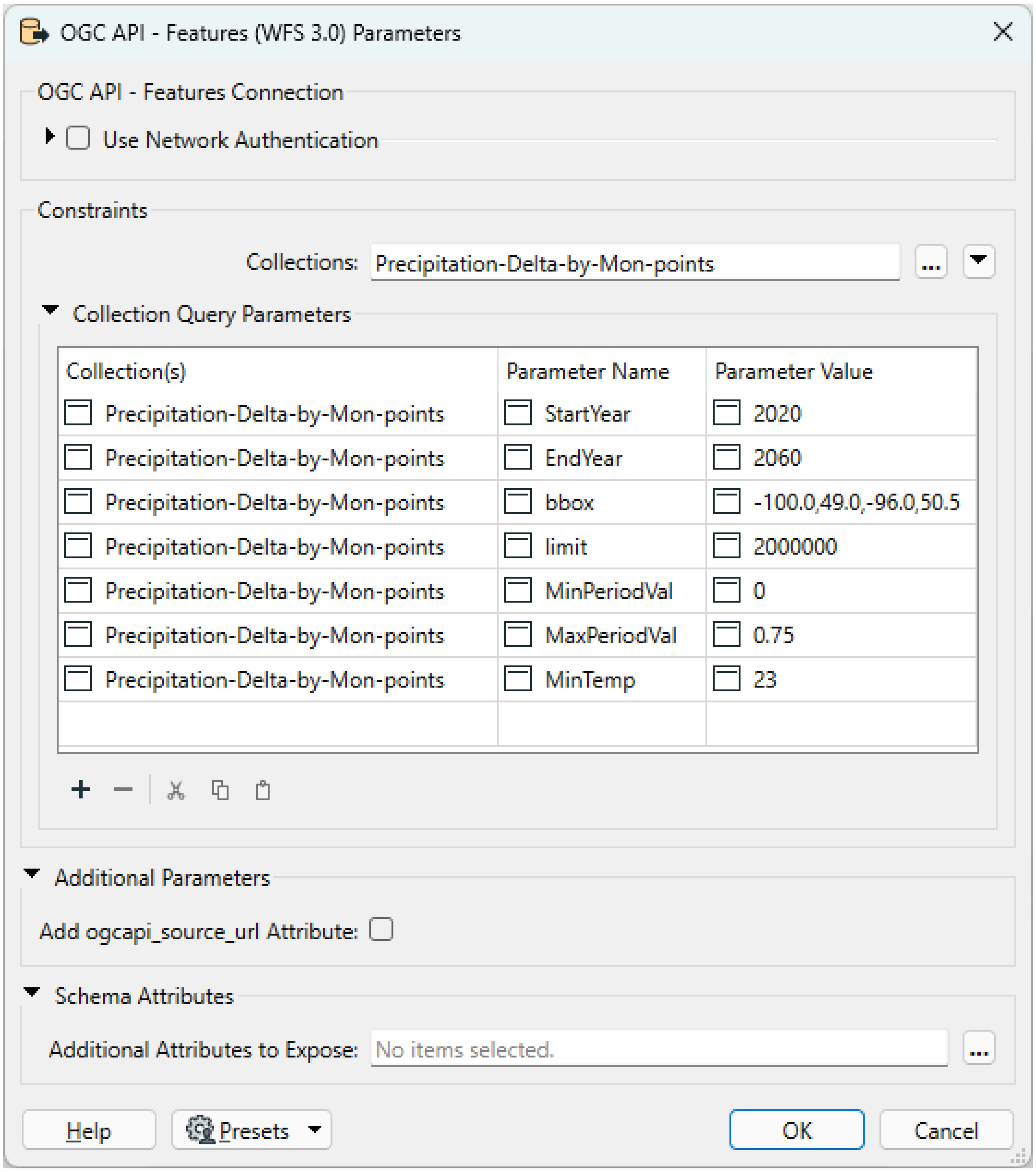


Figure 101 — OGC Features Query Parameters for mean temperature > 23C and precipitation change > 25% dryer

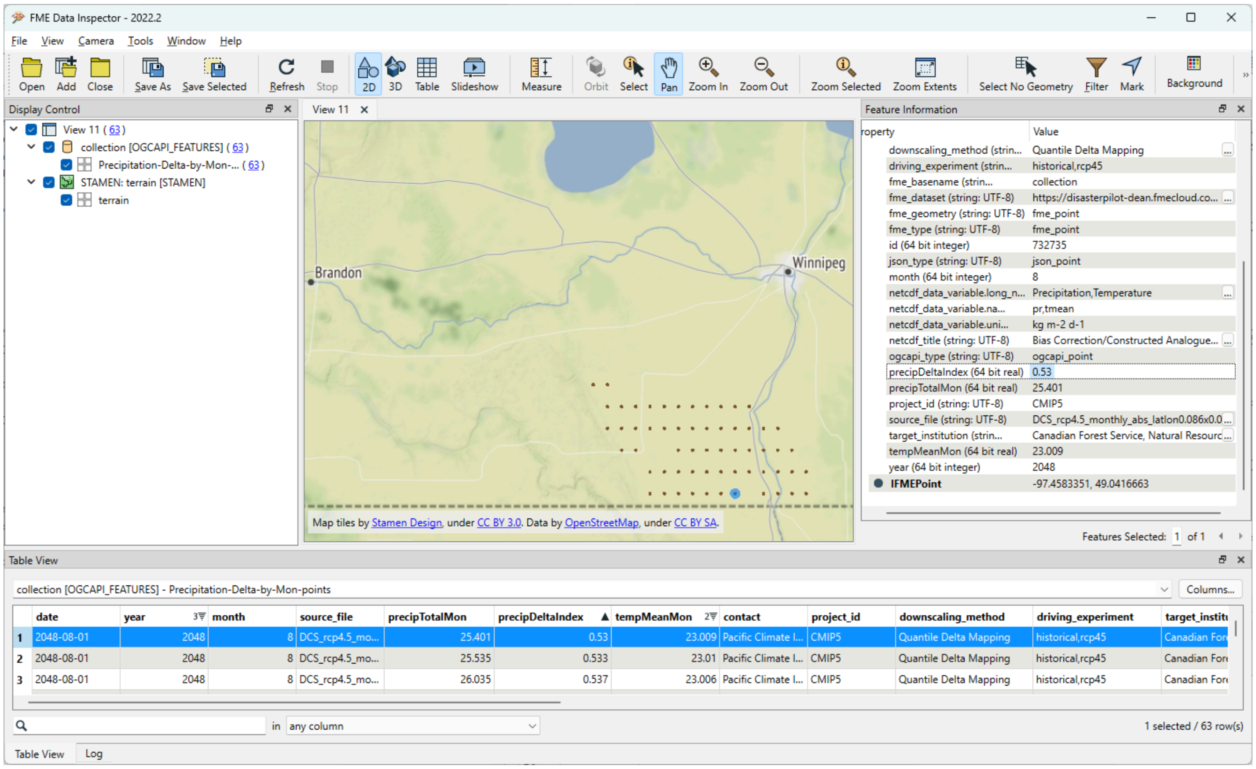


Figure 102 — OGC API Features Response to above query: 63 temporal points with associated temperature and precipitation values, as shown in FME Data Inspector client.

This data is displayed in Safe Software's Data Inspector client using the OGC API Features reader. This result shows climate model points derived from the RCP4.5 business as usual scenario that result from the query above. That is, these points from August 2048 and 2058 represent the hot and dry areas and times that satisfy the query above and could constitute increased drought and fire risk. The ultimate goal is to make climate model outputs more accessible in a form and structure easy to consume by those used to working with GIS tools.

Metadata Harvest Service

The Metadata harvest service allows users to provide datasets or data service links which it then reads and automatically extracts key properties and information metadata. This metadata can be supplied to data catalogs which enable the dataset to be discovered by users searching for that type of data. In particular, the Metadata harvest workflow reads the source data and dynamically extracts properties such as table and field names, extents, IDs, and time stamps and then fills out an ISO 19115 template with those values.

Metadata harvest process steps as follows:

- Read feature type name
- Capture cumulative extents for all feature type records
- Extract all feature type attribute names
- Generate time stamp and unique ID

- Write properties to ISO 19115 metadata template

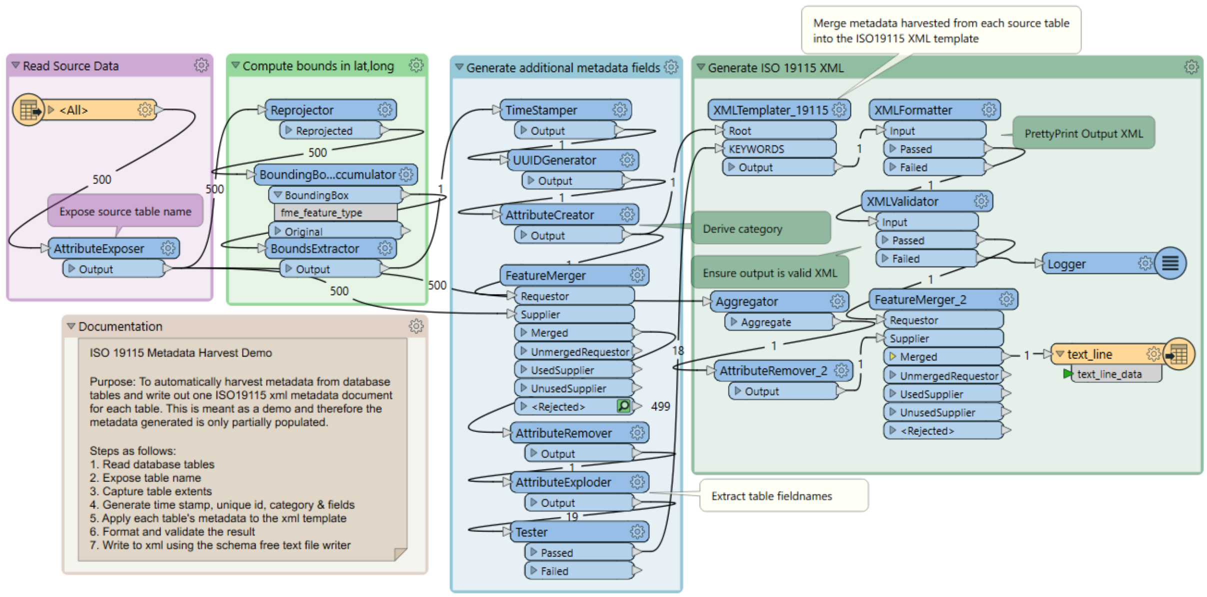


Figure 103 — Metadata harvest FME Workflow

At the moment this workflow is a stand-alone service. In the future, it would be good to integrate this with the OGC API services currently available. For example, when publishing new datasets to an OGC API Features service and registering them with an OGC API Records service, this metadata harvest service could be used to auto-generate a description which could include the feature types, properties and extents that characterize the dataset.

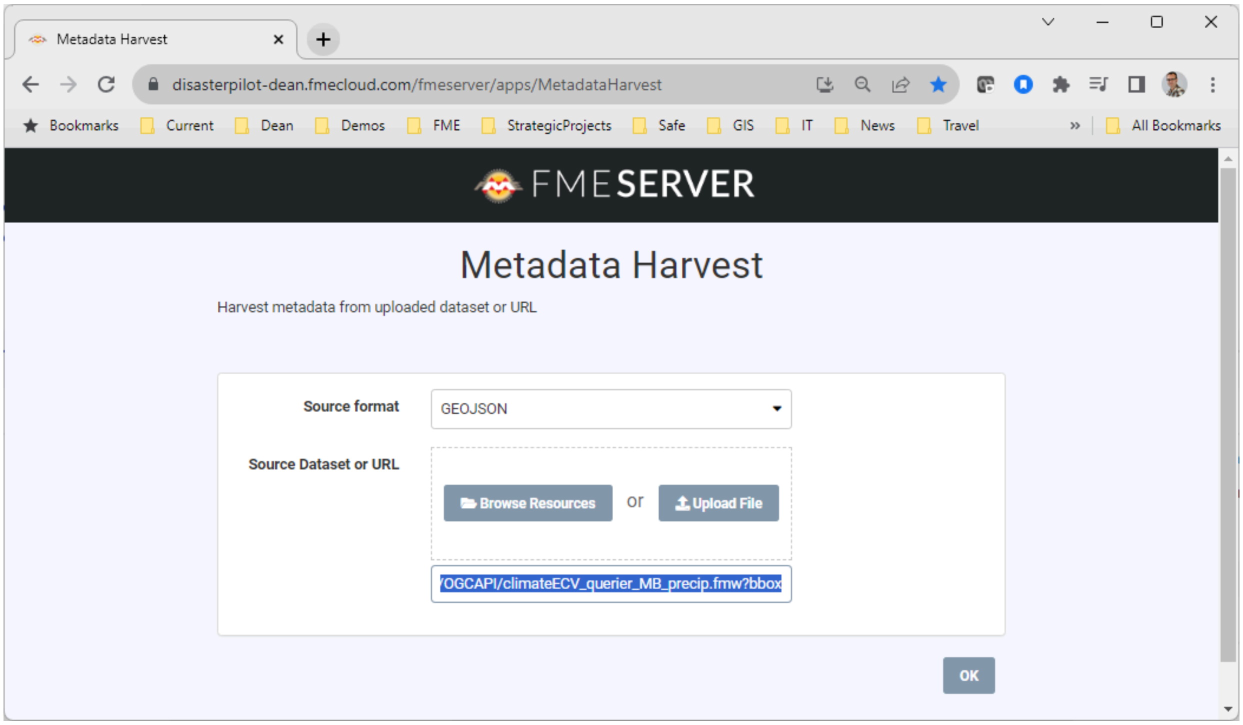


Figure 104 — User form for specifying dataset service link or dataset upload to harvest metadata from. This can also be invoked via an API call.

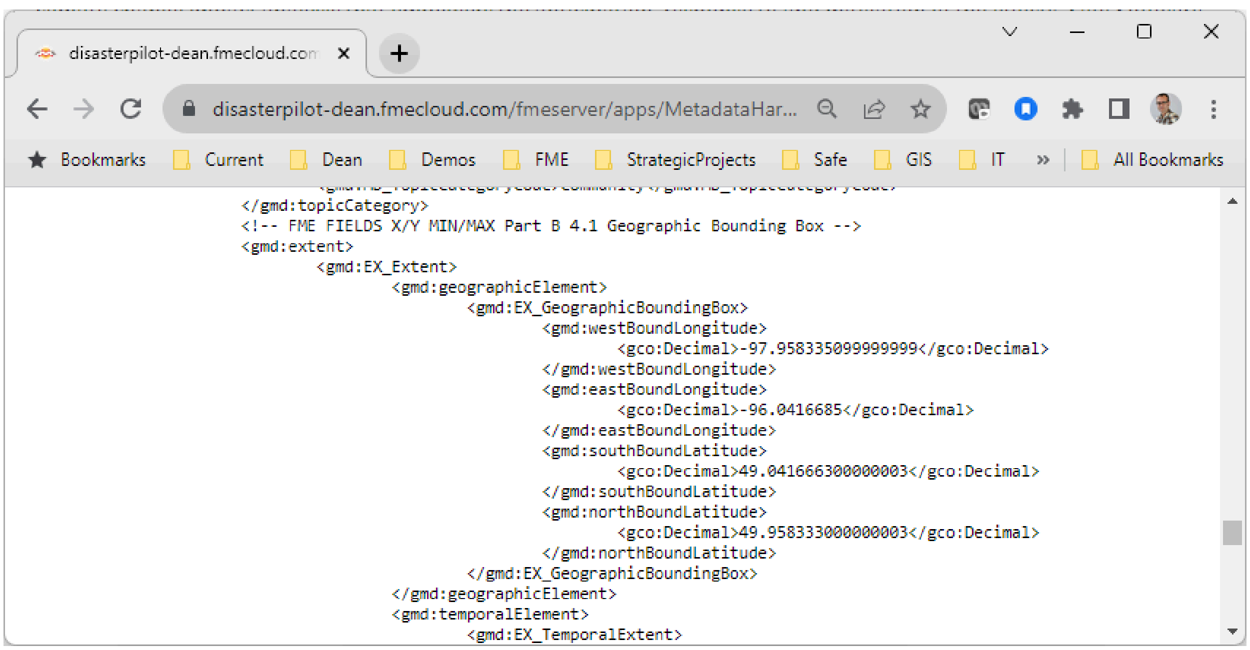


Figure 105 — Metadata result harvested from user specified data service showing the data extents.

This metadata harvest service could also be enhanced to support coordinate systems, autodetect date fields to extract temporal range, and perhaps detect other data types, value ranges, and statistical information.

OGC API Records Service

Given the tight timelines for this pilot and the focus on developing ARD-oriented feature data services to provide climate data feeds via OGC APIs, there was limited time and resources for implementing our catalog service. Not having encountered the OGC API Records service before, we had to review the specification and some example implementations. We then implemented a limited, experimental OGC API Records service, which provides metadata on the climate data services and datasets delivered by the ARD component described above. The service is a basic implementation in that it simply provides the standard landing page, collection, conformance, and item information depending on the REST request made by the Records client. This allows other components in the pilot to interrogate our catalog service and use the resulting metadata to assess and query our other feature data services.

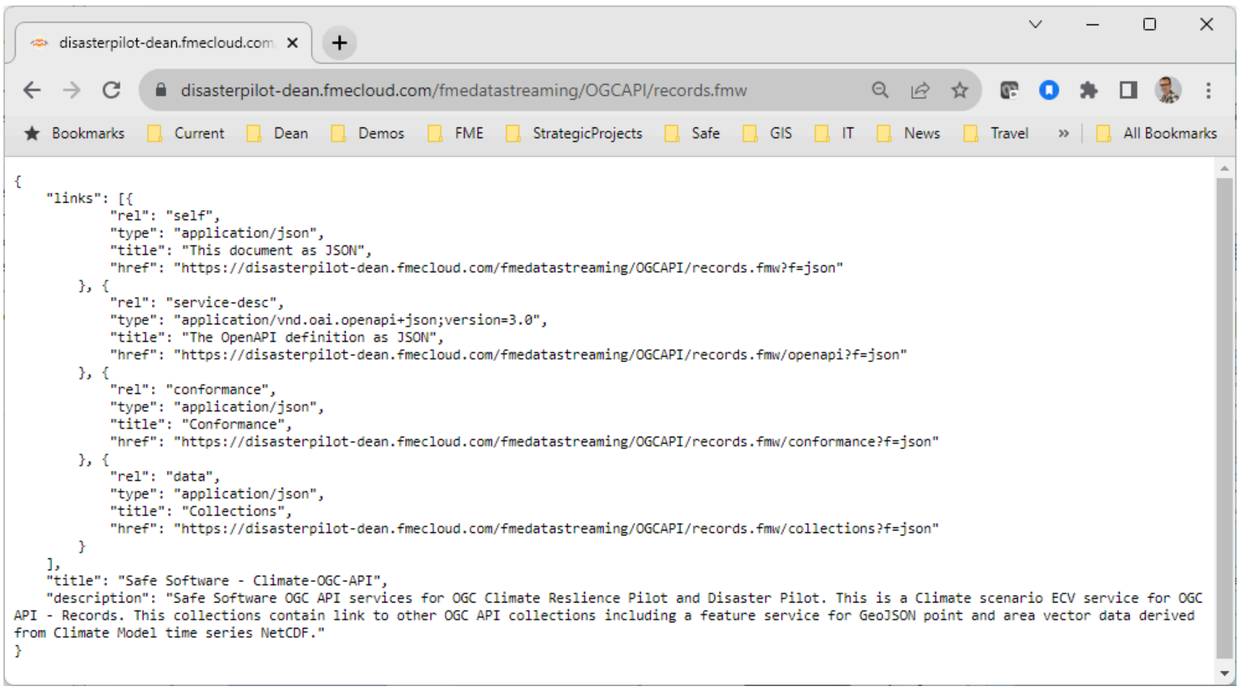


Figure 106 — Safe's OGC API Records service landing page

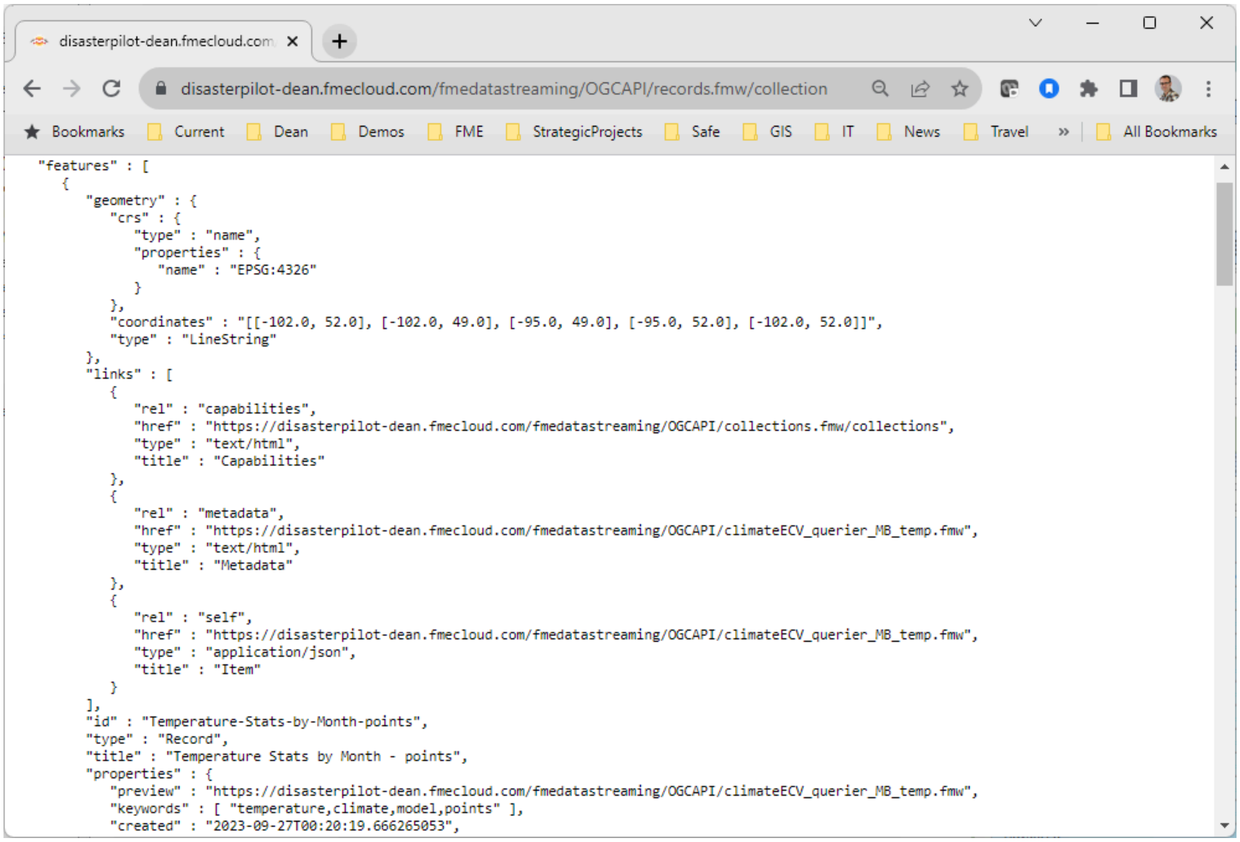


Figure 107 — Safe's OGC API Records service: item collection page

Currently, this service is a read-only catalog service that publishes metadata on the datasets and services Safe Software has contributed to the pilot. It should also be emphasized that this is an experimental limited implementation of the OGC API Records standard. It only implements a subset of the methods described in the standard sufficient to offer the basic catalog and collection information mentioned above. We will leave it to future pilot phases to improve the service's automation, including clients' ability to publish or update items based on ID.

As limited as this implementation may be, it does illustrate the way in an FME workflow can be designed to implement message handling in order to support a REST API such as this one based on OGC API Records. A typical FME workflow or transformation pipeline is designed to translate from one dataset to another, such as CAD to GIS. This implementation shows that FME workflows can also be designed to handle message pipelines such as those associated with an OGC API. Instead of a source dataset the input is simply a client request message. The data transformation workflow becomes a message handling workflow, which ultimately produces a response message instead of a response dataset. When run on FME Form on the desktop this simply reads one input URL or JSON message and outputs another, writing to an output text file. When published to FME Form (Server) this results in a service that continually monitors an endpoint, accepts GET or POST messages and produces the appropriate JSON responses via a data streaming service.

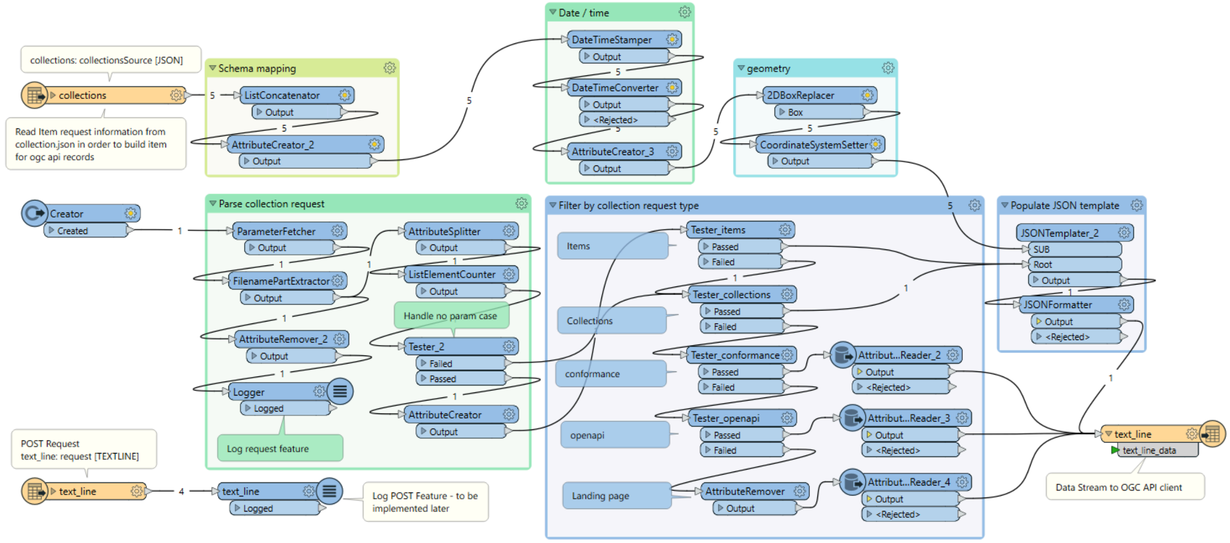


Figure 108 — OGC API Records service: message handling FME workflow

In the case of the OGC API Features messaging workflow, a get capabilities or collection request produces the collection JSON response listing the available layers that include embedded get feature request URLs. When the API client selects a specific dataset and layer, a feature request associated with that calls a specific FME data transform workflow configured to query the requested data based on the user request parameters. This Geopackage to GeoJSON FME workflow then streams GeoJSON features back to the client. So, it is possible to have a message-driven FME workflow published to FME Flow (FME Server), which ultimately streams features back to the client based on the parameters of the initial request message. The ultimate goal is to make climate model outputs more easily accessible in a form and structure easy to consume by those used to working with GIS tools.

Also, by using OGC API interfaces, the data services are provided with sufficient parameterization such that end users can compose queries in order to retrieve the environmental variables and statistics for the specific spatial and temporal ranges of interest. In this way a query against potentially gigabytes of time series data may generate a query response of a few kilobytes of environmental variable point data that satisfies the composite query. For example, consider the query looking for all time step points where mean monthly temp > 23.5C and precipitation has dropped > 25%. The initial implementation would require posing 2 queries: 1) mean monthly temperature is > 23C and 2) precipitation dropped more than 25%. Each of these queries might yield tens of thousands of points or more, and combining them would require joining the results of both queries together by location and time, which can be very process intensive. By appending these environmental variables to each associated time step point, a composite query can filter on both value ranges at the same time and produces only a few hundred points as the result with no client side joins required. The principle here is to let the database do the work which keeps the client side traffic much lighter.

6.12.4.3. Scenarios

Climate Scenario

Manitoba Regional Climate Model (RCM) Details

Spatial Extent: Lat 49 N to 52 N, 102W to 95W

Temporal Extent: 2020-2060

Model generation: CMIP5

Model scenario: RCP45

Downscale approach: bias-corrected and spatially downscaled

6.12.5. Results

6.12.5.1. Observations, Challenges and Lessons Learned

While the basic OGC API Feature service was not so difficult to implement once the specifications were reviewed and understood, it took some development effort and testing to refine the service and scale performance so that it could handle the millions of records required to deliver the climate data cube in the form of GeoJSON points. Key to this process was a combination of memory storage management and query-based data filtering. We reduced the size or memory footprint of each record in the database by only selecting the fields that were felt to be essential information as record-level metadata. Field widths were also reduced where possible. While record sizes need to be kept small to protect performance, retaining climate model information was key to understanding the context of the environmental projections in the database. Also, tying the OGC API request parameters into the SQL queries given to the database allowed us to minimize the amount of data to read, process, and ultimately transit to the OGC API client.

Early in the development process, we provided a datastream to Pixalytics, and they noticed that the values were outside the expected range. After some diagnostics, we discovered that what we published as precipitation were temperature values. At this point, we decided to start including record-level metadata to help us trace back the data flow to its source and help detect problems in the data extraction and transformation process. In the future, it may be beneficial to have more verbose record-level metadata during development with an option to switch to linked metadata once consistent outputs have been verified.

This also raises the issue of validation. We found several user requests produced no results, resulting in a Server error. We then added a server side test for no output and generated an error record stating that the request was invalid or too restrictive. This should help the OGC API clients understand the status of their queries and make adjustments as needed rather than waiting for an answer that might never come or wonder why there is no response.

These data services developed by Safe Software for this Disaster Pilot provided a range of crucial capabilities to disaster responders, managers, planners and analysts. The metadata and records services provide tools to describe and make datasets and services easier to characterize and discover. The ARD data service allows planners and analysts to combine historical, current natural hazard risk assessments with models of future risk in order to better evaluate the resilience of their infrastructure and mitigation strategies. Composite query capabilities allow users to interrogate a combination of environmental variables for different value ranges and changes relative to past norms using OGC APIs. This means that analysts can experiment with different business rules and tolerances to explore trends in the data that may correspond to increased natural hazard risks over time, whether for heat waves, drought, flood or fire.

Specifically, this ARD data pipeline is able to consume climate model outputs and use them to feed forecast and impact models related to the hazards of interest such as drought, fire or flood. The workflow transforms climate services data cubes such as NetCDF or ZARR to a form of ARD — analysis ready data — more easily consumable by GIS applications, via publication of this via vector themes on OGC API Feature services. The underlying goal is to feed the data value chain from raw source data — in this case climate model data cubes, through to ARD in order to feed DRI or decision and impact indicator workflows.

It is important to underline that this particular ARD component is more of an interactive service than one meant to yield one specific result or prediction. As such, it is up to the end user, whether they be domain experts, analysts or managers, to develop the impact or indicator business rules that they deem most appropriate. This ARD service provides a means of interacting with the relevant environmental variables from the climate model projections, such as precipitation and temperature, to see when and where problems might occur. What is defined as problematic will naturally differ depending on whether the end user is concerned about. This ARD service then provides an access point where end users can explore the climate scenario data as it relates to southern Manitoba. The cases shown here are just examples and are only meant to serve as a starting point for further testing and exploration.

6.12.6. Discussion and future developments

For this pilot, Safe Software's Data Service component primarily focussed on serving environmental variables from selected climate scenarios by providing OGC API Feature service for climate data and related OGC API Records catalog and metadata. However, this data service component can also serve EO (Earth Observation), elevation (DEM) ARD data, and vector data themes for relevant natural themes, populations, and infrastructure. For future pilots, it would be useful to explore the provision of a wider range of datasets and types, still focusing on providing them in the form of ARD relevant to the specific type of data involved. This should make it easier for downstream applications to request a range of data themes for a specific area of concern and then combine the results to build richer risk indicators. This way, projected climate variables could be combined with elevation data, vegetation, land use, infrastructure, and population data to build composite indicators with more detailed risk assessments related to human, economic, and social impacts.

Perhaps the next step may be to explore other back-end storage options that may be more scalable, such as cloud-native formats. For example, at this point, our data is stored in monthly time steps. If we moved towards weekly or daily timesteps, the data would increase by one or more orders of magnitude. In that case, performance would likely degrade to the extent that it would limit the service's usability. It is felt that in the future, it would be useful to explore the use of cloud-native data stores such as Geoparquet or ZARR as the backend storage for this data. Caching approaches should also be explored for any production system.

To improve performance and scalability in the future, we could significantly reduce data redundancy by creating a reference dataset or scenario table. That way, instead of storing a dozen fields as record-level metadata, many with repeating values, we could simply have a reference dataset ID and store the metadata in that table. For example, we could store the climate scenario information such as mode generation CMIP5, emissions scenario RCP4.5, downsample method, and contact agency in the reference dataset table and then simply reference that table with an id. Given that millions of point records arise from a typical climate scenario data cube, this should reduce the size of the underlying database by an order of magnitude or so.

Besides back-end storage, we could also explore options for offering various delivery formats. While GeoJSON points may serve a wide range of users, there may be other use cases where subsetting data cubes into smaller localized AOI data cubes in the form of ZARR or NetCDF. Raster grids in TIF or COG may be more useful in other cases.

The FME platform currently has some limitations in terms of data virtualization. In the context of hosting OGC API services, one of the effects of this is that it is difficult for FME Flow (Server) to autodetect GETs vs POSTs. Currently, the FME workflows must be designed to catch the different message types, filter them, and handle them as needed. In the future, enhancements to FME's data virtualization should make this message-handling process easier.

It would be useful to explore the provision of other OGC API services to augment the ones already provided. An OGC API Process service would allow us to package FME workflows hosted on FME Flow (Server) and make them available in a more modular fashion to any other service that can interface with the API. We could then explore options for breaking up some of our more complex workflows into a series of smaller process building blocks and then exposing these as microservices. For example, the current climate data cube workflow includes data filtering, segmentation, raster-to-vector conversion, and property extraction. Each process could be provided as a Process service, allowing users to mix FME processes with other processes hosted on a Jupyter Notebook to assemble whatever data value chain they wish.

One area we did not have time to explore sufficiently was validation. To verify that a given climate data cube was loaded correctly into the staging spatial database, it would be good if there were some way to query both and make sure the results align appropriately. In addition, it would be good to have a series of business rules to check the loaded data and ensure no values outside of an expected range or blank or duplicate values in required or unique value fields, respectively. Spatial and temporal extents could also be checked, along with checks for continuity or gaps. Finally, statistical reports could be generated to characterize a specific scenario and serve as a checksum to validate the load process further.

Finally, because of the automated nature of the underlying FME workflows, it is also relatively easy to process different climate scenario inputs from data cube to geopackage, to support a range of scenario analysis downstream. The ability to evaluate a range of climate scenarios from low to mid to high emissions is crucial to testing the resilience of communities. In future pilots, it would be important to evaluate a wider range of emissions scenarios to better understand the effect of these scenarios on a range of climate impacts, and how infrastructure and mitigation policies stand up to the these impacts. Ultimately the goal of incorporating climate model outputs in disaster management planning is not so much to predict the specific level and type of natural hazard at a particular place and time, but rather to better understand the range and probabilities of hazard risks that can be expected, and what overall trends are likely.

For further information on Safe Software's pilot components and associated persistent demos, see Safe Software's contributions to OGC Disaster and Climate Pilots.

6.13. Energy Demand and Production Indicator Workflow (by GECOsistema)

6.13.1. Introduction to the company and main activities

GECOsistema srl (Limited Liability Company) was established in 2001 and is a specialist company providing advanced engineering **cloud web**, **data science**, and **modeling** studies and services in environmental, climate risk, and geospatial intelligence.

GECOsistema, headquartered in the heart of Italy, in Rimini and Bolzano, stands at the nexus of engineering and environmental innovation. This renowned entity delivers advanced cloud-web engineering, data science, and modeling studies rooted in environmental, climate risk, and geospatial intelligence. Its offerings are not just limited to studies; it also crafts pioneering solutions to today's most pressing environmental challenges.

Leveraging a robust synergy of data science, machine learning, GIS, remote sensing, and predictive analytics, GECOsistema dives deep into environmental, climate, and geospatial issues, offering unparalleled insights. This isn't mere analysis; it's a groundbreaking amalgamation of ecological modeling, geospatial analysis tools, and sophisticated predictive capabilities.

GECOsistema's innovation could be more consistent. They actively engage in EU (H2020, HORIZON) and EIT-Climate-KIC funded research projects (I-CISK, DIRECTED), continuously pushing the boundaries of what's possible in environmental intelligence. Furthermore, they operate across various scales — from local to global, and this expansive reach is enhanced through collaborations with eminent partners, including government entities, research centers like CMCC and GFZ, universities such as UNIBO and TUWIEN, and prominent Oil & Gas and engineering corporations.

6.13.2. Background and problem description

The power sector is exposed to weather and climate variability at all timescales, with impacts on both demand and supply. It is well established that global and regional temperatures are increasing and will continue to increase with human-induced climate change, resulting in increasing electricity demand for residential cooling. Recent studies investigating the impact of climate change on demand concur that annual heating-induced demand is likely to reduce, whereas cooling-induced demand is likely to increase.

The Energy Climate Indicator aims to produce a minimum viable climate service designed to enable the energy industry and policymakers to assess the impacts of climate variability and climate change on the energy sector in Manitoba (Canada).

The Energy Demand and Hydropower Production indicators will be formulated and validated specifically for Italy, given that daily data for these metrics are unavailable in Manitoba. However, the methodology can be effortlessly adapted and applied to other regions or countries worldwide.

The Indicator provides a time series forecast of electricity energy demand and supply from hydropower with short-term or long-term monthly, seasonal, and climate change outlooks. Improved characterization and prediction of such variability will benefit production and transmission planning, leading to economic and environmental benefits.

The energy indicators and associated time series forecasts can be provided as data files or images. The data can be shared between individuals and organizations, following appropriate standards in various ways.

6.13.3. Objectives and role in the pilot architecture

In today's rapidly changing climate, the necessity for proactive measures and foresight in the energy sector has never been greater. The D104 Energy Service of the Disaster Pilot epitomizes this forward-thinking approach, forging a revolutionary pathway to predict energy demand and hydropower production in alignment with changing climate patterns. This initiative aims to harness the transformative potential of artificial intelligence (AI) and leverage seasonal forecasts and climate projections, particularly those provided by the esteemed Copernicus Climate Data Store (CDS).

1. An Open-Source Paradigm

One of the defining characteristics of the D104 framework is its steadfast commitment to open-source ideologies. Building the entire framework using open-source components ensures that the final product remains freely accessible and can be enhanced by the global community. This technology democratization encourages widespread adoption and paves the way for more collaborative and transparent technological advancements.

1. Adherence to OGC Standards

Ensuring compatibility and interoperability is paramount when creating solutions meant for broader applications. The D104 framework aligns perfectly with this notion by meticulously following the well-established Open Geospatial Consortium (OGC) standards. Moreover, integrating an OGC API Process assures the framework seamlessly aligns with industry standards, guaranteeing smooth interfacing with other OGC-compliant tools and systems.

1. Modular Design: Flexibility and Scalability at its Core

The brilliance of the D104 framework also lies in its modular design. Every system component, from the modeling tool to the various data sources, has been structured to be both extensible and replaceable. This modular approach means that as technology evolves or newer data sources become available, they can be easily incorporated into the framework. Such flexibility ensures the longevity and relevance of the D104 system in an ever-evolving technological landscape.

1. The Power of Predictive Analytics

By exploiting advanced AI models with seasonal forecasts and climate projections, the D104 framework promises unprecedented accuracy in predicting energy demand and hydropower production. This predictive prowess can be instrumental for energy stakeholders, allowing them to anticipate demand surges, optimize hydropower production based on expected water inflows, and make informed decisions to ensure energy security in the face of climatic uncertainties.

In summary, the D104 Energy Service under the Disaster Pilot initiative embodies a monumental energy and climate intelligence stride. By combining the prowess of AI with the insights from climate projections, all while adhering to an open-source and modular design, it promises to revolutionize how energy stakeholders prepare for and navigate the challenges of a changing climate.

6.13.4. Methodology

A meticulous and technologically advanced workflow has been devised to effectively anticipate energy demand and hydropower production in changing climatic conditions. This process, while intricate, promises unprecedented accuracy and utility for its stakeholders. Here's a comprehensive look into its various stages:

1. Data Procurement:

The foundation for any predictive analysis lies in the richness and quality of the data. For this workflow:

- Historical Context: Data from 1979 to August 2023 on Energy Demand and Hydropower production is sourced from the authoritative Copernicus Climate Data Store (CDS).
- Essential Climate Variables: Alongside, historical ERA 5 Reanalysis data for crucial climate variables, including Temperature, Precipitation, Wind Speed, and Irradiance, are retrieved from the Copernicus CDS. These factors play a pivotal role in shaping energy demand and hydropower outputs.

    1. AI-Driven Predictive Modelling:

Artificial Intelligence, particularly the LSTM (Long Short-Term Memory) model, will be harnessed for this purpose.

- Model Design: An AI-based LSTM model is crafted and tailored to handle time-series data inherent in climate and energy datasets.

- Training & Validation: Using the historical data gathered for a specific EU country (Italy being the pilot region), the model undergoes rigorous training and validation to ensure optimal performance.
- Accessibility and Deployment: Post-validation, the model is dockerised, encapsulating it into a lightweight, standalone container. This containerized model is accessible via an API, ensuring easy integration and usage.

1. Forecasting Using AI:

Leveraging the trained LSTM model:

- Scenario Analysis: Both seasonal and future climate scenarios about Energy Demand and Hydropower Production are forecasted. This prediction exploits data from Copernicus Seasonal Forecast and Climate Projections, ensuring it reflects the latest climatic insights.
- API Deployment: These forecasts, along with relevant time series data, are made available to end-users through API Processes utilizing 'pygeoapi', a Python server implementation of the OGC API suite of standards.

1. Result Dissemination:

The API, besides offering various functionalities, notably provides:

CSV Output: A downloadable CSV file containing meticulously forecasted data on energy demand and hydroenergy production. This format ensures easy consumption and integration of the data into various analytical tools and platforms.

1. Cloud Infrastructure and Deployment:

Considering the data-intensive nature of the workflow and the need for scalability:

Docker Deployment: The entire infrastructure, encapsulated using Docker, is deployed in a cloud environment. This ensures scalability and robustness, catering to varying computational demands and providing uninterrupted service.

1. Pilot Implementation:

Before a broader rollout:

Focus on Italy: This intricate workflow will be first tested and implemented for the Italy region. As a pilot test, it will provide invaluable insights into the workflow's effectiveness, potential areas of enhancement, and real-world utility.

This workflow perfectly blends cutting-edge technology, deep climatic insights, and user-focused design. Its structured approach aims to transform the way energy stakeholders anticipate and prepare for the future in an era marked by climatic uncertainties.

6.13.4.1. Area of study

The study area of D104 is Italy.

6.13.4.2. Technical design

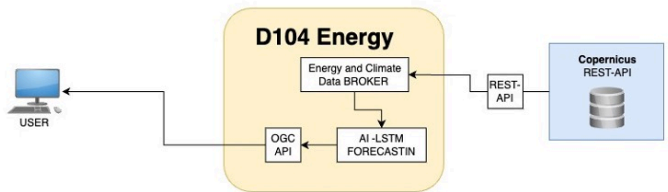


Figure 109 — The architecture of the Energy Forecasting Climate-based service.

Central to the structure of the predictive workflow stands the "Energy Service." This pivotal component acts as the heart of the framework, pulsating with data and intelligence to provide stakeholders with invaluable insights into the future energy landscape.

1. Core Functionality:

The Energy Service has a dual-fold operation:

- Data Acquisition: Primarily, it downloads Essential Climate Variable (ECV) data, providing the historical context and foundation for subsequent analysis.
- Predictive Analysis: The Service then takes the helm to predict, using the procured climate data, both the energy demand and hydropower production for a specific period, as the user delineates.

1. AI-Driven Modeling:

The true power of this Service lies in its utilization of artificial intelligence:

Python Prowess: The forecast model is developed in Python, a testament to the language's versatility and strength in data analysis.

LSTM Integration: Leveraging the prowess of Long Short-Term Memory (LSTM) networks, the model taps into libraries from renowned platforms like PyTorch and Keras. This ensures the model can accurately handle the time-series nature of climate and energy data.

1. Data Source:

The authenticity and accuracy of data are paramount:

Copernicus Climate Data Store: Recognized for its comprehensive climate data, Copernicus CDS serves as the primary data source. The ECV climate data is fetched seamlessly using the provided API, ensuring timely and accurate data retrieval.

1. Service Accessibility:

Ensuring stakeholders can effortlessly access these predictions:

- API Process with pygeoapi: All the framework's services, including the Energy Service, are accessible via an API Process. This is masterfully implemented using 'pygeoapi', a Python server implementation adept at handling such tasks.
- Data Outputs: Users can request the output in two formats — a GeoJSON file for spatially-relevant insights or a traditional CSV file. Both these formats will house forecasts for energy demand and hydropower production based on user-specified timeframes and the relevant climate projections.

    1. Deployment & Scalability:

To ensure robustness and seamless service:

Docker Containers: All framework components, including Energy Service, operate in isolated docker containers. This encapsulation ensures component independence, streamlined updates, and resource efficiency.

AWS Cloud Integration: In line with modern infrastructure practices, these dockerized components are deployed in the Amazon Web Services (AWS) cloud, ensuring scalability, reliability, and global accessibility.

The Energy Service Framework represents a harmonious blend of cutting-edge AI, reliable climate data, and modern infrastructure practices. Its design promises stakeholders timely, accurate, and actionable insights into future energy scenarios, all with the simplicity of a few API calls.

6.13.5. Results

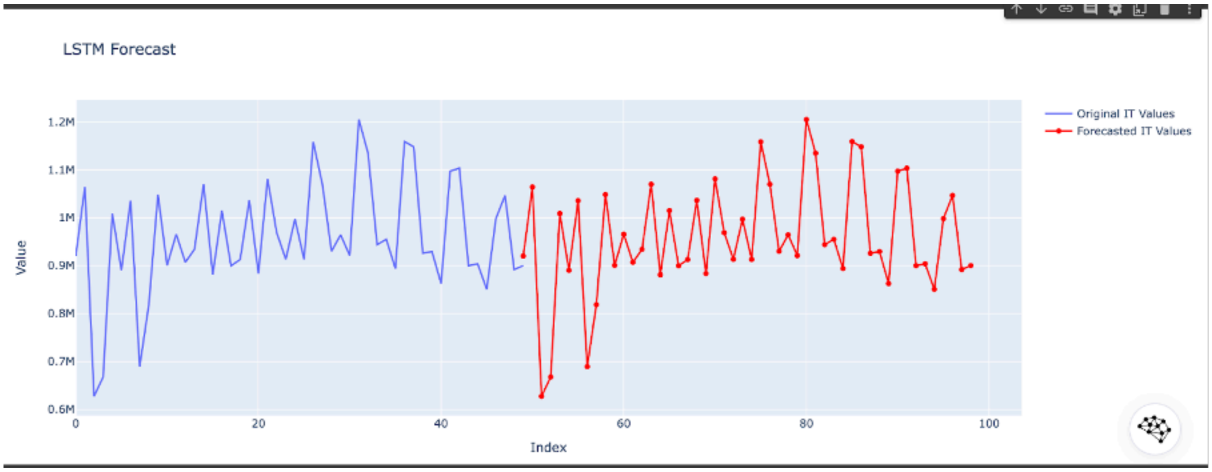


Figure 110 — Time Series Forecast.

6.13.5.1. Challenges and lessons learned

The project initially intended to center its studies around Manitoba. However, a significant roadblock appeared in the form of unavailable energy demand and hydropower data for the region. With this crucial dataset, generating accurate and relevant predictions became possible, which is the cornerstone of the framework's value proposition.

Given the data constraints in Manitoba, the project team strategically shifted its focus to Italy. Italy provided the essential energy demand data and a rich tapestry of historical data, allowing for a more comprehensive analysis and prediction. While this move was a solution, it did demand the recalibration of models and strategies tailored to the European context.

6.13.5.2. Updates and applications

The Indicator provides a time series forecast of electricity energy demand and supply from hydropower with short-term or long-term monthly, seasonal, and climate change outlooks. Improved characterization and prediction of such variability will benefit production and transmission planning, leading to economic and environmental benefits.

6.13.6. Discussion and future developments

1. Geographic Expansion:

Broadening Horizons: While the project has tailored its insights for Italy, the framework's modular design allows it to be applied to other regions. Every region comes with its unique climatic, infrastructural, and consumption characteristics. By adapting to these nuances, the service can deliver valuable energy demand insights to multiple global territories, aiding decision-makers from various corners of the world.

1. Granular Insights with Micro-Energy Districts:

Zooming In: One significant advancement would be to drill down from national or regional predictions to more localized, district-level forecasts. By retraining the AI model with historical data from smaller energy districts, predictions can be made for micro-regions.

Benefits: Such granularity can provide local authorities, energy suppliers, and businesses with exact data, allowing for better infrastructure planning, energy allocation, and sustainable development strategies at a regional scale.

1. Enhanced Downscaling of Forecasts:

Need for Precision: With the move towards smaller energy districts, there arises a need to refine the resolution of our forecasts. In this context, downscaling means providing more localized predictions and, hence, more relevant to micro-regions.

Technological Evolution: The combination of advanced algorithms, high-resolution datasets, and localized weather models can help achieve this downscaling, giving stakeholders pinpoint insights into energy demand and hydropower production for smaller geographic entities.

1. Continuous Model Upgradation:

The Learning Curve: AI models thrive on data, especially those based on deep learning architectures like LSTM. The AI model can be periodically retrained as more historical energy consumption and climatic data become available. This continuous learning ensures the model remains updated with recent patterns, leading to more accurate predictions.

1. Integration with Real-Time Data Sources:

The framework can be integrated with real-time energy consumption and weather data feeds to enhance its predictive accuracy further. This would allow for short-term, highly accurate energy demand predictions, invaluable for energy grid management and immediate decision-making.

7

LESSONS LEARNED AND CHALLENGES

7 LESSONS LEARNED AND CHALLENGES

7.1. Inconsistency of population data sources

For drought and wildland fires, the biggest issue of most reports was the lack of data availability on specific at-risk populations. While this group can receive the brunt of drought impacts, it is still impossible to quantify these individuals affected and to what extent. Population vulnerability to disaster exposure can be quantified using synthetic populations along geographical and demographic dimensions if the source data to build the synthetic dataset is accurate and complete.

Some reports indicated the inconsistency among population data sources. A source of consistent microdata and direct records is necessary for developing rescue and emergency response tools. Although U.S. Census microdata is adequate to generate synthetic population datasets with geographical and health vulnerabilities, the accuracy of subcensus divisions with neighborhood level granularity needs to be improved with additional sources of data, likely from regional authorities. In addition, health condition data from the CDC is only available as aggregate statistics. Canada Census Microdata was unavailable, and only demographic statistics had to be used.

7.2. Lack of adequate fire spread and smoke plume models

A significant limitation to computing population exposure and vulnerability to wildfires was the lack of a spread model that calculates the likely edge movement in terms of direction and speed. Using satellite data from Copernicus poses limitations as it has low resolution and does not count for the effect of wind. On the other hand, using higher-resolution data can increase the amount of storage needed by several orders of magnitude, which would degrade the performance of the service and its usability. The appropriate cloud storage, such as Geoparquet or ZARR, has been recommended.

In addition, no smoke plume model was available, which would have a considerable impact on the population with asthma and COPD and on the closure of road segments due to smoke. It would be strongly recommended to incorporate specific components that implement such models for future work.

7.3. Limitations of routing standards and data for evacuation calculations

The evacuation routing engine did not use the draft OGC API — Routes standard as the use case in this Pilot involved a route generation by the application backend (for estimated exposed areas) and not directly by the user. On the other side, the OGC Route Exchange Model was used as the format to generate and publish routes and proved adequate for the purpose. As a suggestion for the Routes Standard Working Group, this pilot could be analyzed as a use case to consider adding functionality for OGC API — Routes to act as a repository of routes generated by a third party or an internal process.

Due to limitations in Open Street Map datasets in terms of road speed limits and local traffic rules, it is necessary to make adjustments to road data to account for traffic behavior in rural and urban areas. Machine Learning can be used to assign estimated speed values based on road hierarchy, approximate boundaries of urban and rural areas, and other parameters. In addition, human behavior during evacuations was not taken into account, and additional adjustments to model evacuation patterns due to human factors would be advisable.

7.4. Importance of detailed, robust back-end coding

In APIs that use near-real-time data for drought, changes in the inputs by the data provider can sometimes lead to a crash of the underlying code and consequently impact the front-end delivery. Spending time to ensure more preprocessing ahead of time to generate more extensive clauses in the code to work with can reduce the work required downstream by client applications. However, in general, APIs tend to be more robust and require less source-specific coding than older delivery methods such as FTP.

Basing front-end implementations on open-source code allows for re-use rather than starting from scratch. As the OGC API standards develop and are approved, implementations can be used as reference material.

Additionally, the availability of long-term predictions of precipitation and temperature are a critical ingredient in generating forecasted crop suitability maps.

The Disaster Pilot 2023 Engineering Report also emphasizes the importance of participation and interactions with users via web client and citizen science tools for best practices in updates to the existing tools.

7.5. Considerations related to climate service ARD and related indicators

Vector point time serie grids with environmental variable values were found to be a useful Analysis Ready Data (ARD) representation of climate model data cube outputs. OGC API's such as Features were sufficient to feed these results to indicator components.

In some cases, multiple environmental variables merged into the individual location time step points in the relational database was preferable to having a only separate layer for each environmental variable. This allowed combined queries for different environmental variables. This supported a query for a specific temperature and precipitation ranges rather than having to do separate queries and then somehow combine the results afterward. While it involved more preprocessing ahead of time and generated a larger database, it reduced the size of the data response and the work required downstream by client applications.

A simple normalization of changes or trends in key environmental variables was a good first step in looking for regions and times where drought or flood risk may be increasing or decreasing. The normalization approach used involved dividing the projected precipitation by the mean historical precipitation for that location, where 0.75 represents a 25% reduction in precipitation for that location relative to past mean.

There is typically a trade-off between time series resolution and performance. This pilot used monthly time step climate model data inputs. This was deemed to be sufficient for drought modelling. Higher resolution time steps would likely be needed for heat wave, fire risk and flood risk modelling. Percipitation rate is important for flash impact flood assessment for example. This would require significantly more processing and data storage.

7.6. Machine Learning model suitability for different areas of interest

Some challenges were faced performing classification using a RandomForest machine learning approach. One challenge was that classes seen in different areas are not the same as in other areas. Furthermore, a model consisting of a decision tree trained for some specific areas may perform poorly in other areas.

7.7. Building a Digital Site Twin covering a large area

Building a Digital Site Twin on such a massive scale (representing 8400 square km) has been challenging. We faced numerous challenges while (a) processing the Digital Elevation Model and exporting a massive 3D mesh. (b) creating soil, vegetation, road network, and water body layers while maintaining optimum resolution, visual fidelity, and video frame rate.

Memory and GPU resources must be improved at such a large scale. A distributed computing environment is a possible solution.

7.8. Discovery, indexing and optimization of geospatial data from a diverse set of open data source providers

Many geospatial data sources were successfully integrated into the TerriaJS Hub through manual coding efforts into the environment to provide access to web processing systems from providers. However, a significant challenge arose when finding suitable representations for specific data sources in server-hosted files, such as ESRI feature layers and data from other servers. A substantial portion of the existing data points within catalogs related to disaster management often had broken links or were available only for download. Initially, the list of relevant data was much more extensive and the viable sources that were sought had to be reduced significantly. Scouring the internet for geospatial data in TerriaJS-compatable formats proved time-consuming. As data discovery becomes less arduous, it will reduce data entry barriers for users and decision-makers to utilize this open-source visualization platform.

The ArcGIS Hub data indexing process had challenges regarding the time taken to register individual data points. These must be manually added, including the metadata, thumbnail imagery, and source endpoints. It took extensive time to add 685 data items manually and required that each item in the ArcGIS Hub's content library were copied. Creating a duplicate of the data causes problems maintaining a data's provenance and authority. While Esri has an extensive library of authoritative data to browse online within their platform, it still faces the problem of new data-discovery and the time it takes to manually register new data that affects most other platforms if the data needed is not in Esri's library. The results conclude searching for new data affects all industries and data-discovery time needs to be reduced to shorten the workflow to registering new data.

Indexing from open sources in the the Voyager Search catalog and registry presented issues with a lack of data organization, enrichment and visual display where search optimization and data discovery shortcomings were present. Many of the open sources that were indexed in Voyager Search had poor spatial data infrastructure standards that included inadequate naming conventions from providers thus resulting in missing or misplaced data. In the cases where this issue was present, it negatively impacted the quality of the indexing done and the resulting search capabilities where the organization and display of data ultimately makes the discovery, acquisition and action on such data to be difficult to execute.

8

FUTURE WORK

8 FUTURE WORK

Wildland fire evacuation management of large groups has been proven feasible based on predictive models on the population impacted by a wildfire, the timeline, and the impact's severity. Knowledge of specific vulnerabilities and characteristics of population communities (e.g., mobility options, language, age demographics, smoke effect on population with asthma) is advantageous to applying extra resources or giving indications more efficiently during an evacuation. However, there is room for improvement by including better fire behavior models, more accurate local population demographics data, and more customizable road usability data by large groups.

For wildland fires, future improvements could include supporting multiple fires and calculating compounded vulnerability for the population affected, incorporating real-time fire spread models and smoke plume behavior by supporting all lanes available for one approach to increase traffic capacity. For drought, future development includes other parameters such as air and land surface temperature.

For drought, future challenges also include determining the response of plants to severe drought conditions. This response will vary according to the plants, i.e. a crop such as wheat will not respond in the same way as trees. Future developments should also focus on the production of drought health risk index forecasts across multiple years for long-term emergency response planning.

The OGC API could not be used for nested properties of evaluation indicators. That was because the complex JSON schema to support the properties of fire evaluation is not the intended use of OGC API. This can be addressed in future OGC API developments. Work is underway to improve this aspect in OGC API — Features starting with a *Schemas* extension part.

Future developments of drought and wildland fire emergency response are expected to move toward 3D representation of the models. OGC APIs need to become equipped to support such visualization formats for implementation. The draft *OGC API — Coverages* support multidimensional datasets, and the draft *OGC API — 3D GeoVolumes* allows access to 3D content either through Bounding Volume Hierarchies (BVH, such as i3s or 3D Tiles datasets) or through direct tile access.

To develop more indicators based on climate services ARD, considerable work remains to be done to develop business rules relevant to specific climate impacts. Domain experts should be consulted to explore what climate environmental variables, statistics, thresholds and value ranges are associated with increased risk from specific natural hazards. It would also be important to explore how useful are comparisons of forecasts to past historic trends, vs. absolute environmental variable thresholds for projected environmental variables such as temperature or precipitation. Also, approaches should be developed to incorporate higher resolution local data to better reflect local conditions and improve the local accuracy of future projections.

Public health indicators for drought and wildland fire can be expanded to incorporate various other drought and wildland fire related indicators along with taking into consideration the impact of the changing climate on the severity of adverse health outcomes from drought and wildland fires.

For classification purposes of large areas of interest, experimenting with deep learning using neural networks might yield better results than machine learning approaches such as classification trees. For the wildland fire fuel indicator, additional inputs and validation should be considered to improve the accuracy and usability of the predictions.

Engaging stakeholders and domain experts for obtaining feedback on key input data to consider for training and validating outputs would greatly facilitate improving the indicators.

In the future more effort should be made to incorporate real time sensor data into indicator development. This need was reflected in the firefighter first responder interview reviewed early in the pilot. This has also been a critical element in many disasters, the lack of which compounded the impacts of recent disasters such as the wildfires in West Maui in August 2023. Perhaps future pilot persistent demonstrators can have some indicators which incorporate real time sensors so that the indicators they serve up can actually provide a real time view of hazards or risks relevant to the pilot context. Any real time sensors should leverage OGC sensor web enablement standards such as SensorThings API in order to make the data services involved modular interchangeable and readily consumable by downstream applications.

As part of this pilot program, Duality has built the building blocks of a large-scale wildland fire simulation and visualization of various DRIs. In the future, this prototype can be extended to support diverse simulation scenarios and achieve multiple goals like (a) Acquire and manage simulation-ready digital twins of the real-world wildland fire assets: relevant environments, dynamic systems, and associated objects, (b) Customize modular scenarios, © Run real-time, physics-accurate, deterministic simulations of complex real-world scenarios on massive scales with vast numbers of machines and agents, (d) Control every part of any simulation, even at runtime, with Falcon’s flexible Python API, (e) Generate accurate behavior and high-fidelity sensor data with a library of configurable simulation-ready sensors and (f) Simulate in the cloud and collaborate globally with internal and external partners without computing resource limitations.

Further development of the TerriaJS, ArcGIS Disaster Hub and Voyager Search data catalogs and registries is ongoing with continued indexing from open data sources around the world as well as improvements to the UI/UX and to the discovery, profiling, delivery and enrichment of the indexed geospatial data. This continued work will enhance search optimization, improve user experience and allow for more accurate, informative and readily available data for disaster-related stakeholders.

9

SUMMARY AND CONCLUSIONS

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The overall aim of Disaster Pilot 2023 was to implement workflows that can facilitate decision-making and collaboration in the context of a disaster response, and to demonstrate their benefits. This pilot successfully studied several case scenarios, such as wildland fire fuel, emergency wildland fire evacuation plans, drought severity indicators, and crop suitability estimators.

Areas of study from the U.S. (blocks in Fish lake, Utah, California, Arizona, Hawaii, Washington and Colorado), Italy, and subdivisions in Canada (Manitoba) were studied for wildland fire and drought studies.

Collaborative workflows can identify vulnerable populations in drought and wildland-affected areas.

For drought, work has been done on identifying and analyzing vulnerable populations in a drought-impacted area using a weighted combination of the factors that combine public health information and geographical information. This activity successfully achieved a drought health risk index for Manitoba, Canada.

With regards to the drought health risk index, future efforts can be on incorporating predicted changes to drought extent and severity due to climate change on the health risk index. The effort can also enhance the interoperability among participants and stakeholders through further collaborations.

In addition to using sensors and satellite data for temperature, humidity, air quality, and monitoring health conditions, citizen science technology in drought and wildfires is essential for real-time emergency response and informing stakeholders and first responders. Manitoba user community can use Ella to design other survey forms and distribution for fast and timely response to drought-affected areas. Citizen science can significantly reduce wildfire risks and boost resilience. It enables public monitoring of wildfires, providing valuable data to scientists and emergency personnel.

The wildland fire fuel indicator provided an opportunity to demonstrate several new OGC API capabilities such as filtering out unsuitable cells and remapping vegetation types through derived fields using the OGC Common Query Language (CQL2) expressions with coverages. The indicator's workflow also demonstrates OGC API *collections* as input and output of a process, with the indicator itself presented as a virtual collection triggering the necessary processing on demand for data requests. The indicator implementation also makes use of a streamlined coverage request accessing a single ARD collection which is implemented as a frontend to millions of Cloud Optimized GeoTIFF (COG) sentinel-2 data scenes and granules described using SpatioTemporal Asset Catalog (STAC) from the AWS cloud.

Wildland fire evacuation indicator showed the feasibility of introducing synthetic population generation in disaster management to produce fine grained distributions of demographics and health vulnerabilities of population exposed to the evolving disaster. This is a powerful tool to inform emergency responders about tactical and strategic evacuation plans based on the impact suffered from wildfire exposure and the expected assistance required to evacuate in a timely and safe fashion. The evacuation workflow produced indicators such as evacuation prioritization, expected time to evacuate, extra transportation needed, and best evacuation route. It also demonstrated how an agent in the field can change conditions of the fire or road network to recompute evacuations under the new environment.

Disaster management and community planners need to be able to evaluate the resilience of their plans against a range of possible future climate scenarios. By making climate model outputs, such as NetCDF data cubes, more accessible to common analytics platforms typically used by planners (GIS), indicator components can help shed light on what local trends to expect in the future based on various climate model scenarios. This was successfully demonstrated in the Drought Severity workflow and Climate ARD data service component. Tools such as this can help the stakeholders responsible for managing disaster and climate impacts more easily access and interpret the potential risks associated with climate change in their local context.

Climate projection primary indicators can support secondary sophisticated drought models to make more precise projections about possible future drought risk which neither indicator could do on its own. This type of indicator chaining is crucial to build comprehensive views of disaster and climate risks over time at the regional and local scales. Also, the principle of using primary indicators to drive secondary indicators is also important in that it allows a wider range of indicators to be developed without each indicator recipe having to encompass the entire analytical workflow on its own. Also, one primary indicator like projected precipitation may be able to support multiple secondary indicators such as drought, flood and fire.

Geospatial data catalogs and registries help offer insightful and actionable information for stakeholders on a wide variety of use cases including monitoring, response, mitigation and prevention for disasters such as wildfires and droughts. The search and visualization tools developed have the potential to be utilized by first responders, citizen scientists, government officials, and the general public for augmented data collection and analysis, enhanced decision making as well as risk model generation that can have significant social, environmental, political and economic benefits which further promotes a more resilient and sustainable future for humanity and the natural environment.

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