

Web-Based Data Access and Analysis Workbench to Support Environmental Restoration Decision-Making

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Seminar Overview

Objective: Discuss web-based software for accessing and analyzing data in support of environmental decisions



Challenge: Tools for environmental data access and analysis are required to meet needs for consistency, quality, communication, and decision-making.

Approach: Web-based software provides rapid access and analysis capabilities for disparate data from multiple sources.

Impact: Web-based tools effectively provide consistent analyses to support quality requirements and remedy decisions for complex sites.





Outline of Discussion

- What is the nature of environmental data?
- Approaches to software tools for analysis
- Web-based applications using cloud computing infrastructure
- Analysis as support for decision making
- Web-based approaches for data visualization
- Web-based approaches for data analytics
- Conclusions, benefits, broader perspective







Disparate Data Sources

- Data inherently comes in different forms and format
- Data access varies among organizations
- Common when multiple agency and organizational projects are participating
 - Overlapping "authoritative" data sources



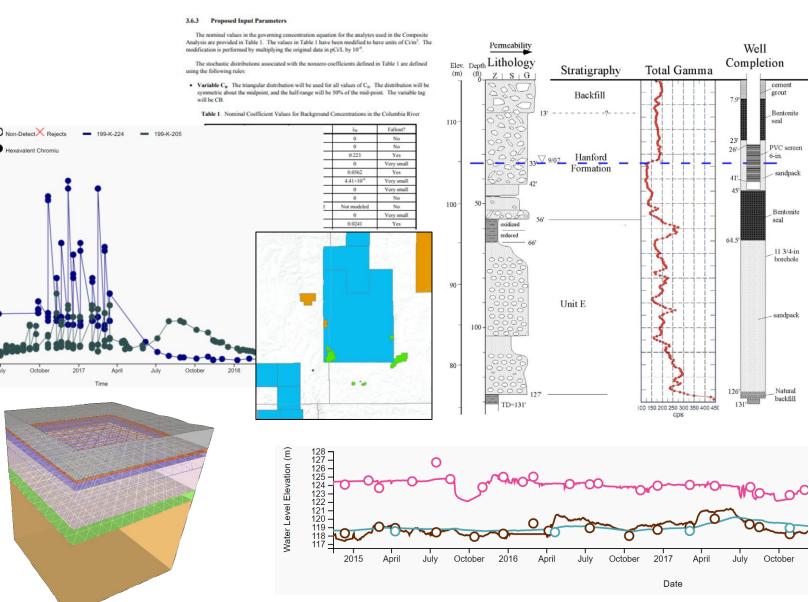




Environmental Data Types/Sources

- Electronic Tabulated data
 - Analytical chemistry
 - Well or waste site information
- Information from reports
 - Tables, figures
- Well log or geophysical data
- Sensor data
- Spatial data
 - Points, polygons
- 3D model information
- Satellite/remote sensing
 - Images, datasets



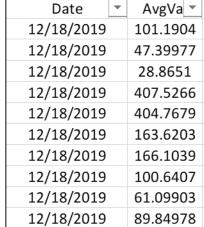




Nature of Data

- Impacts storage, access, and manipulation
- Structured data
 - Data fields in a record
 - Tabular data
 - Typically stored in a relational database
- Semi-structured
 - Non-tabular
 - Uses markers to separate semantic elements and enforce record/field hierarchies
 - e.g., JSON
- Unstructured
 - No pre-defined model/organization
 - e.g., text documents, audio, sensor data, etc.





"scenarioTitle": "Inga Sit "analysisConfigurationAlgo "aquiferPorosity": { "title": "Aquifer Poro "value": 0.3 }, "aquiferThickness": { "title": "Aquifer Thic "value": 100, "units": "ft" },

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| 1.755548 | 411.603 | 403.2118 | 85 |
| 1.518011 | 408.2755 | 399.7396 | 86 |
| 0.416473 | 164.3519 | 162.2685 | 78 |
| 0.432044 | 166.8981 | 165.0463 | 87 |
| 0.102121 | 100.8391 | 100.4051 | 72 |
| 0.126984 | 61.34259 | 60.65538 | 79 |
| 0.101705 | 90.09694 | 89.62674 | 78 |



Quality Assurance – Data and Software

- Data provenance
 - How, where, when, why, and by whom was the data was produced
 - Key information for trust, credibility, and reproducibility of data and results using that data
- NQA-1
 - ASME Nuclear Quality Assurance standard
 - Structured program of procedures
 - ► Evaluating, reviewing, and documenting data and calculations
- Key quality concepts:
 - Traceability
 - Reviewing the work
 - Software requirements and testing









Traditional Approaches to Software Tools

- Traditional
 - Compiled executable for desktop
 - Microsoft Excel-based tool
- Issues
 - Installation on desktop/mobile platforms
 - Users need to have specific software (Excel)
 - Potential version issues
 - Less flexible data access
 - Less flexible geospatial functionality
 - Indirect sharing of results



| | | | | SI | /EET2 (Soil Vapor | Extraction End | state 1 | (lool) | | | | |
|---|--|--|--|-------|--|--|---|--|---|--|---|--|
| arameter | Permissible | | | | escribed in: SVEET2 User Gr | | | | | | | 2020-5 |
| Name | Range | Key Values and Notes | | | | | | | | | | |
| T | 5-99 | 20 | | Us | er Input - Source/Tran | sport Parameter | s | | | | | |
| R | 0.4-15 | 0.4 | | | | Scenario Name: | - | Case A | Case B | Case C | Case D | Case E |
| ω | varies* | Sr key value equivalents * | | | | Contaminant | - | CT | TCE | TCE | | |
| Burlar | 0.1-0.5° | 0.3 | | | T | Temperature: | [°C] | 19.6 | 20 | 20 | | |
| Phult | 1.1 - 2.0* | 1.855 | | | R | Avg. Recharge: | [cm/yr] | 0.5 | 0.5 | 0.5 | | |
| VZT | 3 - 150 | 3, 10, 30, 60, 110, 150 | | | ω Avg. Soil 1 | Moisture Content: | [wt %] | 8 | 1 | 1 | | |
| 41 | varies* | - | | | Protai | Total Porosity: | [] | 0.3 | 0.3 | 0.3 | | |
| Z | varies ^d | - | | tes (| Doute | Dry Bulk Density: | [g/mL] | 1.8 | 1.8 | 1.8 | | |
| w | 10-100° | - | | | | Zone Thickness | [m] | 60 | 30 | 30 | | |
| q | 0.005 - 1.0 | 0.005, 0.03, 0.3 | | | L1 Depth | to Top of Source: | [m] | 40 | 21 | 21 | | |
| \$ | 1-30 | 5 | | | | Source Thickness: | [m] | 10 | 5 | 5 | | |
| d | cc1-850 | cc = 1.75 to 7.5 | | W | | Width (= Length): | [m] | 50 | 15 | 15 | | |
| | | Values < 0 are upgradient | | | | | [m/day] | 0.3 | 0.165 | 0.165 | | |
| dx | -850 - 850 | of source center | | | | ell Screen Length: | [m] | 5 | 10 | 10 | | |
| dy | 0-370 | - | | | | Compliance Well: | (m) | 25 | 50 | 50 | | |
| dz | 1.0 or 4.0 | sub-slab or sub-basement | | | dx Longitudinal Dist | ance for Soil Gas: | [m] | 20 | 30 | 30 | | |
| | 0.001 - | | | | dy Transverse Dist | ance for Soil Gas: | [m] | 20 | 20 | 20 | | |
| $C_{\mu\nu}$ | 100000 | 159 | | | dz Depth of Base | ment/Foundation: | [m] | 1 | 4 | 4 | | |
| 144 | | From STOMP simulations | | | | ength input Type: | - | Gas Concentration | Gas Concentration | Mass Discharge | | |
| Mart | 0.1 - 40000 | at 3 months elapsed time | | 1 | | as Concentration: | [vmqq] | 159 | 50 | | | |
| he pre-mode | led scenarios u | se residual saturation (Sr), not | oravimetric | | and the second se | Mass Discharge: | | | | 10 | | |
| oisture cont | ent (u). Howe | ver, percent gravimetric moisture | content is | | ing overed | mass orsenarge. | [9-00)] | | | 10 | | |
| | | or for user convenience. The key va Moisture content is constrained to the | | | | 2.2 < particle density | 2.0 abol | | | | | |
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(Truex et al., 2013; Johnson et al., 2021a)

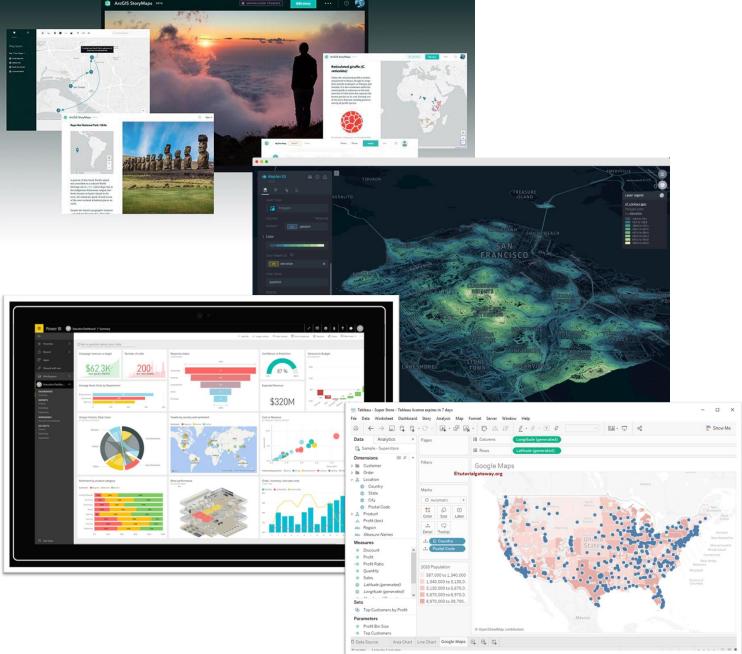
PNNL Custom Development vs Commercial-offthe-Shelf (COTS) Platforms

Geospatial based

Pacific

Northwest

- Esri ArcGIS Online
 - ► Intuitive, programming knowledge not required
 - Free and subscription-based hosted applications
- Kepler.gl
 - Open-source geospatial analysis tool for large data sets
- Analytical with some geospatial
 - Power BI
 - Tableau









Use the Approach that Fits the Need

- Spreadsheet tools are suitable when
 - Users have the spreadsheet software
 - Quick development is needed
 - Familiar interface is useful
 - External data and geospatial needs are minimal
- Use exploratory data analysis when
 - Very little is known about the data
 - Objectives are vague mainly about data capture and discovery
- Power user type tools used when
 - Analytics are independent and fragmented
 - Expertise in the tool already exists
- But...web-based applications have advantages





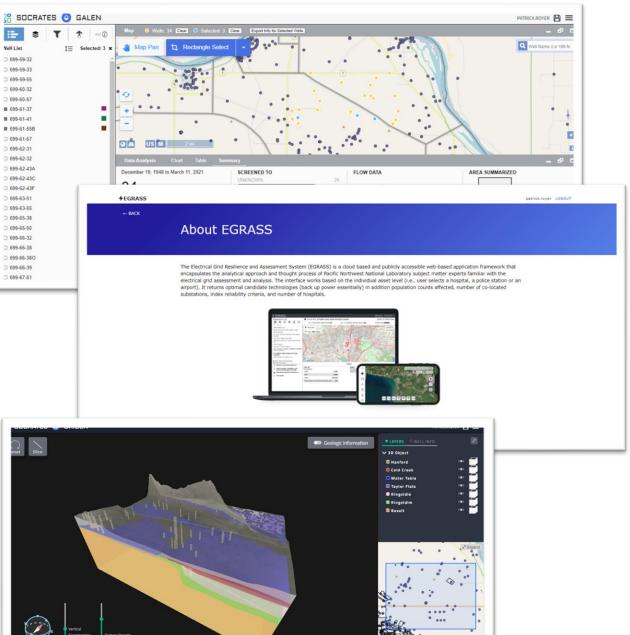


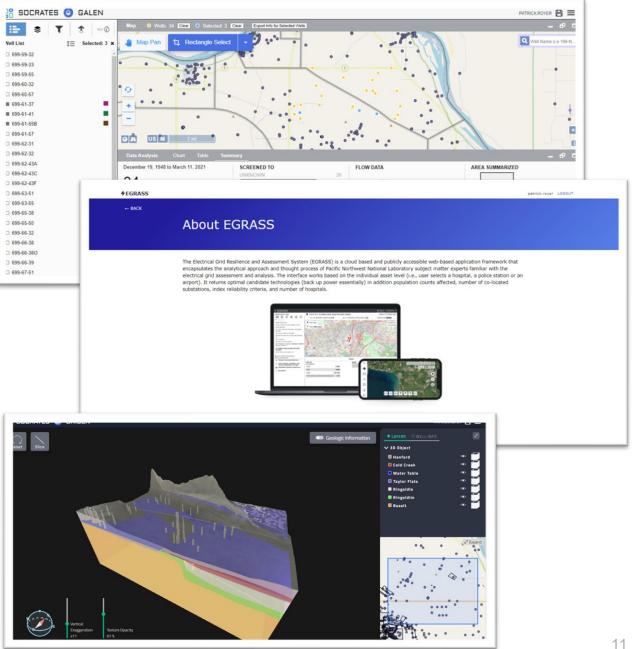
Web-based Applications that Leverage a Modern Cloud Approach

- Domain knowledge coupled with computational and development expertise
- Custom web applications with emphasis on cloud-based architecture
- Managed cloud services
 - AZURE, AWS, and Google Cloud
 - ► Government, Gov Cloud
 - Support from internal cloud team to guide application developers
- Modular and extensible platform translated to different domains
 - Environmental management
 - Electrical grid emergency and response
 - Chemicals of mass destruction throughout Asia











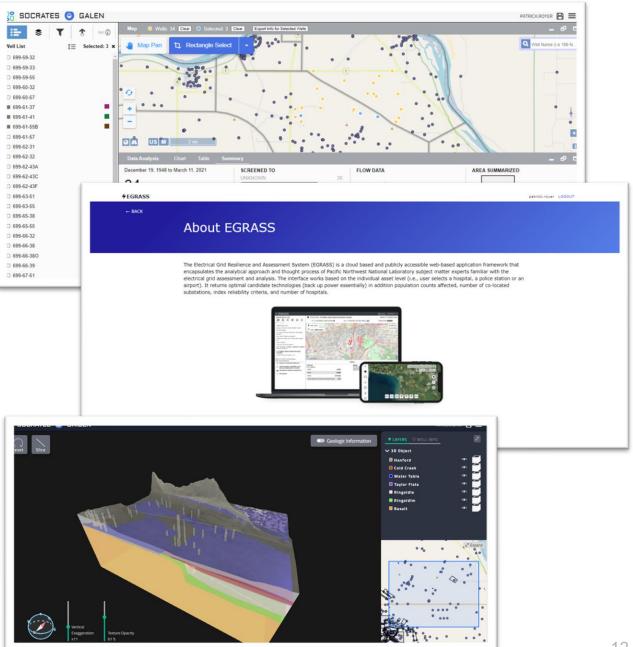


Web-based Applications Leveraging Modern Cloud Approach

- Targeted vertical applications
 - Meet enterprise-scale analytic objectives
 - Extensive user experience (UX) and user elicitation outreach
 - Tightly coupled with regulatory requirements
 - Transferable to different cloud accounts
- Build and deploy modern, focused analytic and data services
 - Analysis as a Service (AaaS)
 - Data as a Service (DaaS)
- Role based access and profile management









Migration to Cloud? Shifting to Cloud Architecture with emphasis on Serverless

Authenticate (Set JWT)

> Traditional REST andpoint to meet

</>>

Landes

- Serverless computing
 - Machine resources allocated on-demand opposed to virtual machine paradigm
 - Cost-effective
 - Maintenance assumed by cloud provider and customer
 - Elastic scalability
 - Improved productivity
- When to use virtual machines
- Implications for migrating from an on-premise server to the cloud
 - Legacy to modern –"lift and shift"











Amazon Web Services (AWS) Components

- S3 Simple Storage Solutions
 - File storage "bucket"; shared access, like FTP
- EC2 Elastic Cloud Computing
 - Virtual machine; can be used for automated processing
- Lambda serverless compute service; automated processing
- RDS Relational Database Service
 - e.g., SQL Server
- DynamoDB unstructured/noSQL key-value data
- Cloudwatch monitoring services & applications
- Cognito authentication and user management















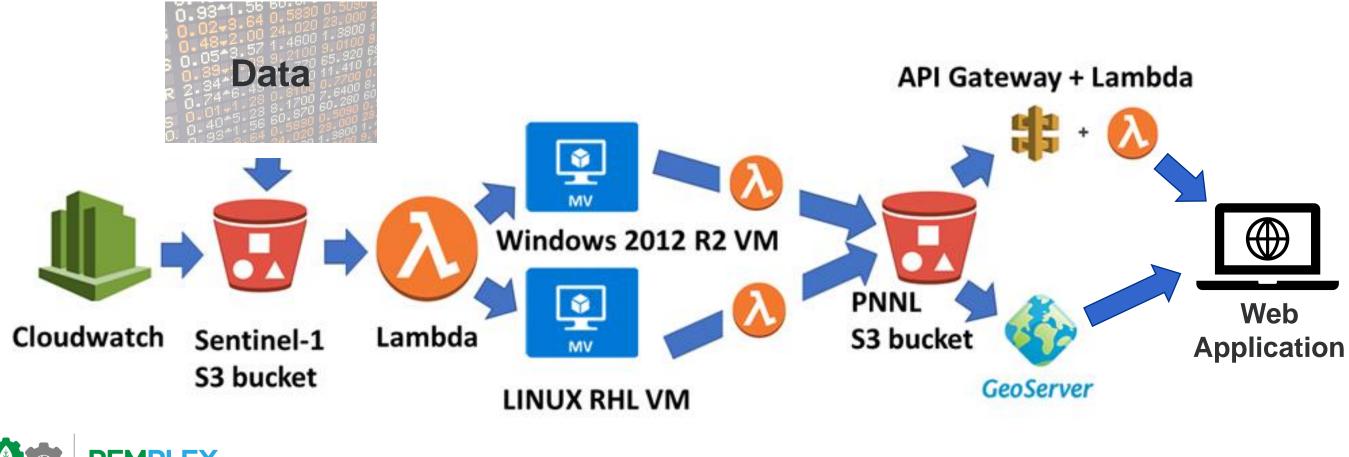
Amazon DynamoDB





Automated Workflow Example

• AWS and cloud architecture for automating complex, multistep workflow







Exposing the Application Programming Interface (API) Directly for Power Users

- Combining role-based access with varying data solutions and direct API access
- Data integration and assimilation
- Custom, input-driven API
- Facilitates collaboration between organizations

| NDPOINT EXPLORER (Select an Endpoint) | Endpoint: calculateFragilityCurv | ves | | | | |
|--|---|---|--------------|--|--|--|
| calculateFragilityCurves | Info: | | EDIT | | | |
| getAllItemsInMongoDBCollection | Calculates fragility curves based on a Route: | database. | | | | |
| calculateFragilityCurves | api/dynamicContingencyAnalysis/cal | IculateFragilityCurves | | | | |
| getDynamicContingencyAnalysisAssets | Parameters: TEST | | | | | |
| getPointOfInterestIndex | returnResultsInCall: | | | | | |
| calculateFragilityCurvesFromInputs | storeResultsInS3Bucket: returnAsCSV: | | | | | |
| getPointOfInterestData | s3OutputID: | fragilityCurveOutputAllSubstationsAndTowers | | | | |
| calculateFragilityCurvesMonteCarlo | | | | | | |
| getTechnologyIndex | | | | | | |
| getDynamicContingencyAnalysisCalculate | | | | | | |
| getCategoryIndex | | | | | | |
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| | mounes | | | | | |
| | - | | | | | |
| | Recovery | | | | | |
| | Extract near real-time implementation of expert judgement rules used to identify optimal back up power sources for recovery of critical end use | | | | | |
| | loads, which include hospitals, police stations, drinking water treatment plants and ports. This module has enables users to query and interact with relevant geospatial data such as point based population estimates and electrical grid topology. It is also used to display reliability indicators by | | | | | |
| | | to Rico power authority. This includes The System Average Interruption Duration Index (SAIE | | | | |
| | Average Interruption Frequency Inde service. | dex (SAIFI), Customer Average Interruption Duration Index (CAIDI), and total number of cl | ients out of | | | |
| | service. | | | | | |
| | Storm Analysis | | | | | |
| | Simulate storm impact on critical grid infrastructure from NOAA storm track and storm database. This module estimates windspeed at critical | | | | | |
| | | illure probability for each asset along storm track. Users can refine temporal resolution from 1 information at the respective time lap. This module also includes more sophisticated Monte Ca | | | | |
| | predicting outage period. | | | | | |
| | Endpoint Explorer | | | | | |
| | | rithms for the EGRASS platform and limited set of Sandia National Laboratory algorithms and | | | | |
| | | data that is natively stored in EGRASS database or upload files into share folder to run algorit I to sharing and socializing our analytical approach with collaborating entities. It enables more | | | | |
| | alignment between datasets and app | oproach and is more in line with modern data era data as a service (DaaS) and analytics as a | | | | |
| | also enables the user to integrate di | ifferent analytics in a stream lined workflow which vary from the user interfaces provided. | | | | |
| | | | | | | |
| | File Share | of Amazon Web Services Simple Storage Solution (S3). Access and permission are managed w | | | | |



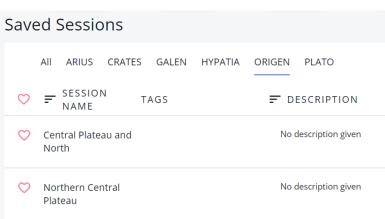




Profile Management

- User login allows user-specific customization
- Control user access based on role, organization, etc.
 - Data access
 - Functionality
 - Pre-defined styles
- Define and maintain user-specific options
 - Favorite contaminants, waste sites, etc.
 - Colors, styles, analysis options, etc.
- Save scenarios
 - Record of work, reproducibility
 - For sharing with colleagues





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| 01/26/2021 | ORIGEN | Open Delete Share |



Analytics for Environmental Decision Making

- Web-based applications provide
 - Availability, convenience, rapid assessment
 - Consistency and reproducibility in analyses
 - Inter-operability of tools and data
 - Vehicle for communication with technical, management, and regulatory personnel
 - ► Sharing, reporting
 - Basis for supporting environmental decisions
 - ► Feeds into approaches such as adaptive management of complex sites
- Examples of tools to support decision making
 - Analysis based on published guidance (e.g., EPA) and standard statistical methods
 - Data access and visualization
 - Rapid data analytics



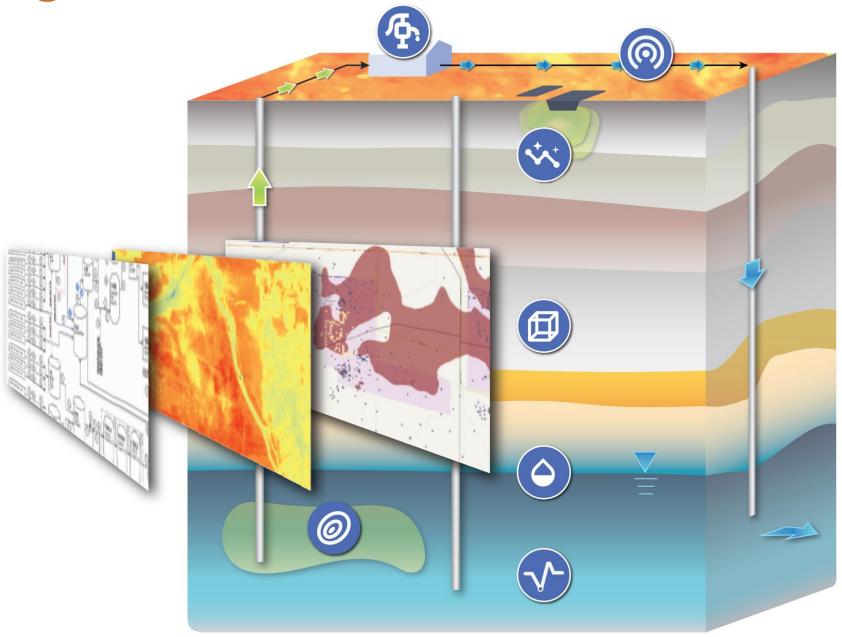




Web-based Tools for Environmental Decision-Making

- Environmental aspects
 - Groundwater
 - Wells
 - Waste sites
 - Remedies
 - Remote sensing
- Supports
 - Exit strategies/endpoints
 - Optimization
 - Adaptive remedy decisions
 - Decisions related to protecting human health and the environment



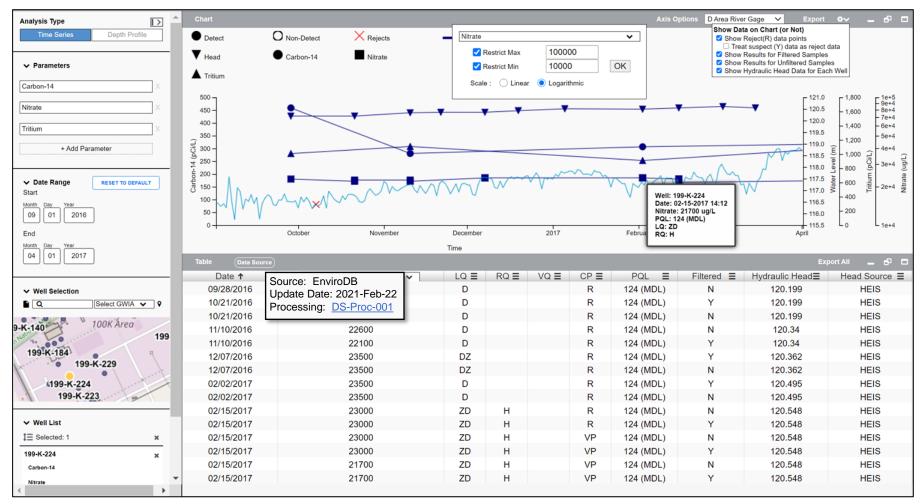




Access and Visualization of Groundwater Data

- Time series and depth profile visualizations
- Show data in chart and table
 - Multiple measured parameters
 - Specified time frame
 - Filtering based on attributes
- Water table/river levels
- Export figures/data for reporting
- Used in context of remedy and guidance (e.g., EPA, 2013)



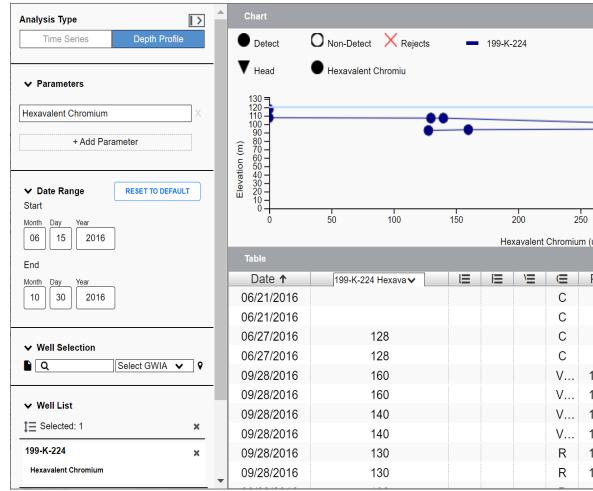




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Depth profile information – can help target optimization or adaptive remedy approach

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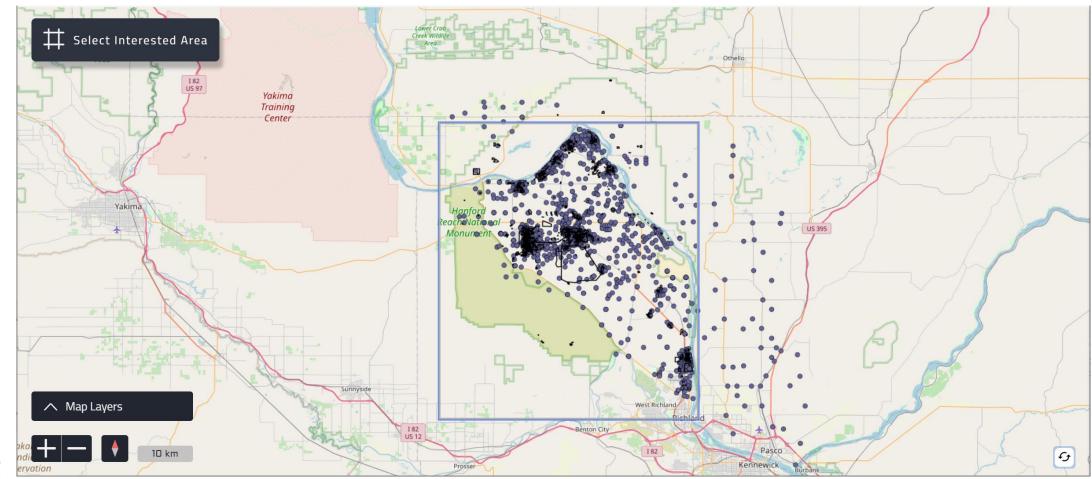
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Access and Visualization of 3D Geology

- Hydrogeological units
- Point elevations
- Cross section viewer
- Well construction information
- Link to other tools
 - Provides relevant context





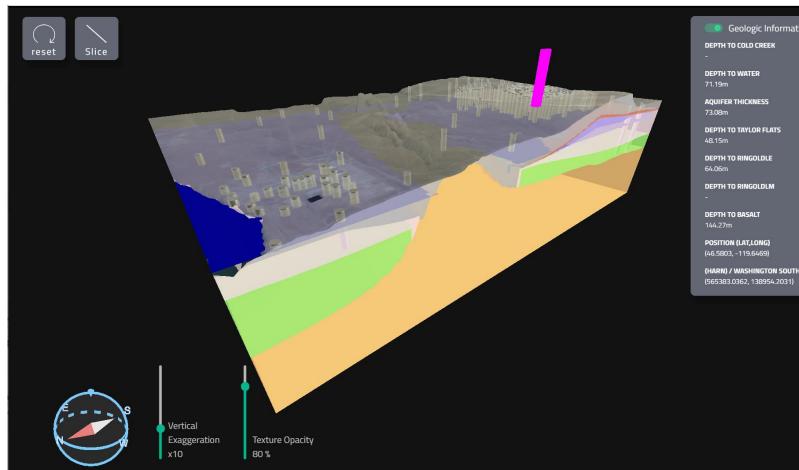




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Geologic Information

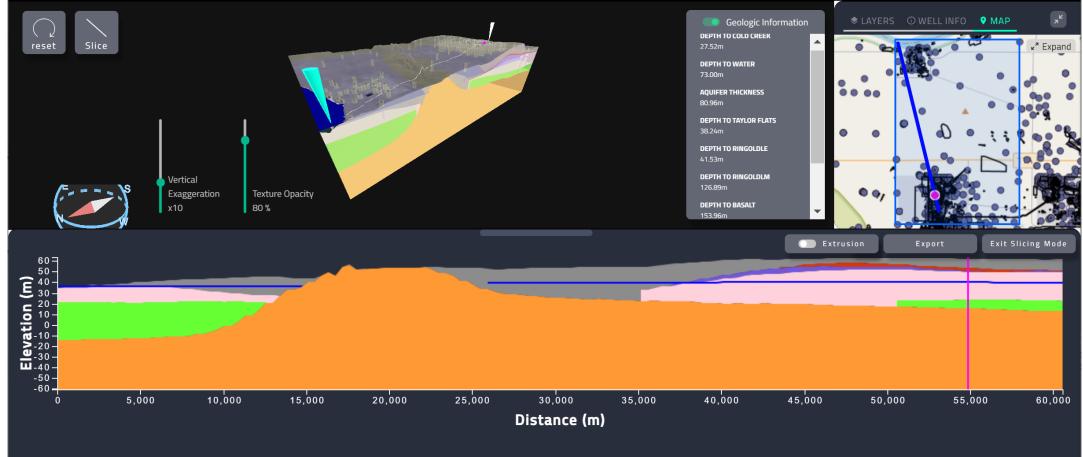
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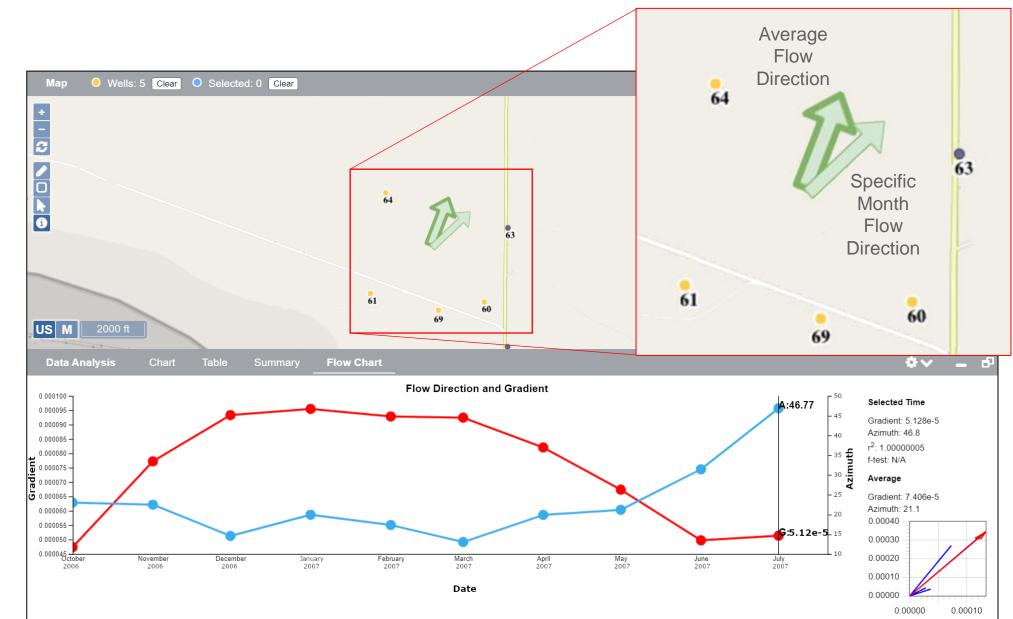


Analysis of Water Level and Flow Direction

- Groundwater elevation data
 - Key for plume understanding
- Where is contamination going?
- What seasonal effects exist?
- How fast is water and contaminant migrating?









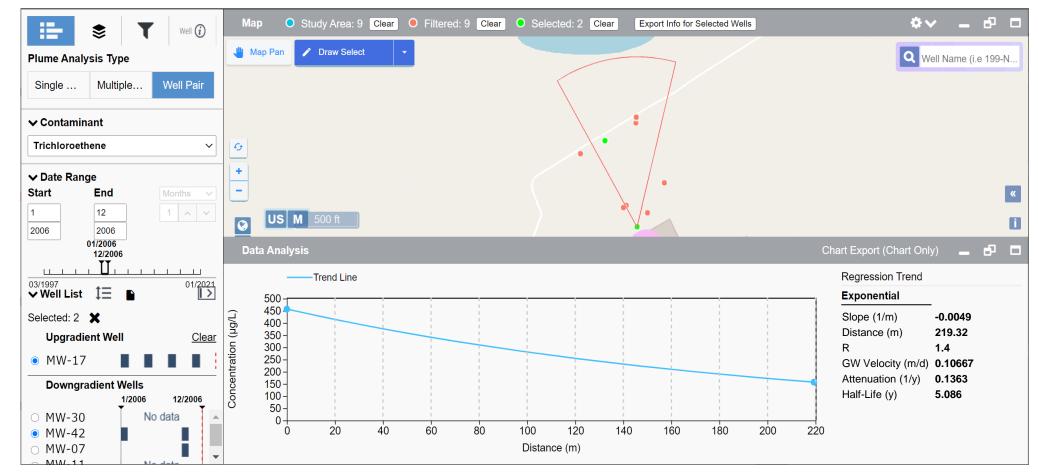


Attenuation Capacity Analysis

- Contaminant attenuation capacity?
 - Attenuation zone between source and compliance point
 - Distance/time and attenuation
 - Under natural conditions
- Threshold source concentration
 - Or max. mass flux
- Based on guidance
 - EPA, 2002; Truex et al. 2015



@PNNI



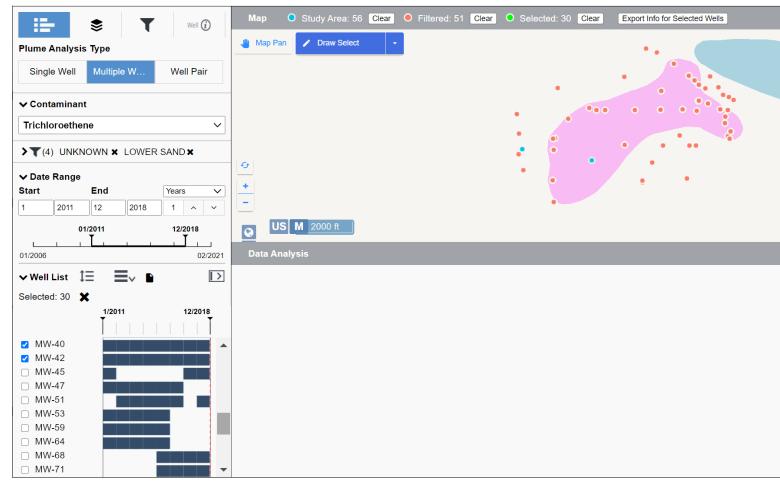
Compliance point is about twice the distance, say 400 m Compliance point target concentration = $5 \mu g/L$ Thus, attenuation capacity \rightarrow source concentration must be 35.5 µg/L to meet target



Plume Analysis

- Plume behavior over time
- Temporally consistent well set
- Trend/ attenuation
- Is remedy working?
 - Optimize? Done?
- Based on guidance
 - EPA, 2002; Truex et al. 2015





Wells sampled at different times (different temporal patterns)

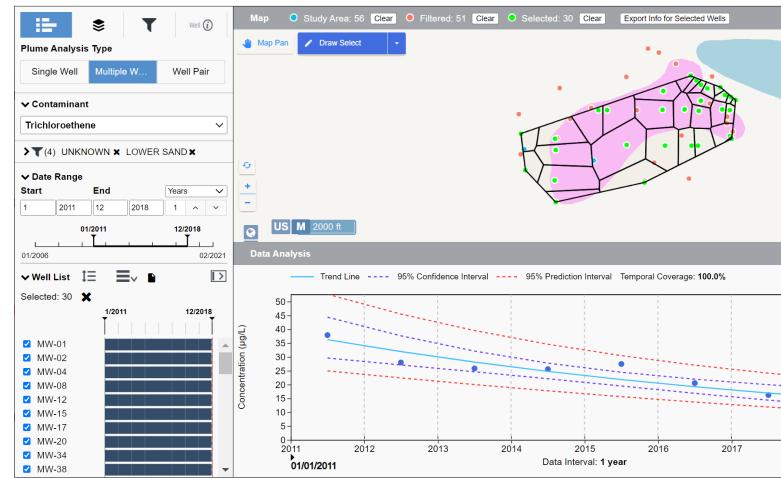
¢∨ _ ₽ ¤ Q Well Name (i.e 199-N. Chart Export (Chart Only) 🌣 🗸 🗕 🗗 🗖



Plume Analysis

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| | | *~ _ 0 0 |
|------------|----------------------------|-------------------------|
| | | Q Well Name (i.e 199-N |
| | | |
| | | |
| | | |
| | | |
| | | « |
| | | 0 |
| Ch | art Export (Chart Only) | *∨ _ 6 ⊡ |
| | Regression Trend | |
| | Linear | Exponential |
| | Meaningful slope? | Yes (p = 6.8e-4) |
| | Slope (1/yr) | -0.1267 |
| | r ^a | 0.8726 |
| | Mann-Kendall Trend | Desmassing |
| | Trend Kendall's tau | Decreasing -0.8571 |
| •••••••• | RSD (COV) | -0.8571 0.3149 |
| | M-K Confidence | 99.9% |
| | *Note: Calculations a | |
| 2018 | nondetect values as | reported |
| 12/31/2018 | | |
| | | |

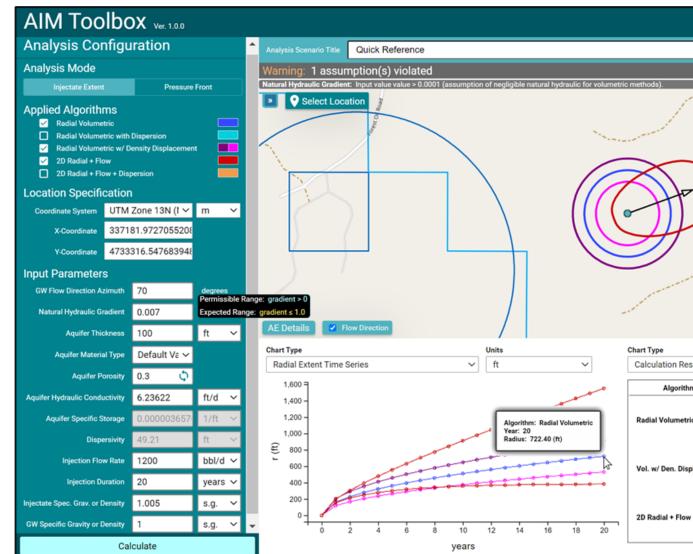


Aquifer Injection Evaluation

- Injection of produced water (typically a brine)
- What is the radius or area of impact?
 - Displacement
 - Dispersion
 - Groundwater flow
 - Density differences
- Used for assessing aquifer exemption applications



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Aquifer Injection Modeling Toolbox – set of analytical models (Johnson et al., 2021b)

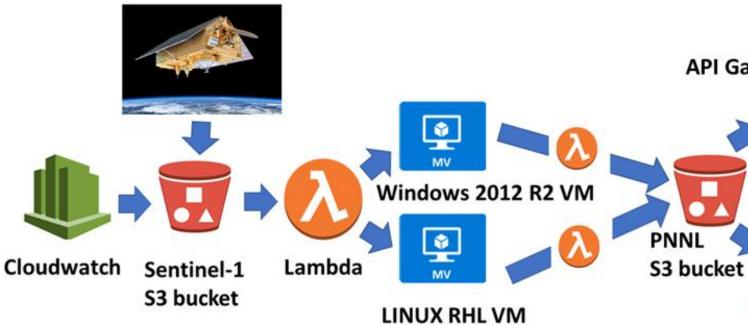
Show Info Panel Calculation Results Table ✓ ft Radius, Major/To Radius, Minor/Bo Area 722.40 ft 0.06 mi² 529.35 ft 916.17 ft 0.09 mi² 1551.01 ft 382.60 ft 0.06 mi²



Remote Sensing Analyses

- Satellite, airborne data
 - Automated processing
- Thermal data to assess groundwater flow into river
- Subsidence
 detection
 - Automated alerts





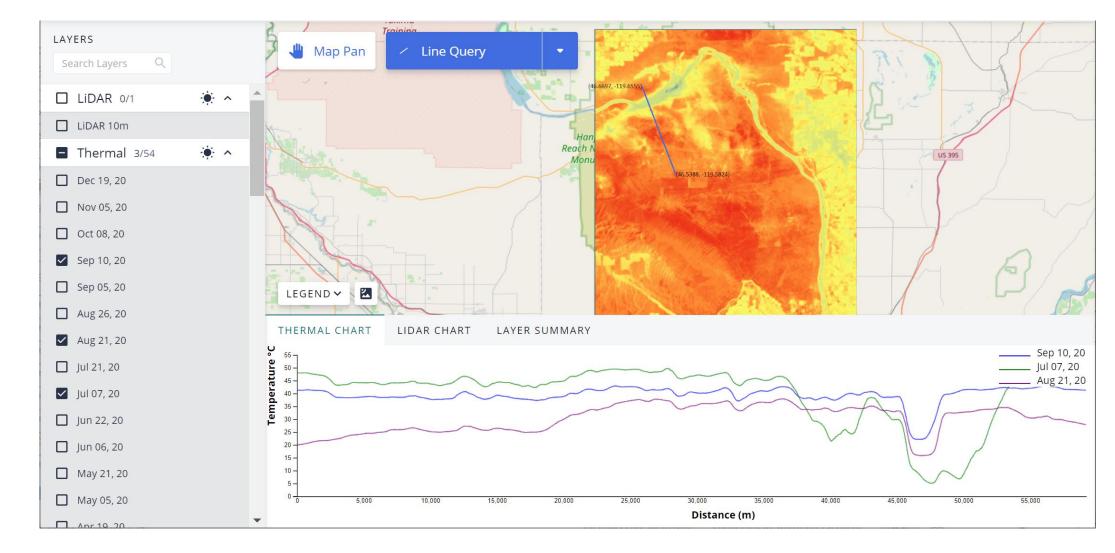
API Gateway + Lambda



Remote Sensing Analyses

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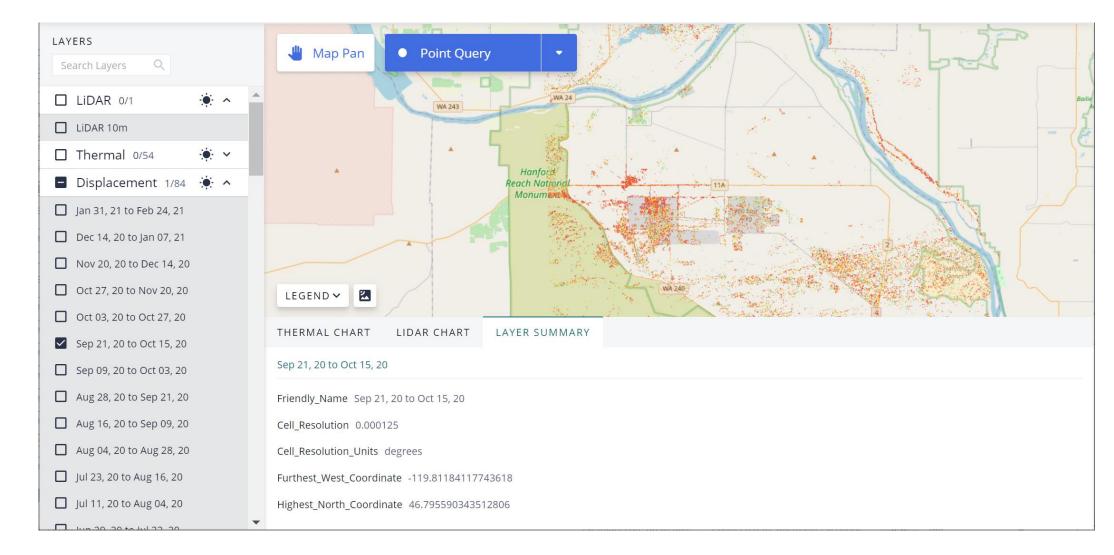




Remote Sensing Analyses

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Conclusions and Benefits

- Environmental professionals and managers need tools
 - Access to environmental/remedy data
 - Consistent and quality-approved approaches for analysis
 - Communication with other technical, management, and regulatory personnel
 - Supporting remedial decisions
- Web-based applications for subsurface remediation and long-term management
 - Minimize complexity associated with large data sets and analytics
 - Maximize consistency and productivity
 - Promote technical communication through sharing, reproducibility, and availability
 - Provide robust and reliable performance
 - Provide a technical basis for environmental decision-making





Impact and Broader Application

- Data management resilience/adaptability
 - Large volumes of data (e.g., satellite, sensor, climate)
 - Variety of analytics
 - User experience adapting to changing human interaction patterns
- Cloud computing/serverless architecture
 - Robust and rapid analytics from analytical methods to complicated machine learning
 - Big data processing
 - Integrating disparate data types, relational and unstructured data
- Web-based tools can support decision making in a range of contexts
 - Water and other natural resources
 - Climate resilience
 - Disaster response





- EPA. 2002. Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies. EPA/540/S-02/500. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, Ohio.
- EPA. 2013. Guidance for Evaluating Completion of Groundwater Restoration Remedial Actions. OSWER 9355.0-129, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.
- Johnson, C.D., K.A. Muller, M.J. Truex, G. Tartakovsky, D.J. Becker, C.M. Harms, and J. Popovic. 2021a. SVEET2 Final Report. ESTCP Project ER-201731, U.S. Department of Defense, Environmental Security Technology Certification Program.
- Johnson, C.D., T. Franklin, V. Molina, J.Q. Wassing, P.K. Tran, M.S. Kump, I. Demirkanli, C.M. Yonkofski, F. Zhang. 2021b. Aquifer Injection Modeling (AIM) Toolbox User Guide. PNNL-31087, Pacific Northwest National Laboratory, Richland, Washington.
- Truex, M.J., D.J. Becker, M.A. Simon, M. Oostrom, A.K. Rice, and C.D. Johnson. 2013. Soil Vapor Extraction System Optimization, Transition, and Closure Guidance. PNNL-21843, Pacific Northwest National Laboratory, Richland, Washington.
- Truex M.J., C.D. Johnson, D. Becker, M.H. Lee, and M.J. Nimmons. 2015. Performance Assessment for Pump-and-Treat Closure or Transition. PNNL-24696, Pacific Northwest National Laboratory, Richland, Washington.





Center for the Remediation of Complex Sites

Technical Leadership

Independent technical resource with proven track record of supporting deployment of advanced technologies and alternative strategies



REMPLEX **OF COMPLEX SITES** @PNNL

Multi-institutional Collaborations Integration and leveraging across federal and private partnerships to facilitate

solution development

Solution Development

Leverage existing capabilities spanning all TRLs to provide solutions in adaptive remediation and long-term stewardship that enable risk-based remediation





Thank you

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