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Open Geospatial Consortium

OGC CLIMATE AND DISASTER RESILIENCE PILOT IV: D-123 GENERATIVE AI IN WILDLAND FIRE MANAGEMENT ENGINEERING REPORT

ENGINEERING REPORT

FINAL

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I KEYWORDS

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

open science, workflows, Earth observation, reusability, portability, transparency, OGC, Open Geospatial Consortium, Wildland Fire, NIMS, ICS, Artificial Intelligence, Generative AI, GenAI, LLM, RAG, AI Agent, GAN

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DOCUMENT SUMMARY

1 DOCUMENT SUMMARY

As part of OGC Disasters and Climate Resilience Pilot IV (D123 — AI Advances of SDIs Report Section), this D-123 Generative AI in Wildland Fire (WF) Management Engineering Report focus was to assess the domain adaptation needed for Generative AI to support advancements in the wildland fire community as informed by user needs assessments as well as technical assessments of potential advances and efficiencies.

The Wildland Fire community leverages data and advanced tools to enhance planning and operational decision-making, aiming to supplement rather than replace experiential knowledge and anecdotal evidence. GenAI, while early in its technical evolution, with a human-in-the-loop approach, offers transformative potential by enabling scalability in data processing beyond human capabilities.

Exploring GenAI further, particularly in scenarios where significant efficiency gains are feasible, is imperative. Integrating GenAI into wildfire management necessitates a comprehensive strategy encompassing data, process, technical, and ethical considerations. This report explores the needed input, tools, challenges, and recommendations for next steps to implementing GenAI to support the Wildland Fire Management lifecycle.

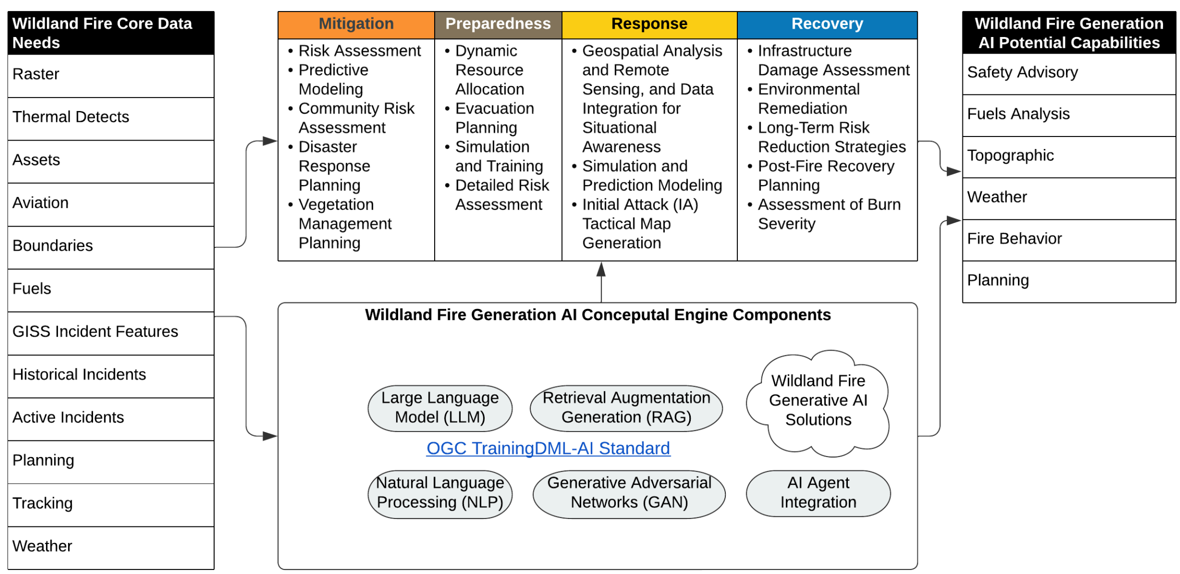

Figure 1

The diagram outlines potential data inputs, **NIMS** processes supporting the **Disaster Management Phases** mapped to GenAI capabilities and maturity, technical mechanisms to adapt to Wildland Fire Domain needed, and finally core Wildland Fire Capabilities which could gain from GenAI efforts. GenAI will require multiple technologies (RAG, GANs, Agents, NLP, Etc.) to augment LLMs to support real-time and highly contextual Wildland Fire data to provide acute and accurate responses, sourced from dozens of systems, document repositories, and APIs. Capabilities range across processes included in the National Incident Management System

(NIMS) phases. Governance will require careful consideration of data provenance, traceability, model limitations guidance, ethical application, and testing.

Table 1 — Generative AI Definition

For the purposes of this paper, Generative AI is defined as follows: Generative artificial intelligence (generative AI, GenAI, or GAI) is artificial intelligence capable of generating text, images or other data using generative models, often in response to prompts. Generative AI models learn the patterns and structure of their input training data and then generate new data. Crucial to this definition is the concept of GenAI being able to generate new content, automatically, derived from a variety of input sources. We distinguish this capability from standard algorithms or models which process inputs and provide prescriptive outputs. What we seek in this paper is an exploration of true generative capabilities for the Wildland Fire community.

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WHERE GEN AI CAN SUPPORT WILDLAND FIRE IN DISASTER MANAGEMENT PHASES AS PART OF NIMS AND ICS

2 WHERE GEN AI CAN SUPPORT WILDLAND FIRE IN DISASTER MANAGEMENT PHASES AS PART OF NIMS AND ICS

Within Wildland Fire Operations alone there are hundreds of **NWCG Positions**. A focus on GenAI needs to hone where in the Incident Command System **ICS** lifecycle and positions the stakeholder needs centered on.

ICS roles include within the functions of Command, Planning, Logistics, Operations, Finance, and Administrative. Each have different indicator interests in each phase. Generally speaking, know that these are the following primary stakeholders:

- **National / Regional Planners / Managers want**: National Readiness & Overall Incidents Metrics, GACC Risk Awareness, and Asset Tracking/Inventory for Government, Fire Districts and industry including Utilities, Insurance, etc.
- **Incident Command wants**: Command Decision Informatics (Fuels Behavior, Changing Conditions, Base Topography), Resource Tracking, Latest GISS Updates.
- **Incident Operations wants**: Individual View to understand Division/Group Informatics to follow Command Leaders Intent; Single Resource/Boss Views Tactical Changes in Features to Support Routing, and Pre-On Scene information on newly assigned incident.

Table 2 — Quote: **Hans Egholm, US Forest Service, Fire & Aviation Management (USFS FAM)**

"A lot of the talk of GenAI is so early, it is hard to tell what it will look like on an incident. As a firefighter you have a pretty good sense of the weather, fire effects, fuels, and wind. The potential of GenAI seems high but we will have to see how it develops. Applying it to these cases right now may be premature. Too early to tell. Without knowing the benefit vs the cost you can't really make a logical assessment of it."

GenAI solutions will need to ensure accurate and most up to date data is available, integrated, and processed to advise and analyze to support the emergency response planning and operations community. Any data and capability provided will need to understand how such will be used in the workflow context of disasters, specifically in Wildland Fire, as part of the national incident management systems **NIMS** phases[1].

In the U.S., Incident Command Structure (ICS) follows the **phases of a disaster the NIMS supports**: 1) prevention-mitigation 2) preparedness 3) response and 4) recovery. The **stakeholder feedback in bold and yellow** shows interest in all phases, with a strong preference for AI tools that enhance situational awareness, improve safety through advanced modeling and prediction, and optimize resource allocation during firefighting operations. Addressing these capabilities

[1]NIMS aligns with NIST phases fairly well NIST Preparation; Detection and Analysis; Containment, Eradication, and Recovery; and Post-Event Activity.

and data needs will be pivotal for developing effective AI solutions tailored to the needs of fire personnel.

Table 3 — Generative AI Potential Solution Topics across the Disaster Phases

Disaster Phases	Generative AI Potential Solution Topics
Mitigation (Planning)	• **Risk Assessment** • **Predictive Modeling** • **Community Risk Assessment** • **Disaster Response Planning** • **Vegetation Management Planning** • Resilience Planning • Building Code Compliance Analysis • Public Education Campaigns
Preparedness (Planning, Logistics)	• **Dynamic Resource Allocation** • **Evacuation Planning** • **Simulation and Training** • **Detailed Risk Assessment** • Reliable Anomaly & Initial Detection
Response (Command, Operations, Logistics)	• **Geospatial Analysis and Remote Sensing, and Data Integration for Situational Awareness** • **Simulation and Prediction Modeling** • **Initial Attack (IA) Tactical Map Generation** • Decision Support Systems • Crisis Communication • Smoke Dispersion Modeling • Document Examination and Summarization • Fire Behavior Modeling Scenarios • Field Assessment Support • Real-Time Perimeter Mapping
Recovery (Operations, Planning)	• **Infrastructure Damage Assessment** • **Environmental Remediation** • **Long-Term Risk Reduction Strategies** • **Post-Fire Recovery Planning** • **Assessment of Burn Severity** • Ecosystem Recovery Planning • Post-Event Remediation

"Appendix B: NIMS Process to GenAI Maturity Needs" further breaks down potential Generative AI by NIMS Lifecycle Phases.

3

POTENTIAL GEN AI WILDLAND FIRE FIELD CAPABILITIES/TOOLS

3 POTENTIAL GEN AI WILDLAND FIRE FIELD CAPABILITIES/TOOLS

Wildland Fire Management could benefit from GenAI tools where productivity and speed of response can enhance rapid generation of quality information that supports decision making with early and accurate results. Potential tools to consider and lift into earlier sections. **Bold and yellow were top priorities**

Safety - Safety interest for field level and Single Resources was of high interest including **Egress Modeling** to aid in planning and executing safe evacuations during fire incidents. e.g., Temporary refuge areas Identification (yellow), Good LCES areas Identification (green), No-Go zones (red). This could include **Safety Zones and Crew Utilization** on factors like fuels, slope, direct fire attack feasibility, and fire size. They included understanding resource needs and aiding agency administrators in resource allocation. e.g., for Draw-D — defend; reinforce; advance; withdraw; and, delay.

Table 4 — Quote: **Connor Miller, Helitack, Bureau of Land Management (BLM) HotShot**

"Anything that AI does for safety needs to be checked and verified. There is too much at stake and too many factors outside of straight up data that need to be considered."

Fuels — GenAI for Fuel Identification: GenAI for identifying fuel types and providing additional fuels information was mentioned by a couple of respondents, indicating interest in advanced technologies that assist in understanding fuel characteristics. This could include:

- Photo/Video Feature extraction to support structure triage RYG AI (Red, Yellow, Green – RYG)
- Public fuels risk AI through Photo/Video Feature extraction on submitted data
- Generative AI fuel type identification with additional fuels information
- Powerline-Fuel risk Identification (e.g., Lidar powerline feature extraction)
- Evaluate Fuels via Remote Sensing products (Imagery, UAV, LiDAR) with AI to uncover fuel types (e.g., **2020 California Wildfire uncovered unhealthy forest/Dead tress large fuel load major cause**

Topo - Topo is available now in Augmented Reality. Real-time identification via AR of risk features (mid-slope, chimney, box canyon) AI (Red-Yellow-Green-RYG) could help those in the field quickly identify risks. An example is **Slope Risk** and features related to topography were mentioned by multiple respondents, showing a concern for tools that assess and manage terrain-related risks, particularly for heavy equipment operations. Less highlighted was consider a Local Watershed tool model based on recent burn severity AI tool.

Weather — Wind Run Tools were highlighted tools to assist in understanding wind behavior and its impact on fire and risk severity (RYG). Taking into consideration the Quick AI model from derived data RH, moisture, hills, wind on Fire Behavior Potential (e.g., AI could generate improved Spot Weather tools which feed Generative AI with observation medium scale impacts as mentioned to a lesser degree).

Fire Behavior — Response Modeling for Dispatch: Systems that can model response times based on current fire conditions and predict fire growth, recommending appropriate response actions based on these predictions. This could take into account NWCG S-131, S-215 and other NWCG guidance on Plume, Smoke, Topo, Weather, Fuel load, RH, etc. and advise changing conditions response notifications advisory or awareness. This could expand **Wildfire Analyst Pocket like tools** — Fire Behavior Guide (PMS 437) tools.

Planning - Additionally, Command and IMT support for **Population Analysis and Strategies to support** develop appropriate response **Resource Prepositioning Models** that use current fire conditions and historical data to preposition firefighting resources effectively, optimizing response times and effectiveness, as well as tools to support faster IWI (Incident Within an Incident), and enhancing safety measures during firefighting operations. Additionally, **Special Evacuation AI:** Special evacuation AI was mentioned by a few respondents, highlighting a desire for AI tools that can assist in managing and executing evacuation plans effectively (ranches, cattle, road width, veg on roads).

Table 5 — Quote: **Harrison Leahy, Squad Leader, BLM HotShot Crew**

"Response modeling for dispatch would be a really great use of GenAI in wildland fire. A system that would detect how long the response time would take with the current fire condition and recommend a response based on the predicted size of the fire by the time units arrive."

4

CORE DATA NEEDS TO SUPPORT WILDLAND FIRE GEN AI

4

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To support such capabilities, GenAI would rely heavily on pre-trained models augmented with additional domain contextual data updated with real-time API data where needed for highly changing emergency scenarios. Wildland Fire Stakeholders cited the yellow bolded core data needs to support priority capabilities as highest priority. Data to be considered will be unstructured documents, tabular datasets, knowledge graphs **embedding with Entity Resolution**, and raster collections. GenAI solutions will require well-tuned models with a well-defined continuous training and labeled data Improvement lifecycle. When considering more real-time and large Wildland Fire data, components, the following data subject areas and information classes[2] are of highest priority beyond what is cited in "Appendix A Wildland Fire Data Reference Model and Source Inputs".

Table 6 — Core Data Needs to Support Generative AI in Wildland Fire

CORE DATA NEEDS	TYPE
Raster	Airborne Imagery, Airborne Video heavily used by ICS-Ops
Thermal Detects	Small Scale IR Alerts & Detects, Large Scale Detections (National FireGuard, Satellite, State AI Detection (e.g., **AlertCalifornia.org**
Assets	Information about resources available for an incident, such as personnel, equipment, and vehicles. Resource Bases, AirTanker Bases, Active Aviation Resources, Short Haul, Shelters, Fire Buildings, IROC Location Data
Aviation	Charts, Drop Avoidance Areas, Military Routes, Vertical Obstructions
Boundaries	US National Grid, USA Wilderness, Administrative Boundaries, Surface Management Agency, Residential Areas (WWRA), US County Boundaries, Jurisdictional Agency/ Unit Boundaries, Sage Grouse Habitat, Dispatch Office Boundaries, GACC Regions/ Boundaries, Predictive Service Areas (PSA), Fire Management Units, Federal Lands
Fuels	Data on fuel types and conditions are crucial for assessing fire behavior potential and strategizing fire suppression efforts. Hazardous Fuels Treatments, Tree Mortality, Wildfire Suppression Difficulty Index, Potential Operational Delineations (POD's), Fuel Moisture, NDVI Greenness
GISS	Geographic data from NWCG certified GIS Support Services (GISS) teams that aids in mapping, spatial analysis, and decision-making during firefighting operations. Operational Features GISS data, Approved Dip Site Tracking, Pre-identify map nodes (i. e. DP or helispot) to lower fuel/air time, resources tracking (DART)

[2]NWCG workflow, model, and data flow based on **NWCG Standards for Geospatial Operations, PMS 936**.

CORE DATA NEEDS	TYPE
Historical Incidents	USFS Historical Fire Data, Before 1980, 1980s, 1990s, 2000s, 2010s, Current Decade, Prev Year
Active Incidents	Active Incidents, Wildland Fire Perimeters Current Year (Daily, Current, YTD, Final, Decade), PIO Information Active Incidents, Assignment Breaks, Event Point, Event Polygon, GISS PMS-936 Feature Data, Briefing Data
Planning	Data used for incident planning and management, including tactical decisions and resource allocation. infrastructure, population characteristics, Shelters, At-risk population locations, Residential Areas, Fire Danger Indices, NIROPS Scanner Requests
Tracking	Retardant Drops, Automated Vehicle Location
Weather	Essential for understanding current and forecasted weather conditions, which greatly influence fire behavior and operational planning. e.g., wind, atmospheric pressure, lightning, Watches & Warnings (Fire, Flood, Cyclones, Coastal, etc.), Fire Danger, Fire Weather, Outlooks, Precipitation Accumulation, RAWS, Flood Hazard

5

TECHNOLOGY COMPONENTS NEED TO SUPPORT GEN AI

5 TECHNOLOGY COMPONENTS NEED TO SUPPORT GEN AI

Generative AI to support wildland fire management requires technology solutions that can address the real-time nature of data updates, the accuracy requirements to ensure responses are free of "hallucinations", "slop", and other "goal drift"[3] replies that can come from Large Language Models (LLMs[4]) solutions alone due to the scarcity of context in LLMs which can hinder their ability to perform effectively in certain scenarios. LLMs need additional context to ensure responses are complete and trustworthy[5]. In other industries (e.g., Financial Analysis[6]), LLMs are proving very powerful when done right. LLMs can be used as a foundational model and extended or augmented to achieve goals.

LLMs, as foundation models[7], can be augmented with Multi-Modal AI solutions such as RAG, GAN, NLP, and AI Agents to provide more context. Further, model tuning including reinforcement learning can enhance fire behavior prediction and fuel input. However, augmenting LLMs with techniques like RAG, GAN, NLP, and AI agents requires caution due to their limited reasoning ability, despite their intuitive responses. The following captures recommendations to consider in addressing such gaps.

Retrieval-Augmented Generation (RAG) [GenAI 1.5]

- Enhance contextual understanding and accuracy of AI-generated responses by developing vector store ETL pipeline via linear transformations[8] to clean and load content and then chunk, embed.
- Store embeddings to fit into an LLM prompt or query (e.g., or LLM can be used as an embedding model using **LLM2Vec**).
- Add semantic data sources (e.g., **convert text to knowledge graph concepts**) to further enhance model training and performance.

[3]**https://arxiv.org/abs/2308.03296 — Studying Large Language Model Generalization with Influence Functions**

[4]Key Gen AI terms

[5]**https://arxiv.org/abs/2305.04388 — Language Models Don't Always Say What They Think**

[6]**Financial Statement Analysis with LLMs**

[7]A foundation model is a large-scale machine learning model trained on a diverse dataset, making it versatile and suitable for fine-tuning across various applications and downstream tasks. These models are recognized for their generality and adaptability.

[8]**Linearity of Relation Decoding in Transformer Language Models**

- Add recurrent neural networks (RNNs) that require cautious consideration to address potential limitations and ensure effective performance in complex scenarios.
- Integrate other Foundation Models(e.g., **Aurora for Atmospheric**.
- RAG is most effective in “knowledge-intensive” scenarios. RAGs may create ‘goal drift’.
- RAG does have some limitations. RAG solutions can get “distracted” by irrelevant content in documents, especially long documents.
- RAG can also be expensive to scale. RAG is not currently strong at “reasoning-intensive” tasks such as coding and math.
- **Technologies**: Hugging Face transformers library, LangChain, Gemma-2b-it, Streamlit, Faiss vector database, Amazon Bedrock for Foundational Model integration.

AI Agents [GenAI 2.0] -

- AI agents with NLP capabilities can orchestrate real-time API requests, depending on various factors such as their design, infrastructure, and the nature of the tasks they are performing.
- AI agents can also call modeling services (traditional, ML, etc.) via OGC APIs or other APIs for niche specific modeling analytical tools.
- AI Agents can separate data gathering, reasoning and action taking components to enable a much more flexible set of complex tasks.
- AI Agents require an orchestration layer that optimizes the flow of information from real-time APIs. **AI Agent Benchmarks** are needed to measure confidence.
- Use where importing data in RAGs is not a reasonable solution.
- **Technologies**: Rasa, LangChain LlamaIndex, Semantic Kernel, Griptape, Microsoft Bot Framework, Amazon Q, Lex, Dialogflow, IBM Watson Assistant, devin.ai.

Natural language processing (NLP) -

- Complement LLMs with NLP-driven analytics through interpretation of textual data in wildfire contexts.
- NLP excels at extracting information from named entities, key concepts, sentiment, and intention from text
- Consider if LLMs are paired with abstraction libraries e.g., **LILO**, **Ada** and **LGA** which help robots better understand their environments to develop more feasible plans blends human-like neural networks and program-like logical components.
- NLP can be used for nuanced analysis and decision-making in specific tasks, enabling deeper insights from unstructured data, particularly in text-based datasets relevant to wildfire management. This includes extracting actionable information from incident logs, weather reports, and community feedback.

- Use for nuanced analysis and decision-making and specific tasks to enable deeper insights from unstructured data, particularly in text-based datasets relevant to wildfire management.
- **Technologies**: NLTK (Natural Language Toolkit), BERT, NER, HuggingFace, AllenNLP.

Generative Adversarial Networks (GAN) -

- AI goes beyond Text, Math, and data retrieval and synthesis; AI can consume and generate imagery.
- GANs can generate synthetic imagery for training models or improve the quality of existing images, aiding in tasks like fire detection and damage assessment. This capability is particularly useful in tasks such as fire detection and damage assessment, where high-quality and varied imagery can significantly improve accuracy and effectiveness.
- GANs can enhance the resolution and quality of satellite and aerial imagery, making it easier to identify fire hotspots and assess damage over large areas.
- By generating various scenarios of fire spread based on historical data and current conditions, GANs can aid in predictive modeling, helping to forecast the potential progression of wildfires.
- Post-fire, GANs can be used to generate high-quality before-and-after imagery, facilitating more accurate damage assessment and aiding in the planning of recovery efforts.
- GAN-generated visualizations can be used to create realistic simulations and educational materials to raise public awareness about fire risks and safety measures.
- **Segment Anything Model** can leverage object masks to generate precise segmentation of images. Moreover, the Segment Anything Model (SAM) can utilize object masks to generate precise segmentation of images, enhancing the detail and usability of the generated content.
- **Technologies**: TensorFlow, PyTorch, GANLab, ProGAN.

6

KEY CONSIDERATIONS FOR GEN AI MODEL DEVELOPMENT:

6 KEY CONSIDERATIONS FOR GEN AI MODEL DEVELOPMENT:

1. **Maintain a balance between LLM augmentation** and other technologies to ensure effective integration and performance via careful consideration of model limitations and integration complexities to address "hallucinations", "slop", "Goal Drift", or other echo chamber aspects (aka, "eating its own output") which can further cause self-induced bias or goald drift. Some papers go as far as LLMs **over-confidence should be challenged**. Use specialized models or **reinforcement learning models** to think logically, learn from its mistakes, and improve its processes without human input.

2. **Establish Zero Trust Architecture concepts** to block/filter unwanted data. Clean prompts of PII data (e.g., via AWS Bedrock GuardRails, Aurelio AI Semantic Router) and establish re-/de-identifying sensitive values in solutions (e.g., Skyflow GPT Privacy). Setup LLM token limits via token calculators (e.g., tiktoken) to limit inference attempt failure.

3. **Ensure high quality content in your pipeline with micro-citations** and data headers leveraging **OGC TrainingDML-AI Standard** or **Detailed** to ensure traceability and provenance as well as remove unnecessary markup in your ETL pipeline. This could also help provide feedback to the **AI ML XML/JSON encoding effort**. **OGC Training Data Markup Language for AI standard** in areas of: Incorporate Synthetic Data Generation Protocols to complement real-world data; Enhanced Metadata and Geospatial Metadata to provide context for for pipeline, training data, and Generative Models such as GANs, RAGs, AI agents; Support for Multimodal Data Integration to facilitate more complex and capable models; and Provenance and Ethical Considerations including origin tracking and synthetic data.

4. **Tune your data pipeline** splitting strategies in text chunk sizes, update system prompt expectations, filter vector store results against metadata elements, and finally experiment with the right embedding models (e.g., examine HuggingFace **MTEB leaderboard** of models).

7

CHALLENGES IN LEVERAGING GEN AI

7 CHALLENGES IN LEVERAGING GEN AI

1. **GenAI is changing and maturing very rapidly**. Challenges persist in terms of model performance and data availability. Sufficient talent, data, compute power, facilities, energy/power will be in transition much like early internet days as **solutions envisioned scale**. New architectures even in the next 2 — 5 years suggested by **Hype Cycle**. (e.g., **RAG 2.0 as Contextual Language Models (CLMs)**, **GraphRAG**.

2. **Legislation is reactively adjusting** at the national and state/local levels to the advancements in GenAI technology to ensure safe, proper application of such. (e.g., National **U.S. White House Executive Order on the Safe, Secure, and Trustworthy Development and Use of AI**; state/local **State of California GenAI Guidelines** and **Executive Order on GenAI** and **State of Colorado Artificial Intelligence Act (CAIA)**.

3. **Current GenAI capabilities tend to have poor traceability** and do not provide clear data provenance and micro-citations with a limited culture supplying such, e.g., via the **OGC Training Data Markup Language for AI standard** .

4. **Pre-trained models e.g., LLMs are closed loops systems and do not adapt** to feedback loops as part of updates which emergency-based models will require domain-specific validation and verification processes. Multi-Modal AI as discussed will be needed to augment LLM (not work on the LLMs). It is plausible that in 2-5 years, LLMs will have completely new architectures.

5. **Poorly trained models can produce undesirable outputs** such as inaccuracies, bias, lazy responses, hallucinations and goal drift. Security, scaling, latency, cost optimization and data/response quality are all emerging topics that don't have standard solutions in the space of LLM based applications. RAG integration, for example, can be challenging to integrate.

6. **Users will be slow to adapt** to changing existing models in the Wildland Fire community due to historical culture, high risk of life and property impacts without proof of reliability, consistency, proof in AI outputs repeatability, and literacy **education** campaigns.

8

WILDLAND FIRE GEN AI RECOMMENDATIONS

8 WILDLAND FIRE GEN AI RECOMMENDATIONS

Given the challenges, data needs, capabilities, and potential technology implementations, the following are recommendations suggested for enterprises and pilots to consider to address Mission Stakeholder, Mission Governance, Data and Technology Solution and overall Wildland Fire Enterprise Management.

Table 7 — Recommendations Summary

RECOMMENDATIONS	SUMMARY
Mission Stakeholder:	• Invest in key datasets and GenAI models for fire • Synthesize real-time data • Develop human-in-the-loop solutions • Tie in Data Provenance. Consider **OpenEO ProcessGraphs** and/or **OGC CWL Prov** for **sharing interoperable workflow**
Mission Governance:	• Establish clear enterprise workflows and inventory • Adopt data training and deployment standards to ensure high quality content in your pipeline with micro-citations and data headers via **OGC TrainingDML-AI Standard** **Detailed** and provide GenAI feedback on Synthetic Data Generation, Generative Model Metadata, Multimodal Data Integration, and Provenance and Ethics • Ensure effective data governance • Ensure continuous research collaboration
Data:	• Establish a continuous training and labeled data improvement lifecycle • Embed and include knowledge graphs and consider OGC RAINBOW registration • Integrate with raster collections and metadata toolkits
Technology Solution:	• Augment LLM with NLP, RAG, GAN, and AI Agent techniques • RAG — Domain Specific • NLP — Task/Named Entity Specific • GAN — Imagery/Computer Vision Extraction • AI Agent — API and model integration Specific • Implement MLOps practices
Wildland Fire Enterprise Management:	• Integrate GenAI with existing Federal Wildland Fire systems (e.g., EGP) • Integrate with live data collection (e.g., BLM inFORM, IRWIN) • Establish enterprise ontological and knowledge graph solutions • Establish a comprehensive disaster management roadmap

Mission Stakeholder Recommendations:

- *Invest in key datasets* and GenAI models for fire forecasting, operational fire behavior tools and prediction to understand fire dynamics to adjust containment strategies in real time to improve data access and integration across critical datasets like weather, fuels, and geographic information systems will be essential for advancing AI applications in firefighting.

- *Synthesize real-time data* to automate product generation of accurate forecasts of fire outbreaks and behavior and ensure fits into overall conceptual architectures and workflows.

- *Develop human-in-the-loop solutions* with confidence intervals to allow command and planners to make final decisions including other inputs and experience. Based on the stakeholder findings, it is recommended to focus AI development efforts on enhancing wind behavior tools, egress modeling capabilities, and integrating advanced predictive modeling for response planning.

- *Tie in Data Provenance* to all GenAI capabilities via closing the feedback loop with micro-citations for confidence intervals and traceability to establish clear source and establish trust in security, accuracy, ethics, and control for end-user adoption. Consider documentation using OpenEO ProcessGraphs and/or **OGC CWL Prov** for **sharing interoperable workflow provenance: A review of best practices and their practical application in CWLProv**.

Mission Governance Recommendations:

- *Establish clear enterprise workflows and inventory* of sources, transformation, tools, services, and GenAI within wildfire management to understand what data is used from authoritative data source stewards to ensure data availability and interoperability within the Wildland Fire community.

- *Adopt data training and deployment standards* to allow for data to be consumed and up to data in the best possible models, data patterns and common practices for organizing and structuring data (e.g., **US DoD SHIELD Assessment Responsible AI Toolkit** and **US DoD Data Analytics AI Adoption Strategy**. Consider implementing standards such as **OGC TrainingDML-AI Standard** via lifecycle practices such as **AI Guide Government best practices** and **adjusting Governance for GenAI**.

- *Ensure effective data governance* validates, complies, and maintains privacy of GenAI-generated outputs and clear user permissions, Personally Identifiable Information (PII) handling, access controls, and transparency measures. Ensure **protects integrity of data and results**[9].

- *Ensure continuous research collaboration* to ensure alpha, beta, live progressions consider the rapidly evolving perplexity and complexity landscape of LLM models (e.g., new neural networks or self-reasoning models (e.g., **Quiet-STaR; QStar**.

Data Recommendations:

- *Establish a continuous training and labeled data Improvement lifecycle* to tune GenAI models over time and ensure the reliability and accuracy of generated outputs.

- *Embed and include knowledge graphs* as a data source to enhance GenAI's understanding of wildfire management dynamics. Collaborate with GeoPlatform.gov Ontology and other

[9]NAS commissioned papers on Strategies to **Govern AI Effectively** and **PNAS Summary article**

engagements to streamline data management to support critical areas with named entities within the wildfire ecosystem. Evaluate **OGC RAINBOW** ecosystem registration.

- *Integrate with raster collections and metadata toolkits* for computer vision outputs to enhance data accessibility and facilitate seamless data exchange within the Wildland Fire management framework.

Technology Solution Recommendations:

- *Augment LLM with NLP, RAG, GAN and AI Agent techniques* to address their strengths and limitations effectively. Utilize NLP with task-focused solutions on named-entities. Utilize RAG solutions to address both LLM gaps to further enhance domain specific Q&A, content creation, chatbots, data augmentation through targeted extended retrieval of specialized information and even generate graph fragments from document and image processing. Understand options RAG, RAG 2.0, or **GraphRAG**. Utilize GAN to support imagery computer vision capabilities specific to wildland fire needs. Utilize AI Agents for calls to external systems and uses models could learn to use APIs[10] Evaluate build own LLM vs. using Global LLMs alone (e.g., **TCS Survey**.

- *Implement MLOps practices* for selecting, applying, interpreting, and maintaining models within an AI-enabled system. Consider Balanced Model Integration, Establish Reinforcement Learning Models, Tune GenAI Pipeline and Models, and Establish Zero Trust Architecture.

Wildland Fire Enterprise Management Recommendations:

- *Integrate GenAI with existing Federal Wildland Fire systems*, such as the USFS National Wildland Fire Enterprise Geospatial Portal to streamline data delivery, access and management.

- *Integrate with live data collection tools* such as BLM inFORM is fed into the U.S. IRWIN and GISS databases per PMS-936 geospatial operations to ensure latest data is consumed.

- *Establish enterprise ontological and knowledge graph* solutions to enhance overall resilience and response capabilities across disaster response efforts.

- *Establish a comprehensive disasters management roadmap* for integrating GenAI across various disaster response scenarios efforts to include Wildland Fire.

[10] AI Agent Research papers **Toolformer** and **Gorilla**

9

APPENDIX A: WILDLAND FIRE DATA REFERENCE MODEL AND SOURCE INPUTS

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Table 8 — Conceptual Wildland Fire Data Reference Model

DATA SUBJECT AREA	INFORMATION CLASS	EXAMPLE ELEMENTS
Wildland Fire National Strategy & Management	*STRATEGIC GUIDANCE*	*Principles, Policies, Performance Measures, Disaster Declarations*
	STRATEGIC RESOURCES — PERSONNEL	*Budget, Human Resource Mgmt, Strategic & Workforce planning/readiness (Certifications/Qualifications, Availability, Dates), Prevention Workload Analysis, Performance Evaluations*
	STRATEGIC RESOURCES — ASSETS	*Asset allocation & planning, Budget, Asset Mgmt*
	PLANNING INDICATORS	*Regional/National Plans, Budget, Natural Resource Management, Strategic , Active Incidents, Seasonal Outlooks, Interagency Initial Attack Assessment, Fire Statistics*
	INFORMATION MANAGEMENT	*Knowledge management, Records management, Resource Ordering Controls (Apparatus, Air, Organization. Person)*
National Base Data Layer Information	*TOPOGRAPHIC*	*Elevation (NED/#DEP), Hydrographic (NHD, 3DHP, AGRAM), Transportation, Structures, Boundaries, Names, Land Cover, Imagery, Grids (NG, PLSS, etc.)*
	MAPS/REPORTS	*Multiple Base maps, Historical Topos, Incident GISS (PMS-936), FS Catalog (Avenza), NWCG Readiness, IAPs*
	FOREST/ GRASSLAND PLANS	*Fire Management, Invasive Species, Lands and Realty Management, Natural Resources, Private Land, Recreation Management, Sustainability / Climate, Urban Forests, Fire Program Analysis, Budget Alternatives, FireWise*
	REMOTE SENSING	*Incident, IR, Fire Detection, Vegetation, Fuel, Disturbance, Drone Imagery, Video, Aircraft, GPS (Resource/Flight), Ignition (Haines), Weather Stations, Stream Gauges, Atmospheric (Wind, Aerial Moisture,Thermal,Cloud Cover,)*
National Base Data Layer Information	*LAND ANALYTIC PRODUCTS*	*Land Cover/Disturbance Change, Species Monitoring, Climate Models, Habitat Activities, Ecological Models, Soil Models, Fuel Models, Rainfall accumulation*
	FIRE ANALYTIC PRODUCTS	*Fuel Treatments, Fire Suppression, Fire Management Plans, Active Fire Management, Fuels and Post-fire Report, BAER, Monitoring Trends in Burn Severity, Plume Models, IR*

DATA SUBJECT AREA	INFORMATION CLASS	EXAMPLE ELEMENTS
	DISPATCH	Centers, Coverage, Jurisdiction
	FIRE EXTENT & INTENSITY	Suppression Response, Fuels, ignition, Weather, Topography, Burn Probability
Wildland Fire Incident Command Structure Data	COMMAND — STRATEGIC	Performance, Program evaluation, Standard, Resource Planning, Evacuation, Situation Analysis/Reports, Alerts
	PLANNING	Controls and oversight, Assessment, Conservation (Life, Property), Fire Extent & Intensity, Staging/PIO Plans, Fuels, Weather, Fire Behavior, Ignition
	PLANNING — GISS (PMS-910,938, 936)	Geospatial, Location, Remote sensing and imagery, IR, Field Collection, Incident Markups
	LOGISTICS — PERSONNEL	Personnel/Apparatus Request/Fulfillment, (Certifications/Qualifications, Availability, Dates), Prevention Workfload Analysis, Assignment
	LOGISTICS — ASSET/ GENERAL	Assets (Air, Apparatus, Equipment, Radio), Fixed asset (Aviation, Obstructions, JFOs, Shelters, Interagency Cache, Weather Stations, Dispatch, Staging), Land, Personal property and equipment, Resource Availability/Location/Status, CAD, Real-Time Location
	OPERATIONS	Incident, Occurrence, Resource Location, Response, BAER, Supp. Repair, Navigation Routes, Prescribed Event Plans, Safety Reporting
	FINANCE	Account, Collection and receipt, EFFPay, AP/AR, Billing
	ADMINISTRATION	Acquisition and procurement, Resource Orders, ICS Reports, Staging
Risk Indicators, Analysis, and Assessment	POPULATED AREAS	Low Density, High Density, Residential Areas, Disaster Potential (Quakes, Slides, Flood, etc.)
	AIR QUALITY	Non-Attainment Areas, Class 1 Areas, Environmental Science, Atmospheric
	RECREATION iNFRASTRUCTURE	Trails, Ski Areas, Sites, Campgrounds, Cultural Resources
	ENERGY INFRASTRUCTURE	Power Lines, Power Plants, Power Farms, Cell Towers, O&G Pipelines, Fuel Storage
	SPECIES & WATER PROTECTION	Endangered Species, Habitat, Wildlife, Watersheds (AFRAM), Critical Habitat
	FIRE SCIENCE ANALYTICS	Response Capacity, Fuel Treatments, Prevention Programs, Exposure Reduction, Specialty Models (Predictive, Fire Effects, Public Health, Smoke Estimation, Plume,,etc.), Forest/Grassland Plans, Contingency planning, Health and safety,
	FIRE RISK ASSESSMENTS	Fire Behavior Models, Spatial Value Patterns, Loss/Benefit Functions, Fire Ecology, Landscape Risk Assessment, Management Options, Goals, NEPA, Risk Management Strategy

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WILDLAND FIRE APPLICATION/SYSTEMS

10 WILDLAND FIRE APPLICATION/SYSTEMS

Table 9 — Example list of U.S. Wildland Fire Application/Systems

NAME	LINK
FEMA Wildfire Incident Journal Wildfire Hazard Overview Dashboard (Structure Damage Status)	https://fema.maps.arcgis.com/apps/MapJournal/index.html?appid=58585e471e484cffbc398c5830d0b4dd
Daily SitReps (Incident Management Situational Reports — IMSR)	https://www.nifc.gov/nicc/sitreprt.pdf
National Wildland Fire Outlooks	http://www.predictiveservices.nifc.gov/outlooks/outlooks.htm
National Oceanic and Atmospheric Administration — National Weather Service — Fire Weather	https://www.weather.gov/fire/
inFORM	https://in-form-nifc.hub.arcgis.com/
USFS FACTS	https://data.fs.usda.gov/geodata/edw/datasets.php?xmlKeyword=facts
U.S. Drought Monitor	https://www.nifc.gov/nicc/predictive-services/outlooks
USFS Ent. Geo Portal (Data, Lightning, Situational Awareness and multiple internal Fire & Aviation Applications	https://egp.wildfire.gov/
IRWIN	https://irwinoat.doi.gov/rollcall/resources
NIFC Maps	https://www.nifc.gov/fire-information/maps
National Fire Weather Forecasts	https://www.weather.gov/fire/
Wildland Fire Application Information Portal	https://www.wildfire.gov/
NIFC ArcGIS Online	https://nifc.maps.arcgis.com/

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WILDLAND FIRE DATA SOURCES

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WILDLAND FIRE DATA SOURCES

Table 10 — Example list of U.S. Wildland Fire Data Sources

NAME	LINK
Homeland Infrastructure Foundation-Level Data (HIFLD)	https://hifld-geoplatform.opendata.arcgis.com/
Disasters Geoplatform	https://disasters.geoplatform.gov/
NASA sources	https://www.nasa.gov/mission_pages/fires/main/missions/index.html
National Land Cover Dataset (NLCD)	https://www.usgs.gov/centers/eros/science/national-land-cover-database
Normalized Difference Vegetation Index (NDVI)	https://eros.usgs.gov/media-gallery/earthshot/ndvi
Monitoring Trends in Burn Severity	https://www.mtbs.gov/
Rapid Assessment of Vegetation Conditions	https://fsapps.nwcg.gov/ravg/ravg-data-extract/
USFS Burned Area Emergency Response (BAER) program	https://fsapps.nwcg.gov/ravg/background-products-applications
National Fire Plan Operations & Reporting System	https://www.nfpors.gov/
BAER models for post fire	https://www.fs.usda.gov/naturalresources/watershed/burnedareas.shtml
Historical Imagery	https://earthexplorer.usgs.gov/
NIFC data	https://data-nifc.opendata.arcgis.com/
NASA — Wildland Fires Application Area	https://disasters.nasa.gov/fires
Wildland Fire Assessment System (WFAS)	http://www.wfas.net/
NIFC Predictive Services	https://www.predictiveservices.nifc.gov/
FEMA RAPT tools	https://www.fema.gov/emergency-managers/practitioners/resilience-analysis-and-planning-tool
NASA landfire (Landfire data inputs for training data)	https://landfire.gov/

NAME	LINK
Activity Range Vegetation Improvement	**https://data.fs.usda.gov/geodata/edw/edw_resources/fc/S_USA.Activity_RngVegImprove.gdb.zip**
USFS Enterprise Data Warehouse services	**https://apps.fs.usda.gov/arcx/rest/services/EDW**
Forest Service Enterprise Data (Enterprise Data Warehouse	**https://data.fs.usda.gov/geodata/edw/**
USFS Geospatial Data Discovery (EDW) — Hub	**https://data-usfs.hub.arcgis.com/**
Invasive plants	**https://data-usfs.hub.arcgis.com/datasets/current-invasive-plants-feature-layer/explore?location=38.689713%2C-107.164279%2C7.59**

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WILDLAND FIRE SOLUTIONS & MODELS TO WATCH

12 WILDLAND FIRE SOLUTIONS & MODELS TO WATCH

Table 11 — Example list of U.S. Wildland Fire Solutions & Models

NAME	LINK
All Hazards DHS ESFLG models and data inventory	https://gis.fema.gov/Model-and-Data-Inventory/
NWCG models	https://www.nwcg.gov/publications/training-courses/s-190/course-materials
USGS Models	https://www.usgs.gov/special-topics/wildland-fire-science
FEMA models	https://www.fema.gov/emergency-managers/practitioners/hazardous-response-capabilities/imaac
FS models	https://www.fasmee.net/
EPA models	https://www.epa.gov/sciencematters/tracking-smoke-models-protect-public-health#:~:text=Models%20are%20an%20integral%20part,may%20be%20harmful%20to%20health.
NASA Plume	https://airbornescience.nasa.gov/content/Space-based_observational_constraints_for_1-D_fire_smoke_plume-rise_models
Fuels Knowledge Graph Project	https://resources.data.gov/assets/documents/CDOC_Fire_Fuels_REPORT_Final.pdf
Fuels Knowledge Graph Project (Article)	https://resources.data.gov/assets/documents/CDOC_Fire_Fuels_REPORT_Final.pdf
Shared Wildland Fire Risk Management (SWRM) prototype to support the new Fuels and Post-fire Reporting Modules — Recorded webinar	https://greatbasinfirescience.org/event/shared-wildfire-risk-mitigation/
Wildfire Prediction Using Spatio-Temporal Knowledge Graphs	https://ceur-ws.org/Vol-3401/paper5.pdf and https://ceur-ws.org/Vol-3401/paper5.pdf

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REFERENCES — WILDLAND FIRE PROGRAMS & STRATEGIC PLANS

13 REFERENCES — WILDLAND FIRE PROGRAMS & STRATEGIC PLANS

Table 12 — Sampling of References for Wildland Fire Programs & Strategic Plans

NAME	LINK
National Cohesive Wildland Fire Management Strategy	https://www.forestsandrangelands.gov/strategy/
National Park Service — Wildland Fire Program	https://www.nps.gov/orgs/1965/index.htm
U.S. Department of Interior — Office of Wildland Fire	https://www.doi.gov/wildlandfire
U.S. Fish and Wildlife Service — Fire Management	https://www.fws.gov/fire/
U.S. Forest Service — Fire Research and Development	https://www.fs.fed.us/science-technology/fire/fire-research
USFS Fire Science Strategic plan	https://pubs.usgs.gov/publication/cir1471
USGIF — Building Resilient Communities Through Geospatial Intelligence	https://www.unisdr.org/preventionweb/files/61620_usgifbuildingresilientcommunitiesth.pdf
USGS Wildland Fire Science	https://www.usgs.gov/special-topics/wildland-fire-science
FS Wildland Fire Science Research	https://www.fs.usda.gov/science-technology/fire/fire-research
Bureau of Indian Affairs — Branch of Wildland Fire Management	https://www.bia.gov/bia/ots/dfwfm/bwfm
Bureau of Land Management — Fire and Aviation Program — Joint Fire Science Program (JFSP)	https://www.firescience.gov/

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APPENDIX B: NIMS PROCESS TO WILDLAND FIRE GEN AI MATURITY NEEDS

14 APPENDIX B: NIMS PROCESS TO WILDLAND FIRE GEN AI MATURITY NEEDS

14.1. NIMS Phase 1 (Mitigation), Planning

Wants indicators to demonstrate threat levels and opportunities for fuel mitigation — seasonal expectations fuel moisture, wind, predictive indicators, drought, human travel vegetation conditions- to guide plans for prevention (fuel breaks, grants, education). This could yield:

- **Risk Assessment:** Identified by almost all stakeholders as a critical function in mitigating fire-related risks. Mature from simple identification of known fire risks to assessing fire risks based on historical data and fuel conditions to Predictive modeling of wildfire risk factors including climate change impacts.
- **Predictive Modeling**: Enhance predictive modeling capabilities to improve the accuracy of fire behavior forecasts and support proactive decision-making. Highlighted for anticipating fire behavior and planning responses proactively.
- **Community Risk Assessment:** Generative AI can assess the vulnerability of communities to wildfires by analyzing factors such as population density, infrastructure, and proximity to wildland areas. This information can help prioritize mitigation efforts and target resources to areas with the highest risk. Emphasized across responses for understanding local vulnerabilities.
- **Disaster Response Planning:** Basic wildfire response protocols can be reviewed and loaded to develop wildfire response plans considering terrain and weather to further support real-time adaptive response planning incorporating AI predictions and forecasts. This can be for simulation, training, or advanced scenario modeling.
- **Vegetation Management Planning:** To provide automated fuel reduction support, Generative AI can analyze historical fire data, vegetation types, and environmental factors to develop comprehensive vegetation management plans. These plans can include strategies such as prescribed burns, fuel breaks, and defensible space zones to mitigate the risk of future wildfires.
- **Resilience Planning:** Basic assessments of community vulnerability to wildfires can support the development of resilience plans for communities and infrastructure via incorporating adaptive strategies and risk analysis.
- **Building Code Compliance Analysis:** Generative AI can analyze building codes and regulations related to wildfire resilience and assess compliance levels across different regions. This information can identify areas where enforcement or improvements are needed to enhance community safety and resilience.

- **Public Education Campaigns:** Generative AI can develop targeted messaging and educational materials to raise awareness about wildfire risks and prevention measures. By analyzing demographic data and communication channels, AI can tailor messages to specific audiences and increase engagement with wildfire preparedness initiatives.

14.2. NIMS Phase 2 (Preparedness) Planning/Logistics

Wants to coordinate near-term weather to guide logistics pre-placement for nearer-term threat levels and guide readiness levels including various operations preparation functions — tools like **Rapid Assessment of Vegetation Conditions** as well Logistics wants to be able to plan readiness levels and coordinate awareness — e.g., **NWCG Inciweb** and **Daily Incident Management Situation Reports**. This could yield:

- **Dynamic Resource Allocation Optimization:** Resource allocation optimization and management brings an emphasis on efficiency and importance of tools that streamline resource deployment. Universally recognized as essential for preparedness across all stakeholders. Generative AI algorithms can optimize the allocation of resources such as firefighting crews, equipment, and aircraft based on real-time data and predictions of fire behavior. This can help ensure that resources are deployed efficiently to areas where they are most needed. Could support manual allocation of resources based on historical data, optimizing resource allocation using geospatial analysis , and AI-driven resource allocation models considering dynamic fire conditions.

- **Evacuation Planning:** This could range from support of basic evacuation route planning to developing evacuation plans incorporating real-time data with dynamic routing and risk assessment. Real time updates to route planning based on how a fire is behaving and where its going based on weather, fuel availability, etc. Generative AI can be used to simulate the behavior of wildfires based on various parameters such as weather conditions, terrain, and vegetation types. Highlighted for ensuring efficient and safe evacuations during fire incidents. These simulations can help predict the spread of fires, allowing incident management teams to make more informed decisions about resource allocation and evacuation plans. Stressed for maintaining readiness and improving response effectiveness.

- **Simulation Training and Education:** Generative AI can be used to develop realistic training simulations to practice their skills in simulated wildfire scenarios. These simulations can help improve preparedness and response capabilities, ultimately leading to more effective wildfire management. Can support limited simulation exercises for response training, conduct realistic simulation exercises using geospatial data and/or AI-enhanced simulation and training scenarios for diverse wildfire scenarios.

- **Detailed Risk Assessment:** Generative AI models can analyze historical fire data along with environmental factors to assess the risk of wildfires in different regions. This information can be used to prioritize areas for preventative measures such as controlled burns or vegetation management.

- **Reliable Initial Detection**: Early detection of wildfires is critical for prompt response and containment. Current detection methods may lack reliability or coverage. Generative AI models can be trained to identify anomalies or unusual patterns in wildfire data, such as sudden changes in temperature, wind direction, or vegetation density, which could indicate the presence of a fire or heightened risk of ignition.

14.3. NIMS Phase 3, (Response) Operations/Logistics

Wants indicators of theater metrics for environmental sensors, GPS/ALV/Flight location sensors, resources, and staff to increase response decisions, more rapid efficient logistics decisions and follow-thru including resource incoming, fire behavior, nightly or intra-daily updates on IR, wind, spot weather, local, drone, in-situ or HRO imagery, feature detection from various IR (e.g., VIIRS) to improve GIS Trailer generated GIS products integrated with IAPs — e.g., boost current ftp.wildfire.gov approach. Integrating Generative AI with human-in-the-loop systems allows for collaborative decision-making, where AI systems generate recommendations or predictions that are reviewed and validated by human experts before being acted upon. This approach can improve the reliability and trustworthiness of AI-generated insights in wildfire management. This could yield:

- **Situational Awareness:** In cases where there is limited situational awareness during wildfires, situational awareness enhancements with real-time fire behavior data powered with AI can provide additional predictive analytics for incident management beyond data alone. This includes:

- **Geospatial Analysis:** Analyzing fire behavior and potential spread patterns could benefit from AI prediction in changes in fire behavior, intensity, perimeters, and smoke dispersion.

- **Remote Sensing:** Moving beyond basic interpretation of satellite imagery, AI analysis of satellite and UAV data for fire detection and monitoring. Autonomous interpretation and analysis of multi-source remote sensing data. This could include feeding past imagery to generate synthetic imagery products of what could happen based on predictive AI algorithms.

- **Data Integration:** Integrating weather, topographic, and vegetation data for fire modeling into GenAI could allow for increased AI capabilities based on real-time integration of satellite imagery, geospatial data, weather, and sensor data for analysis and predictive modeling.

- **Simulation and Prediction Modeling**: Generative AI combined with Advanced Modeling Techniques as suggested here-in can be used to simulate the behavior of wildfires based on various parameters such as weather conditions, terrain, and vegetation types. Gen AI could automate the generation of predictive fire probability reports based on inputs of soil conditions, vegetation, red flag, precipitation, humidity, etc. These simulations can help predict the spread of fires, allowing fire management teams to make more informed decisions about resource allocation and evacuation plans. Important for forecasting fire behavior and planning response strategies. Stakeholders unanimously prioritize predictive modeling across phases, indicating a strong desire for AI tools that can forecast fire behavior and assess risks. Such modeling can include basic trend analysis, forecasting of fire seasons, predictive models for fire behavior and ignition probabilities, wildfire spread, hotspot detection, containment, etc..

- **Initial Attack (IA) Tactical Map Generation**: Highlighted for creating actionable maps during the response phase. Initial GIS resources and availability of local data is typically limited early on. Generative AI can generate initial attack tactical maps by analyzing available resources and determining the most effective deployment strategy. This can help incident commanders make rapid decisions during the initial stages of a wildfire incident. This could automate the generation of original output geospatial files depicting fire perimeters from IR and GIS data to remove the human from the loop.

- **Decision Support Systems:** Implementing decision support systems for tactical and strategic planning can apply incident protocol guidance and augment existing complexity analysis and DSS for dynamic resource allocation and logistics, and other input into resource decisions.

- **Crisis Communication:** GenAI could assist PIO and liaison functions on key triggers, indicators, and other tools to support, basic communication protocols during wildfires, coordinated communication across agencies and public during emergencies and provide suggestions real-time for adaptive communication strategies incorporating AI-driven alerts — initially at least indirectly with human-in-the-loop solutions.

- **Smoke Dispersion Modeling**: Generative AI can be utilized to model the dispersion of smoke from wildfires, taking into account factors such as wind patterns, temperature, topography, imagery, and on the ground air quality sensors. This information can help predict air quality impacts and assist in issuing warnings to the public and vulnerable populations and impacts to evacuation planning where not directly related to fire danger, yet related to air quality.

- **Document Examination and Summarization**: Generative AI can examine documents related to fire management, such as incident reports, weather forecasts, and resource inventories, and summarize key information for decision-makers. This can be presented through dashboards or provided as ad-hoc requests, streamlining the planning process. Updated in real time, generated automatically as graphics and text reports.

- **Fire Behavior Modeling Scenarios**: Generative AI can generate rough fire behavior model scenarios by leveraging existing proven model inputs. By simulating different scenarios, fire management teams can better understand potential outcomes and adjust their strategies accordingly.

- **Field Assessment Support**: Generative AI can analyze images captured by in situ or field personnel's cameras to identify key factors such as LCES (Lookouts, Communications, Escape Routes, and Safety Zones), fuel types, fire behavior, and potential risks. This information, based on National Wildfire Coordinating Group (NWCG) materials and models in the US, can be provided within seconds, aiding in on-the-ground decision-making.

- **Real-Time Perimeter Mapping:** Accurate real-time mapping of fire perimeters is crucial for effective fire management and resource allocation. Tools leveraging remote sensing and evaluating such for real-time mapping and spatial analysis are crucial for enhancing situational awareness during responses. This is being done via tools such as the **US FireGuard** via **DoD FireFly**.

14.4. NIMS Phase 4, (Recovery) Operations

Wants to guide safety and further disaster factors such as soil, watershed, land and suppression repair recovery, and other burn severity products such as the USFS BAER program - **RAVG Applications** and planning for longer deployment of less resources.

This could yield:

- **Infrastructure Damage Assessment:** Generative AI can analyze aerial imagery and field reports to assess the damage to infrastructure such as roads, bridges, and utility lines caused by wildfires. This information can help prioritize repair and reconstruction efforts to restore essential services and infrastructure functionality. This includes basic assessment of immediate damages, conducting detailed damage assessments with remote sensing data, and/or AI-driven damage assessment models incorporating multi-source data. This can assist in post-event emergency management functions (e.g., mop-up, hotspot detection, burned area emergency response (BAER), and suppression repair), insurance entities, as well as other burned area emergency response efforts which could impact populations downstream of impacted watersheds.
- **Environmental Remediation:** Manual identification of environmental hazards, Identifying and prioritizing areas for environmental remediation, and/or AI-guided environmental impact analysis for targeted remediation strategies.
- **Long-Term Risk Reduction Strategies**: Generative AI can analyze the root causes of wildfires, such as land use practices, climate change, and human behavior, to develop long-term risk reduction strategies. These strategies can include policy recommendations, land management practices, and community resilience initiatives aimed at reducing the frequency and severity of wildfires over time. Stakeholders emphasized preventing future incidents and improving resilience.
- **Post-Fire Recovery Planning:** After a wildfire has been contained, generative AI can be used to support burned area emergency response efforts to assess the damage and predict the potential for erosion, landslides, and other post-fire hazards. This information can inform post-fire recovery efforts and help mitigate the long-term impacts of wildfires on ecosystems and communities.
- **Assessment of Burn Severity**: Generative AI can analyze satellite imagery and ground-based data to assess the severity of burn areas following a wildfire. This information can help prioritize post-fire recovery efforts and identify areas at risk of erosion, landslides, and other post-fire hazards.
- **Ecosystem Recovery Planning**: Generative AI can develop ecosystem recovery plans by analyzing the impacts of wildfires on vegetation, soil, and wildlife habitats. These plans can include strategies such as revegetation, erosion control, and habitat restoration to

facilitate natural regeneration and recovery. This includes basic recovery plans focusing on infrastructure restoration or developing comprehensive recovery plans considering long-term impacts.

- **Post-Event Remediation:** Effective post-event remediation efforts are necessary to mitigate the long-term impacts of wildfires on ecosystems, communities, and infrastructure. Highlighted for mitigating environmental impacts post-fire.