Pathogens and Permafrost Workshop II
September 18-19, 2024

Workshop Report

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Acknowledgements:

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Problem Statement

Planetary scale environmental dynamics are resulting in the thawing of large tracts of permafrost soils in and beyond the Arctic. To date, an estimated three to four percent of global permafrost has thawed since observations began, but the rate of thaw is accelerating. Permafrost is a reservoir of mostly uncharacterized microorganisms, fungi, and viruses, several of which carry the potential for pathogenesis through either direct or indirect pathways. Our current knowledge of permafrost-resident microbes' viability during thaw to transition into pathogenesis pathways relevant to human activity is limited. Therefore, we lack a foundational basis on which to assess risks to field operations or the public in polar regions.

On November 2-3, 2023, the first Permafrost and Pathogens Workshop brought together military operators, medical professionals, academic scientists, and cold regions scientists and engineers to establish a knowledge baseline from which the implications for human health and the sustainment of operations in an evolving Arctic environment could be assessed and developed. Three dominant themes emerged from that first workshop: there is a need for a coordinating authority; planning needs to start now to address accelerating, compounding processes; and a first step must be the aggregating and meta-analysis of existing data and samples. Four suggested lines of effort (LOE) emerged from the session: addressing requirements, developing a working model, establishing baselines, and identifying monitoring and surveillance indicators (Figure 1).

Suggested Lines of Effort	
LOE 1 Requirements – Disseminated through coordinating DOD agency/gaps provided to science agencies	
	Strategic communications package: Education and Awareness (maps to Arctic Implementation Plan)
	Coordination to establish a comprehensive baseline
	Protective measures such as minimizing thermal footprint, waste handling, etc.
LOE 2 Working Model (harness lessons learned and leverage underutilized programs/translators)	
	Scenarios of future conditions we should plan toward
	Assess microbial reservoirs in permafrost and identify controlling variables for pathogenesis
	Human impacts broadly – (DOD impacts on permafrost and potential to probability)
	Permafrost impact on mission in all domains
LOE 3 Establishing baselines	
	Sharing data – International and national guidelines
	Permafrost and pathogen level baseline maps (used to assess changes relative to)
	Clinical indicators and existing information from diverse resident communities working and living in permafrost: native communities, mining operations, DOD operations, etc.
LOE 4 Monitoring and surveillance indicators for early detection	
	Applies to both permafrost and clinical surveillance (which is a public health approach)
	Canada and U.S. Surgeon Generals' Offices: best practices
	Physical conditions (rate of thaw, ice content, carbon content, water quality)
	Data sharing and Guidelines – International and national
	Wildlife monitoring through partnerships with other agencies such as USFWS, USDA etc.

Figure 1: Lines of Effort (LOE) from the first Pathogens and Permafrost workshop.

This workshop, P&P-II, focused on expanding the knowledge base and addressing each LOE in greater depth to further enhance our ability to anticipate the risks and develop pathways to support resilience in food, water and energy in the changing circumpolar North. To provide a logical flow of discussion, LOE's 2 through 4 were addressed prior to LOE-1.

Methodology

The P&P-II workshop followed the Quadrant Enabled Delphi (QED) methodology as per Alessa et al. 2018, hybridized with two traditional facilitated discussions based on topic. The workshop operated under the Chatham House Rule.

Initial group elicitation (brainstorming) identified scenarios of concern relative to pathogens and permafrost, which was then expanded into a discussion on developing a working model. Subsequent phases covered establishing baselines, monitoring and surveillance indicators, strategic communications, and potential next steps to expand our body of knowledge and capability.

The Pareto/N3 Dot exercise was used to prioritize participant responses, based on criticality, urgency for action (timeliness), and the single most significant issue for each participant. In addressing the second half of LOE-2 (establishing baselines), participants determined that the topic needed to be expanded to address known pathogens (e.g., smallpox) as different from unknown pathogens. Two Pareto/N3 exercises were conducted simultaneously to capture the differences. The exercises included the following assessments:

- Criticality as a measure of importance for an issue to be addressed, evaluated as "critical," "important," and "helpful."
- Urgency/time frame for action, evaluated as "within 1 year," "1-5 years," "5+ years."
- Most significant priority – the identification of the single highest priority issue to be addressed for each participant.

Data analysis was conducted using weighted linear regression of data acquired through the brainstorming and Pareto/N3 process. A total of 1,961 data points were collected over two days.

Demographics

Twenty individuals attended, 50% male, 50% female. Two individuals were under the age of 35, 7 between 35 and 50 years old, 8 between 50 and 60 years old, and 3 above 65 years old. Ten participants held Doctorate Degrees, with two having dual PhDs. Four held Masters Degrees, and the remainder held at least a Bachelors Degree.

Two individuals self-identified as strictly academics, thirteen as Arctic practitioners, three as administrative or policy professionals, six as operators (more generally than Arctic-specific practitioners), four as military (either active duty or prior service), and six as Department of Defense (DOD) civilians. (Totals add up to greater than the participant counts due to some participants identifying with multiple roles.)

Attendees represented seven U.S. Federal Government Departments or Agencies, two U.S. universities, one National Laboratory (owned by the Department of Energy), and one “emeritus” member who previously held both Academic and U.S. federal government positions. Participating federal government organizations included: The Department of Defense (Defense Advanced Research Project Agency, the U.S. Army Engineer Research and Development Center/Cold Regions Research and Engineering Laboratory, Special Operations Command North, and the U.S. Army War College), the Department of Homeland Security (Federal Emergency Management Agency and the Office of Health Security), the Office of the Director of National Intelligence, and the Pacific Northwest National Laboratory. Participating Universities included the University of Idaho/Center for Resilient Communities and the University of Alaska Fairbanks.

Line of Effort 2, Part 1 Results: Scenarios to Plan Toward

Following administrative and logistics issues, and a briefing on the results of the first workshop, P&P-II began with a facilitated discussion to elicit possible scenarios of concern.

Initial discussions centered around possible economic and agricultural impacts of a pathogen being released from thawing permafrost. It was felt that direct impacts on agriculture would be minimal, as there simply isn't significant agriculture in areas of permafrost. However, transmitted impacts could be significant and due to a variety of factors, agriculture is slowly moving northward.

The participants expressed that the conditions of exposure and transmittal pathways were important. Both direct (e.g., contact with a released pathogen) and indirect (e.g., a pathogen carried by wildlife) exposures are possible.

This led to a discussion of possible conditions of release. Rate of thaw was seen as important, as rapid thawing might increase the possibility of pathogen survival, while a slower thaw might lead to acclimatization by local organisms. Depth was seen as an additional important condition, not only in terms of potential for release but also in terms of pathogen age (such as release of pathogens from the 1918-1920 influenza epidemic vs. novel Pleistocene pathogens).

Finally, participants expressed that not all organisms are pathogenic. There were also potential untapped benefits from organisms in permafrost that should not be forgotten. Emerging biotechnologies might be discovered, in a similar vein to organisms found in tropical climates by pharmaceutical company exploration.

However, it was also posited that there were potential downsides to such biotechnology discoveries, and adversaries might be able to use novel pathogens for nefarious purposes. Surveillance and research were seen as needing to be closely monitored.

During the first part of discussing LOE-2, the workshop identified fourteen scenarios of concern and prioritized them in terms of how critical the pathway was, what time frame it should be addressed in, and what was seen as the single most critical scenario to be addressed. Negative and positive scenarios regarding agriculture, release by natural degradation (such as shoreline erosion), and direct exposure during indigenous activities such as camping, hunting, etc., were seen as the three most critical (Table 1). When time to act was considered, the same top three scenarios remained, though natural degradation was seen as less immediate than indigenous activities (Table 2). However, when participants rated the scenarios in terms of the single greatest criticality, the potential of a purposeful release was seen as most concerning, followed by natural degradation and direct exposures during military operations (Table 3).

Input:	Criticality	Urgency
Agricultural Scenario - Negative and Positive	79	71
Natural Degradation (e.g., shoreline)	45	58
Indigenous activities (camping, hunting, etc.)	45	62
Significant landscape modification (e.g., construction, natural disaster) - Long Term	40	35
Purposeful release	37	55
Direct Exposure - Military Operations (e.g., FOB, exercises)	37	28
Avian Transport	31	33
Direct Exposure - Commercial Operations (e.g., drilling, mining)	30	41
Excavated Organism (e.g., fungi)	25	51
Wildfire driven permafrost release	24	31
Hysteresis - Long/delayed detection	19	31
Weather change (rapid release)	13	55
Significant landscape modification (e.g., construction, natural disaster) - Short Term	12	32
Direct Exposure - Tourism	10	36

Table 1: Potential permafrost and pathogen scenarios, ranked by criticality.

Input:	Criticality	Urgency
Agricultural Scenario - Negative and Positive	79	71
Indigenous activities (camping, hunting, etc.)	45	62
Natural Degradation (e.g., shoreline)	45	58
Purposeful release	37	55
Weather change (rapid release)	13	55
Excavated Organism (e.g., fungi)	25	51
Direct Exposure - Commercial Operations (e.g., drilling, mining)	30	41
Direct Exposure - Tourism	10	36
Significant landscape modification (e.g., construction, natural disaster) - Long Term	40	35
Avian Transport	31	33
Significant landscape modification (e.g., construction, natural disaster) - Short Term	12	32
Wildfire driven permafrost release	24	31
Hysteresis - Long/delayed detection	19	31
Direct Exposure - Military Operations (e.g., FOB, exercises)	37	28

Table 2: Potential permafrost and pathogen scenarios, ranked by time frame for action.

Input:	Most Critical
Purposeful release	7
Natural Degradation (e.g., shoreline)	6
Direct Exposure - Military Operations (e.g., FOB, exercises)	2
Avian Transport	1
Direct Exposure - Commercial Operations (e.g., drilling, mining)	1
Agricultural Scenario - Negative and Positive	0
Excavated Organism (e.g., fungi)	0
Direct Exposure - Tourism	0
Weather change (rapid release)	0
Wildfire driven permafrost release	0
Indigenous activities (camping, hunting, etc.)	0
Significant landscape modification (e.g., construction, natural disaster) - Short Term	0
Significant landscape modification (e.g., construction, natural disaster) - Long Term	0
Hysteresis - Long/delayed detection	0

Table 3: Potential permafrost and pathogen scenarios identified by participants as the single most critical to be addressed.

Line of Effort 2, Part 2 Results: A Working Model

Following identification of potential scenarios of concern, discussion of LOE-2 progressed to establishing a working model and determining what needs to be measured and understood. Four quadrants were used during the elicitation phase:

- Microbial Reservoirs
- Controlling Variables
- Human Impacts (on the environment)
- Permafrost/Pathogen Impacts on Missions in all Domains.

Participants noted two key variables in understanding pathogenicity: location (for example, sea water, airborne, etc.) and vectors. As an example, if a pathogen were carried by mosquitoes, a population increase of the insects would increase the likelihood of potential transmission. Similarly, the interactions between humans and the vectors need to be accounted for. Mosquitoes have a higher interaction rate with humans than birds, again increasing the likelihood of potential transmission.

To develop a working model, mobility thresholds are necessary, especially those related to operations (e.g., scenarios), and chains of mobilization (i.e., from pathogen release along a vector to pathogen effect). This will require developing rulesets to determine if/when a pathogenic effect occurs, and thresholds for action to determine risk.

Data availability was seen as a potential obstacle to developing a working model. Current data is incomplete, and models are only as good as the data they rest upon. An iterative process whereby a model was improved as state of awareness expanded was deemed a necessity, and an initial proof of concept model with a limited scope and application was considered the most effective path forward.

While identifying what needs to be measured and understood, the workshop participants observed that two models were necessary. The first needs to address pathogens that we know and understand, such as the 1918-1920 influenza epidemic, which is now recognized as having been caused by influenza type A subtype H1N1. The second needs to address what we don't yet know – the novel pathogens.

Immediately prior to conducting the Pareto exercise, applicability was raised. One cohort member noted that an easy, straightforward preventative mechanism was to simply not go where a pathogen had historically impacted a location, e.g. "stay away from where there was anthrax." This led to discussion of how comfortable the group was on understanding how controlling variables affect pathogenesis, and how to use data and identify risks. While there was a generally low confidence in our current understanding (especially in the case of novel pathogens), it was felt that one argument for building a controlling variables list was to eliminate less important variables.

Following the collective brainstorming session, participants were asked to rate elicited topics in terms of criticality, urgency for action (time frame), and overall priority. To identify differences, the Pareto/N3 exercise was adjusted, with each identified input across the quadrants split into a "known" and an "unknown" column and two complete sets of multi-voting dots provided. The two exercises were run simultaneously.

"Known" Pathogens

The highest ranked ten topics regarding "known" pathogens from each rating are displayed in table form in Tables 4 to 6, below. A complete listing of topics and ratings, sorted by quadrant and criticality, may be found in Appendix B.

When ranked by criticality (Table 4), a poor understanding of pathogenic states of known permafrost microbes was seen as most critical, followed by information sharing impediments, and then a need for a predictive capability regarding reservoirs as they relate to permafrost types and conditions. When rated in terms of urgency and time frame (Table 5), the ability to develop timely workflows for planning was evaluated as being needed the most quickly, followed by addressing information impediments, and then being able to determine thaw rates and intensities based on thermal variables.

When evaluated by participants in terms of the single most crucial issue to be addressed (Table 6), understanding pathogenic states was significantly elevated from the next two issues, those of addressing information sharing impediments and developing an ability to plan for unknowns.

Input:	Quadrant	Criticality	Urgency
Poorly understood pathogenic state of permafrost microbes	*Microbial Reservoirs*	38	36
Information Sharing	*Permafrost/Pathogen impacts on missions in all domains*	35	43
Predicting reservoirs based on permafrost type/conditions	*Microbial Reservoirs*	29	14
Thaw Rate & Intensity - thermal	*Controlling Variables*	23	39
Develop a bio-economy w/new knowledge	*Human Impacts*	22	14
Mobility of microbes in the reservoir	*Microbial Reservoirs*	20	16
One Health "Model"	*Human Impacts*	18	17
Threshold of Risk -> Viral, physical, environment (water)	*Permafrost/Pathogen impacts on missions in all domains*	18	2
Permafrost Type - Continuous, Discontinuous	*Controlling Variables*	14	22
Gap - which org have pathogenesis tendencies	*Controlling Variables*	14	24

Table 4: Top ten issues needing to be understood to develop a working model of known pathogens, ranked by criticality.

Input:	Quadrant	Criticality	Urgency
Workflows for Planning (classified/timely)	*Permafrost/Pathogen impacts on missions in all domains*	2	66
Information Sharing	*Permafrost/Pathogen impacts on missions in all domains*	35	43
Thaw Rate & Intensity - thermal	*Controlling Variables*	23	39
Poorly understood pathogenic state of permafrost microbes	*Microbial Reservoirs*	38	36
Risk of unknowns -> Planning	*Permafrost/Pathogen impacts on missions in all domains*	12	26
Operational Detection Kits	*Permafrost/Pathogen impacts on missions in all domains*	4	26
Gap - which org have pathogenesis tendencies	*Controlling Variables*	14	24
Permafrost Type - Continuous, Discontinuous	*Controlling Variables*	14	22
Effects of environment on mutagenesis	*Microbial Reservoirs*	2	22
Reservoirs of ancient microbes that humans haven't encountered	*Microbial Reservoirs*	9	19

Table 5: Top ten issues needing to be understood to develop a working model of known pathogens, ranked by time frame for action.

Input:	Quadrant	Most Critical
Poorly understood pathogenic state of permafrost microbes	*Microbial Reservoirs*	8
Information Sharing	*Permafrost/Pathogen impacts on missions in all domains*	1
Risk of unknowns -> Planning	*Permafrost/Pathogen impacts on missions in all domains*	1
One Health "Model"	*Human Impacts*	1
Human Interactions with: Vectors, Seasons, Mobility	*Human Impacts*	1
Model of known human impacts to known pathogens	*Human Impacts*	0
Amount of Sunshine	*Controlling Variables*	0
Physical environment as a threshold	*Microbial Reservoirs*	0
Risk threshold + impact	*Microbial Reservoirs*	0
(Lack of) Communication of Knowledge	*Human Impacts*	0

Table 6: Issues to be understood to develop a working model of known pathogens, ranked by participants as the single most critical to be addressed.

"Unknown" Pathogens

The highest ranked ten topics regarding "unknown" pathogens from each rating are displayed in table form in Tables 7 to 9, below. A complete listing of topics and ratings, sorted by quadrant and criticality, may be found in Appendix C.

When ranked by criticality, the risk of unknowns related to planning was seen as most critical, followed by the current poor understanding of pathogenic states of permafrost microbes and a need to predict reservoirs based on permafrost types and conditions. When rated in terms of urgency and time frame, impediments to information sharing were seen as the issue needing resolution in the immediate near term, followed by understanding what types of organisms have pathogenic tendances and improving current understanding of pathogenic states of permafrost microbes.

When evaluated by participants in terms of the single most crucial issue to be addressed, the current poor understanding of pathogenic states of permafrost microbes for unknown pathogens was significantly elevated from the next two issues, those of addressing what types of organisms have pathogenic tendances and the application of a One Health model as a framework for action.

Input:	Quadrant	Criticality	Urgency
Risk of unknowns -> Planning	*Permafrost/Pathogen impacts on missions in all domains*	31	21
Poorly understood pathogenic state of permafrost microbes	*Microbial Reservoirs*	23	38
Predicting reservoirs based on permafrost type/conditions	*Microbial Reservoirs*	22	28
Information Sharing	*Permafrost/Pathogen impacts on missions in all domains*	20	48
Thaw Rate & Intensity - thermal	*Controlling Variables*	20	22
Reservoirs of ancient microbes that humans haven't encountered	*Microbial Reservoirs*	16	14
Use phylogeny to better understand unknown microbes & their pathogenicity	*Microbial Reservoirs*	16	17
Ecological controls (i.e. competition)	*Controlling Variables*	15	22
Gap - which org have pathogenesis tendencies	*Controlling Variables*	15	47
Threshold of Risk -> Viral, physical, environment (water)	*Permafrost/Pathogen impacts on missions in all domains*	13	13

Table 7: Top ten issues needing to be understood to develop a working model of unknown pathogens, ranked by criticality.

Input:	Quadrant	Criticality	Urgency
Information Sharing	*Permafrost/Pathogen impacts on missions in all domains*	20	48
Gap - which org have pathogenesis tendencies	*Controlling Variables*	15	47
Poorly understood pathogenic state of permafrost microbes	*Microbial Reservoirs*	23	38
Predicting reservoirs based on permafrost type/conditions	*Microbial Reservoirs*	22	28
Model Workflows	*Microbial Reservoirs*	11	23
Thaw Rate & Intensity - thermal	*Controlling Variables*	20	22
Ecological controls (i.e. competition)	*Controlling Variables*	15	22
Risk of unknowns -> Planning	*Permafrost/Pathogen impacts on missions in all domains*	31	21
Operational Detection Kits	*Permafrost/Pathogen impacts on missions in all domains*	5	20
Human Interactions with: Vectors, Seasons, Mobility	*Human Impacts*	12	19

Table 8: Top ten issues needing to be understood to develop a working model of unknown pathogens, ranked by time frame for action.

Input:	Quadrant	Most Critical
Poorly understood pathogenic state of permafrost microbes	*Microbial Reservoirs*	12
Gap - which org have pathogenesis tendencies	*Controlling Variables*	2
One Health "Model"	*Human Impacts*	2
Model Workflows	*Microbial Reservoirs*	1
Risk of unknowns -> Planning	*Permafrost/Pathogen impacts on missions in all domains*	1
Mobility Threshold	*Permafrost/Pathogen impacts on missions in all domains*	1
Threshold of Risk -> Viral, physical, environment (water)	*Permafrost/Pathogen impacts on missions in all domains*	1
Develop a bio-economy w/new knowledge	*Human Impacts*	1
Prior Occupation Locations	*Human Impacts*	0
Context...Threshold(s) of Physical Environmental Exposure	*Human Impacts*	0

Table 9: Issues to be understood to develop a working model of unknown pathogens, ranked by participants as the single most critical to be addressed.

Line of Effort 3 Results: Establishing a Baseline

Discussion of LOE-3 rapidly focused on determining how a baseline map could be developed as an instrument for identifying change, and who should develop and maintain such a map. Participants worked across four quadrants, though there was consensus that conducting a Pareto/N3 exercise was unnecessary:

- Data Sources (International/National/Local)
- National Data Sharing (Who/How)
- International Data Sharing (Who/How)
- Developing a Baseline Map (Who/How)

In addressing data sources, discussion focused on what types of data would be useful in establishing a baseline and potentially tracking changes against that baseline. Four broad categories emerged: geophysical, health, pathogen-specific, and activities (Table 10). Geophysical data, when combined with activity data, would enable mapping of potential risks. Historical health data (e.g., epidemiologic data) would assist in pinpointing potential reservoirs of known pathogens. Current health data would aid in detecting releases. Pathogen specific data, including potential vectors of transmission, would enable both evaluation and response to a detected release.

Data Source Types			
Geophysical	*Health*	*Pathogen-specific*	*Activity*
Weather	Clinical (Epidemiology)	Metagenomic	Land use (Past/Present)
Spatiotemporal Permafrost	Clinical Signatures	Vector Data	Transportation Routes
Geological		Morphology	Soil Activity
Satellite Imagery			Economic Activity
Wildfires			Census
Environment (Historical/Current)			Local History (Oral)
Atmosphere (i.e., aerosol)			Local Observation
Hydrology			Wildlife Migration
Ecotype/Land Cover			

Table 10: Types of data for developing a baseline.

Multiple national and international data sources were identified, though it was noted that privacy concerns related to information about issues such as healthcare would require differing levels of user access to any specific baseline data, and that some levels of access might extend into the classified domain. Additionally, differing privacy laws could impact data collection, especially internationally. Authorities to collect, hold, and process data were identified as a potential impediment as well.

A wealth of possible sources of data and information were identified, Table 11, and though the list was non-exhaustive, might provide a starting point for developing a baseline. It was universally agreed that a more exhaustive inventory needed to be developed.

National Data Sharing	
Organization (Alphabetical)	*Data/Information*
Alaska Local Governments, e.g., North Slope Borough	Geophysical, Health, Activity
Alaska Native Regional Corporations	Health, Activity
Alaska Native Tribal Entities	Health, Activity
Department of Commerce (DOC) National Marine Fisheries Service (NMFS) National Oceanic and Atmospheric Administration (NOAA)	Geophysical, Health, Activity
Department of Defense (DOD): Cold Regions Research and Engineering Laboratory (CRREL) Defense Intelligence Agency (DIA) National Center for Medical Intelligence (NCMI) Naval Research Laboratory (NRL)	Risk Assessment, Geophysical, Pathogen, Activity
Department of Homeland Security (DHS) Office of Health Security (OHS) Federal Emergency Management Agency (FEMA)	Health, Activity
Local Environmental Observer (LEO) Network	Health, Activity
National Academies (NAS) Polar Research Board (PRB)	Geophysical, Health
National Aeronautics and Space Administration (NASA)	Geophysical, Activity, Satellite
National Geospatial-Intelligence Agency (NGA)	Satellite
National Institutes of Health (NIH)	Health
National Laboratories: Pacific Northwest National Laboratory (PNNL) Los Alamos National Laboratory (LANL) Sandia National Laboratory (SNL) Oak Ridge National Laboratories (ORNL) Next-Generation Ecosystem Experiments (NGEE Arctic) Lawrence Berkeley National Laboratory Joint Genome Institute	Long-term Environmental, Geophysical, Pathogen, Activity
National Science Foundation (NSF) Arctic Data Center (ADC) National Ecological Observatory Network (NEON)	Long-term Environmental, Geophysical, Activity
National Snow and Ice Data Center (NSIDC)	Geophysical
State of Alaska Department of Natural Resources (DNR) Department of Fish and Game (ADF&G)	Geophysical, Health, Human Activity

National Data Sharing	
Organization (Alphabetical)	*Data/Information*
The White House: Office of Science and Technology Policy (OSTP), Arctic Executive Steering Committee (AESC) National Science and Technology Council (NSTC) Interagency Arctic Research Policy Committee (IARPC) –	Interagency Coordination, Policy
Tri-Service (U.S. Navy, Marine Corps, Coast Guard)	Health, Activity
U.S. Centers for Disease Control and Prevention (CDC) CDC Arctic Investigation Program (AIP)	Health, Pathogen
U.S. Geological Survey (USGS)	Geophysical
Vetted Universities (e.g., the University of Idaho)	Geophysical, Health, Pathogen, Activity
Woods Hole Oceanographic Institution (WHOI)	Geophysical

Table 11: Non-exhaustive list of possible national data sources and partners.

Internationally, there was seen to be a wealth of potential data sources to support developing a baseline. Some examples were offered, and it was noted that legacy data from Siberia is available as well, potentially expanding understanding despite current strained relations with the Russian Federation.

- The International Permafrost Microbiome Network
- Provincial Public Health Data from Canada
- INTERACT Network (Sweden)
- Finnish Meteorological Institute
- Vetter international academic institutions

After discussing types of data and possible sources, the workshop turned to the development of a baseline map, parameters that needed to be considered, and potential organizations that might undertake the project.

The consensus was that a geographic information system (GIS) would be most effective, and an initial proof of concept should be developed, with a relatively limited scope (the State of Alaska only), but a resolution of 1.0 km^2 to demonstrate use as an Operational Risk Map. While the initial scope was proposed as limited, later expansion could encompass broader geographies and other use cases such as public health and safety. The map envisioned would need to have different layers identifying unique operating conditions, permafrost and known risk areas (e.g., burial sites), environmental states (e.g., weather and sea states, freeze, thaw, and project timelines), and unique equipment and sustainment requirements.

Privacy concerns and different user access levels were seen as increasing cost, but use of cloud-based systems such as Amazon Web Services offered a cost reduction. Similarly, the use of open-source code to the greatest extent possible would also reduce costs and development time.

Any data ingested would need to be identified as available and ready to use, with minimal curation. Data integrity was seen as critical and requiring care in both acquisition and maintenance.

Multiple possible hosts or developers were discussed, but in the end the belief was that CRREL made the greatest sense, as it already housed GIS capabilities, possesses a wealth of arctic/polar knowledge, and was seen as neutral in terms of serving multiple missions. While currently not tasked with such an endeavor, and in need of resources (funding) to support one, CRREL participants did note that they currently had two applicable Program Element codes in their budget. A proposed model involved the U.S. Army Corps of Engineers as the parent agency, with CRREL coordinating with appropriate partners such as the National Geospatial-Intelligence Agency, Pacific Northwest National Laboratories, etc., in an iterative cycle, Figure 2.

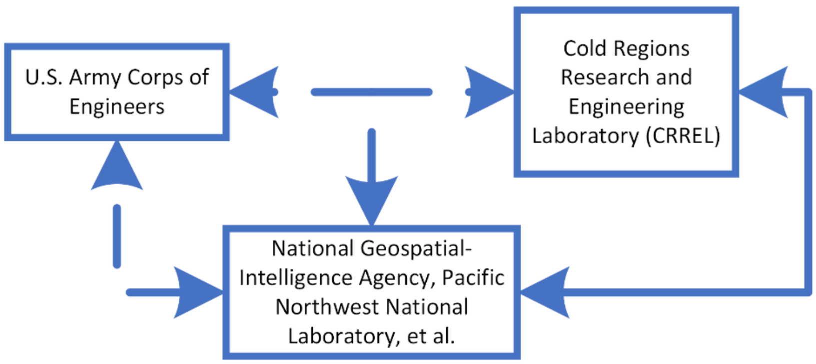

Figure 2: Iterative process for developing proof of concept baseline map.

As a final point in the discussion, one of the participants observed that the Fifth International Polar Year (IPY) preparations are currently taking place. Consultation and engagement with stakeholders and the research community will occur during 2024 and 2025, in preparation for 2032/2033. The individual observed that linking P&P to IPY activities might be beneficial.

Line of Effort 4 Results: Monitoring and Surveillance Indicators for Early Detection

Given a baseline as proposed under LOE-3, discussion moved to its use in detecting permafrost conditions/changes and pathogen emergence, in terms of what needed to be monitored for change.

Four quadrants were used during the elicitation phase:

- Public Health – Clinical Indicators
- Initial National Policy Needs
- Physical Conditions (e.g., thaw, ice content, carbon content, etc.)
- Wildlife monitoring

Monitoring and surveillance of the abiotic components was seen as relatively straightforward, though detailed mapping at scale remains difficult. Use of satellite imagery to detect (for example) ground cover and thermal conditions, as well as other remote sensing technologies, has the potential to narrow this capability gap. Determining physical changes would help to estimate the rate of change and estimate stability, an important variable to both operational guidance and tracking risk.

Monitoring the biological layers, except for such issues as ground cover, will be more difficult, requiring both field observations and instrumentation. Deploying some form of community-based observation system in partnership with local populations will be a necessary means of expanding information collection and has the added benefit of providing context from the observers (Alessa et al, 2015, Griffith et al, 2018).

A third layer of monitoring and surveillance needed is that of the impact of human activity on the environment. For example, understanding the dynamics of commercial activities such as resource exploitation, or military activities such as establishing Forward Operating Bases during exercises, will provide insight into changes driven by such things as heat bubbles, waste, etc.

The use of proxies was discussed in depth, as a means of increasing monitoring with minimal investment. For example, economic data could not only indicate levels of human activity but also increasing illness through tracking of prescription and over-the-counter medications. Construction data from the Department of Transportation could predict potential environmental changes. Data on worker sick days tracked over time might reveal a slow emergence pathogen to which communities are adapting.

Finally, from a scientific perspective, one participant noted that, especially in the case of non-lethal pathogenesis, there was the possibility of tracking and observing immune system training. We could observe adaptation in real time if the Arctic change is “slow enough.”

The ten highest ranked monitoring and surveillance indicators/issues are displayed in table form in Tables 12 to 14, below. A complete listing of topics and ratings, sorted by quadrant and criticality, may be found in Appendix D.

When discussing what was critical for surveillance and monitoring, participants identified as the most pressing issue an initial national policy need, that of countering disinformation. In fact, three of the top ten issues identified fell under the initial national policy umbrella (Table 12). The second most critical was policy and technology transfer, in relation to ensuring continuity and sustainability of the baseline and monitoring/surveillance system. Third was information sharing, specifically with respect to interagency sharing of medical records while protecting privacy and civil liberties.

The remaining indicators addressed physical conditions, public health, and wildlife monitoring to identify differing vectors and potential pathogen sources.

In looking at surveillance and monitoring in terms of time frames for action, the most critical issue was understanding landscape stability/instability. Second was addressing disinformation, followed by enhanced information sharing, especially with respect to medical information. (Table 13).

When ranked in terms of the single most critical issue for each participant, monitoring landscape stability/instability was rated highest by a third of the participants (Table 14). Gathering and evaluating local (village nurse, clinician, health aide) reports through a systematic reporting system was second. Information sharing, especially with respect to interagency medical records was third.

Input:	Quadrant	Criticality	Urgency
Countering disinformation	Initial National Policy Needs	54	48
Policy and technology transfer in support of continuity/sustainability	Other	49	45
Information sharing - interagency medical records (i.e. CDC, DOT)	Initial National Policy Needs	47	48
Landscape stability/instability	Physical Conditions	29	49
Zoonotic disease spread	Wildlife Monitoring	26	34
Use existing reporting systems, if available (who to these data go to?)	Public Health	25	33
Village nurse & clinician & health aide reports through systematic reporting system	Public Health	25	16
Biological incident response plans for interagency operations	Initial National Policy Needs	25	38
How to monitor biological attributes	Physical Conditions	16	28
Population or migration changes of organisms (fish, caribou, etc.)	Wildlife Monitoring	15	22

Table 12: Top ten monitoring and Surveillance Indicators/Issues, ranked by criticality.

Input:	Quadrant	Criticality	Urgency
Landscape stability/instability	Physical Conditions	29	49
Countering disinformation	Initial National Policy Needs	54	48
Information sharing - interagency medical records (i.e. CDC, DOT)	Initial National Policy Needs	47	48
Policy and technology transfer in support of continuity/sustainability	Other	49	45
Biological incident response plans for interagency operations	Initial National Policy Needs	25	38
Microbiological indicators affecting landscape conditions & responding to conditions	Wildlife Monitoring	13	35
Zoonotic disease spread	Wildlife Monitoring	26	34
Use existing reporting systems, if available (who to these data go to?)	Public Health	25	33
How to monitor biological attributes	Physical Conditions	16	28
Arctic investigation service w/CDC - AK native tribal health consortium	Public Health	13	27

Table 13: Top ten monitoring and Surveillance Indicators/Issues, ranked by urgency.

Input:	Quadrant	Most Critical
Landscape stability/instability	*Physical Conditions*	7
Village nurse & clinician & health aide reports through systematic reporting system	*Public Health*	6
Information sharing - interagency medical records (i.e. CDC, DOT)	*Initial National Policy Needs*	5
Use existing reporting systems, if available (who do these data go to?)	*Public Health*	1
Use proxy data (e.g. OTC meds purchased) & economic indicators	*Public Health*	1
Policy and technology transfer in support of continuity/sustainability	*Other*	0
Zoonotic disease spread	*Wildlife Monitoring*	0
Population or migration changes of organisms (fish, caribou, etc.)	*Wildlife Monitoring*	0
Biological incident response plans for interagency operations	*Initial National Policy Needs*	0
Infrastructure	*Physical Conditions*	0
Opportunities for citizen science & industry partnerships	*Initial National Policy Needs*	0
Microbiological indicators affecting landscape conditions & responding to conditions	*Wildlife Monitoring*	0
Arctic investigation service w/CDC - AK native tribal health consortium	*Public Health*	0
Positive side of non-lethal pathogenesis: immune system training	*Public Health*	0

Table 14: Monitoring and Surveillance Issues/Needs ranked by participants as the single most critical to be addressed.

Line of Effort 1 Results: Strategic Communications

Under the heading of strategic communications, the P&P-II workshop participants discussed ways and means of communicating awareness of the potential risks posed by pathogens in permafrost. Quadrants were not used for this session, nor was a Pareto/N3 exercise conducted.

Discussions were framed around both educational outreach and potential use of a baseline map and tool by end users. However, it was emphatically expressed that not all information could be publicly shared due to privacy and security concerns. Participants felt that there was a tension between the public's need to know or right to know and security, creating an issue requiring caution. As an interim solution, it was determined that if a baseline and tool were developed, they would initially be government use only. Access to broader sectors and users might follow if appropriate protocols could be generated.

Multiple potential avenues of outreach were identified (Table 15). Each pathway represented different audiences who would need to have specific, tailored messaging. For example, in communicating with the tourism industry, risk awareness and safety would be primary messages. It was specifically noted that communications with certain entities could be challenged by issues such as aggregation of information that crossed classification thresholds, or limitations on government personnel abilities to speak with legislators.

After identifying potential audiences, the group discussed what types of information could be communicated effectively. In almost all cases, it was determined that not only should possible risks be addressed, but that discussion of potential benefits of organisms identified in permafrost would be useful. The central messages were how to be ready for a potential release, how to prevent one, and how to respond if a pathogen outbreak took place.

It was proposed that the group of participants at P&P-II might serve as a nucleus that could develop a strategic communications plan, complete with talking points. This proposal remains under evaluation. It was also proposed that the results of the two P&P workshops should be written up for publication in peer-reviewed scientific journals, which was generally agreed upon.

Potential Communications Audiences	
Community/Group	*Objective (if identified)*
Someone able to help break down information sharing walls	Seek assistance in information sharing
Citizens	General awareness of risks
Policy Makers – Federal	Awareness, engagement, risk management
Policy Makers – State	Awareness, engagement with citizens and State Government, risk management
Policy Makers – Local	Awareness, engagement with citizens, risk management
Policy Makers – Tribal	Awareness, engagement with tribes, risk management
Decision Makers – Federal	Awareness, support, risk management

Potential Communications Audiences	
Community/Group	*Objective (if identified)*
Decision Makers – State	Awareness, support, engagement with citizens and State Government, risk management
Decision Makers – Local	Awareness, engagement with citizens, risk management
Decision Makers – Tribal	Awareness, engagement with tribes, risk management
Field Personnel – Companies	Awareness, observers, safety
Field Personnel – Operators (e.g., DOD)	Awareness, observers, safety
Field Personnel – Scientists	Awareness, observers, safety
Entertainment Industry	Public awareness
Media	Public education/awareness
Health Care Providers	Observers, safety
Scientists/Academia	Research partners, awareness
Office of Management and Budget	Awareness in support of efforts
Science Journals (e.g., Science, Eos, etc.)	Published research toward education/understanding
Tourists	Awareness, safety
Tourism Industry	Awareness, safety
Native Corporations	Awareness, engagement with tribes, risk management
The Hill	Awareness in support of efforts
Government Communications Personnel	Awareness, engagement with the public and governmental organizations

Table 15: Potential communication audiences and objectives of engagement.

Conclusion

The second permafrost and pathogens workshop began the process of moving from attempting to identify areas of concern toward ways and means of addressing potential risks. By developing concrete solutions to propose to leaders and decision makers, it is hoped that greater focus on pathogens and permafrost will help preserve public health, economic security, and national defense.

While our knowledge base is expanding, the two workshops have helped to identify areas where continued work toward greater understanding would be beneficial. For example, overcoming the current limited understanding of the pathogenic state of permafrost microbes would not only assist in responding to potential releases but also aid in calculating real risk. The workshop found interagency cooperation to be a critical need, particularly around basic science requirements to understand the controlling variable in the pathogenesis process. One recommendation could be to form an interagency working group to better leverage research being conducted across the federal agencies and develop a white paper that maps the priorities of the various agencies with the science and technology needs.

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Appendix B: Permafrost and Pathogens II Workshop Participant Inputs Sorted by Quadrant and Criticality, "Knowns – A Working Model – What needs to be measured and understood?"

		Pareto/N3 Counts						
		Criticality			Time Frame			
{ELICITED INPUTS}	*Quadrant*	Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
Advancing technology to prevent freezing	*Permafrost/Pathogen impacts on missions in all domains*	0	0	0	0	2	1	0
Information Sharing	*Permafrost/Pathogen impacts on missions in all domains*	9	3	2	10	1	0	1
Threshold of Risk -> Viral, physical, environment (water)	*Permafrost/Pathogen impacts on missions in all domains*	5	0	3	0	0	1	0
Risk of unknowns -> Planning	*Permafrost/Pathogen impacts on missions in all domains*	3	1	1	5	2	0	1
Vectors of Exposure -> Mission type/size	*Permafrost/Pathogen impacts on missions in all domains*	1	2	2	1	4	0	0
Mobility Threshold	*Permafrost/Pathogen impacts on missions in all domains*	2	0	0	3	0	0	0
Rule sets for mobility	*Permafrost/Pathogen impacts on missions in all domains*	1	1	0	2	0	0	0
Operational Detection Kits	*Permafrost/Pathogen impacts on missions in all domains*	0	2	0	1	2	8	0
Data (limitations) may contribute to domain mobility	*Permafrost/Pathogen impacts on missions in all domains*	0	1	1	1	0	0	0
Workflows for Planning (classified/timely)	*Permafrost/Pathogen impacts on missions in all domains*	0	0	2	0	22	0	0
"One Health" effect to Humans/Animals/Environment	*Permafrost/Pathogen impacts on missions in all domains*	0	1	0	0	3	0	0

		Pareto/N3 Counts						
		Criticality			Time Frame			
{ELICITED INPUTS}	*Quadrant*	Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
Physical environment as a threshold	*Microbial Reservoirs*	0	0	0	0	0	0	0
Risk threshold + impact	*Microbial Reservoirs*	0	0	0	0	0	0	0
Contemporary databases & data types of microbes are insufficient (known/unknowns)	*Microbial Reservoirs*	0	0	0	0	1	0	0
Poorly understood pathogenic state of permafrost microbes	*Microbial Reservoirs*	8	6	2	4	6	1	8
Predicting reservoirs based on permafrost type/conditions	*Microbial Reservoirs*	7	4	0	2	2	0	0
Mobility of microbes in the reservoir	*Microbial Reservoirs*	4	4	0	4	0	0	0
Reservoirs of ancient microbes that humans haven't encountered	*Microbial Reservoirs*	1	3	0	3	1	2	0
Different Sub-compartments in soil, H20, cryosphere, mineral/rock + their interactions	*Microbial Reservoirs*	0	3	1	0	2	0	0
Use synthetic data to test models	*Microbial Reservoirs*	1	0	3	0	1	2	0
Use phylogeny to better understand unknown microbes & their pathogenicity	*Microbial Reservoirs*	1	0	2	1	0	1	0
Model Workflows	*Microbial Reservoirs*	1	0	1	0	0	0	0
New bioeconomy w/ changing reservoirs	*Microbial Reservoirs*	0	1	0	0	0	0	0
Effects of environment on mutagenesis	*Microbial Reservoirs*	0	0	2	3	0	5	0
Temperature controls (active while cold + when thawed)	*Microbial Reservoirs*	0	0	2	0	1	2	0
Metabolic state (dormant OR active)	*Microbial Reservoirs*	0	0	1	0	0	2	0
Animal, plant + insect reservoirs of microbes	*Microbial Reservoirs*	0	0	1	0	0	1	0
Model of known human impacts to known pathogens	*Human Impacts*	0	0	0	0	0	0	0
Develop a bio-economy w/new knowledge	*Human Impacts*	6	0	4	2	2	0	0

		Pareto/N3 Counts						
		Criticality			Time Frame			
{ELICITED INPUTS}	*Quadrant*	Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
One Health "Model"	*Human Impacts*	5	1	1	0	3	4	1
Human Interactions with: Vectors, Seasons, Mobility	*Human Impacts*	4	0	0	2	0	0	1
Synthetic data to assess impacts to/on humans	*Human Impacts*	1	2	5	3	0	1	0
Health condition at exposure	*Human Impacts*	0	1	8	0	0	2	0
Clinical Relevance of Interaction	*Human Impacts*	0	4	1	2	0	0	0
Adaptation of humans	*Human Impacts*	2	1	0	3	0	0	0
Mobility/Rule Sets	*Human Impacts*	0	3	1	0	1	2	0
(Lack of) Communication of Knowledge	*Human Impacts*	0	1	4	0	0	0	0
Unknown Pathogens	*Human Impacts*	2	0	0	0	0	0	0
Prior Occupation Locations	*Human Impacts*	0	2	2	0	5	0	0
Context...Threshold(s) of Physical Environmental Exposure	*Human Impacts*	0	2	0	0	0	0	0
Model of unknown impacts...New	*Human Impacts*	1	0	1	0	0	0	0
Risk Threshold(s)	*Human Impacts*	1	0	0	0	1	0	0
Amount of Sunshine	*Controlling Variables*	0	0	0	0	0	0	0
Carbon Content	*Controlling Variables*	0	0	0	1	0	1	0
Salinity Levels	*Controlling Variables*	0	0	0	0	0	1	0
Thaw Rate & Intensity - thermal	*Controlling Variables*	6	2	1	9	1	0	0
Gap - which org have pathogenesis tendencies	*Controlling Variables*	4	0	2	4	2	1	0
Permafrost Type - Continuous, Discontinuous	*Controlling Variables*	2	4	0	4	2	0	0
Ecological controls (i.e. competition)	*Controlling Variables*	2	1	1	2	1	1	0
Microbial Community Composition	*Controlling Variables*	1	3	0	0	2	1	0
Disturbance Level	*Controlling Variables*	0	3	0	0	0	1	0
Ice Content	*Controlling Variables*	0	1	0	0	0	0	0
Proximity to activating agents (other microbes) - fungal & changes with water	*Controlling Variables*	0	0	2	1	2	0	0
Atmospheric composition (CO2, etc.)	*Controlling Variables*	0	1	0	1	1	0	0

		Pareto/N3 Counts						
		Criticality			Time Frame			
{ELICITED INPUTS}	*Quadrant*	Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
Wildlife usage & activity type (dens, etc.)	*Controlling Variables*	0	1	0	0	0	3	0
Quality of the Vector (human, plant, or wildlife health) -> ties to transport pathways	*Controlling Variables*	0	0	1	0	0	0	0
Active layer depth	*Controlling Variables*	0	0	1	1	0	0	0
Rain amount & intensity	*Controlling Variables*	0	0	1	0	0	1	0

Appendix C: Permafrost and Pathogens II Workshop Participant Inputs Sorted by Quadrant and Criticality, “Unknowns – A Working Model – What needs to be measured and understood?”

		Pareto/N3 Counts						
		Criticality			Time Frame			
{ELICITED INPUTS}	*Quadrant*	Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
Advancing technology to prevent freezing	*Permafrost/Pathogen impacts on missions in all domains*	0	0	0	0	0	0	0
Risk of unknowns -> Planning	*Permafrost/Pathogen impacts on missions in all domains*	7	4	2	1	5	1	1
Information Sharing	*Permafrost/Pathogen impacts on missions in all domains*	5	2	1	8	4	2	0
Threshold of Risk -> Viral, physical, environment (water)	*Permafrost/Pathogen impacts on missions in all domains*	1	1	8	1	1	3	1
Mobility Threshold	*Permafrost/Pathogen impacts on missions in all domains*	3	0	1	4	0	0	1
Operational Detection Kits	*Permafrost/Pathogen impacts on missions in all domains*	0	1	3	0	2	7	0
Workflows for Planning (classified/timely)	*Permafrost/Pathogen impacts on missions in all domains*	0	1	2	0	0	2	0
Vectors of Exposure -> Mission type/size	*Permafrost/Pathogen impacts on missions in all domains*	0	1	2	0	1	0	0
Data (limitations) may contribute to domain mobility	*Permafrost/Pathogen impacts on missions in all domains*	1	0	0	0	0	0	0
Rule sets for mobility	*Permafrost/Pathogen impacts on missions in all domains*	0	1	0	0	0	0	0
"One Health" effect to Humans/Animals/Environment	*Permafrost/Pathogen impacts on missions in all domains*	0	1	0	0	0	0	0

{ELICITED INPUTS}	Quadrant	Pareto/N3 Counts						
		Criticality			Time Frame			
		Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
New bioeconomy w/ changing reservoirs	*Microbial Reservoirs*	0	0	0	0	0	0	0
Different Sub-compartments in soil, H20, cryosphere, mineral/rock + their interactions	*Microbial Reservoirs*	0	0	0	0	1	3	0
Poorly understood pathogenic state of permafrost microbes	*Microbial Reservoirs*	6	2	1	8	2	0	12
Predicting reservoirs based on permafrost type/conditions	*Microbial Reservoirs*	5	2	3	3	4	2	0
Use phylogeny to better understand unknown microbes & their pathogenicity	*Microbial Reservoirs*	3	3	1	2	1	3	0
Reservoirs of ancient microbes that humans haven't encountered	*Microbial Reservoirs*	4	2	0	2	2	0	0
Model Workflows	*Microbial Reservoirs*	2	2	1	3	3	1	1
Mobility of microbes in the reservoir	*Microbial Reservoirs*	0	4	1	2	1	2	0
Contemporary databases & data types of microbes are insufficient (known/unknowns)	*Microbial Reservoirs*	1	0	0	0	2	2	0
Risk threshold + impact	*Microbial Reservoirs*	0	1	1	1	1	0	0
Use synthetic data to test models	*Microbial Reservoirs*	0	0	3	0	0	3	0
Metabolic state (dormant OR active)	*Microbial Reservoirs*	0	1	1	0	1	0	0
Physical environment as a threshold	*Microbial Reservoirs*	0	0	2	0	1	0	0
Effects of environment on mutagenesis	*Microbial Reservoirs*	0	0	2	0	0	1	0
Animal, plant + insect reservoirs of microbes	*Microbial Reservoirs*	0	0	1	0	0	3	0
Temperature controls (active while cold + when thawed)	*Microbial Reservoirs*	0	0	1	0	0	1	0
Prior Occupation Locations	*Human Impacts*	0	0	0	0	0	0	0
Context...Threshold(s) of Physical Environmental Exposure	*Human Impacts*	0	0	0	0	0	0	0
Human Interactions with: Vectors,	*Human Impacts*	4	0	0	3	1	2	0

{ELICITED INPUTS}	Quadrant	Pareto/N3 Counts						
		Criticality			Time Frame			
		Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
Seasons, Mobility								
Model of known human impacts to known pathogens	*Human Impacts*	2	2	0	3	0	0	0
Develop a bio-economy w/new knowledge	*Human Impacts*	1	2	1	1	1	0	1
Risk Threshold(s)	*Human Impacts*	2	1	0	1	2	0	0
One Health "Model"	*Human Impacts*	1	2	0	1	3	1	2
Clinical Relevance of Interaction	*Human Impacts*	0	2	3	0	0	0	0
Adaptation of humans	*Human Impacts*	0	1	3	1	1	3	0
Unknown Pathogens	*Human Impacts*	1	1	0	2	1	0	0
(Lack of) Communication of Knowledge	*Human Impacts*	0	2	1	1	0	1	0
Synthetic data to assess impacts to/on humans	*Human Impacts*	0	0	4	1	2	2	0
Health condition at exposure	*Human Impacts*	0	1	0	0	0	0	0
Model of unknown impacts...New	*Human Impacts*	0	1	0	0	3	5	0
Mobility/Rule Sets	*Human Impacts*	0	1	0	0	1	1	0
Carbon Content	*Controlling Variables*	0	0	0	0	0	0	0
Ice Content	*Controlling Variables*	0	0	0	0	0	0	0
Rain amount & intensity	*Controlling Variables*	0	0	0	0	0	0	0
Amount of Sunshine	*Controlling Variables*	0	0	0	0	0	0	0
Atmospheric composition (CO2, etc.)	*Controlling Variables*	0	0	0	0	0	0	0
Quality of the Vector (human, plant, or wildlife health) -> ties to transport pathways	*Controlling Variables*	0	0	0	2	0	0	0
Thaw Rate & Intensity - thermal	*Controlling Variables*	6	1	0	4	2	0	0
Gap - which org have pathogenesis tendencies	*Controlling Variables*	1	6	0	8	5	0	2
Ecological controls (i.e. competition)	*Controlling Variables*	3	2	2	1	2	6	0
Microbial Community Composition	*Controlling Variables*	2	1	1	1	3	1	0
Permafrost Type - Continuous, Discontinuous	*Controlling Variables*	0	0	5	0	2	2	0
Active layer depth	*Controlling Variables*	1	0	1	2	0	0	0

		Pareto/N3 Counts						
		Criticality			Time Frame			
{ELICITED INPUTS}	*Quadrant*	Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
Salinity Levels	*Controlling Variables*	1	0	0	0	0	0	0
Proximity to activating agents (other microbes) - fungal & changes with water	*Controlling Variables*	1	0	0	0	0	1	0
Disturbance Level	*Controlling Variables*	0	1	0	0	0	0	0
Wildlife usage & activity type (dens, etc.)	*Controlling Variables*	0	0	1	0	0	1	0

Appendix D: Permafrost and Pathogens II Workshop Participant Inputs Sorted by Quadrant and Criticality, “Monitoring and Surveillance Indicators.”

		Pareto/N3 Counts						
		Criticality			Time Frame			
{ELICITED INPUTS}	*Quadrant*	Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
Countering disinformation	*Initial National Policy Needs*	0	0	0	0	1	2	0
Information sharing - interagency medical records (i.e. CDC, DOT)	*Initial National Policy Needs*	16	3	0	9	4	0	5
Biological incident response plans for interagency operations	*Initial National Policy Needs*	2	5	9	3	3	6	0
Opportunities for citizen science & industry partnerships	*Initial National Policy Needs*	0	4	5	0	7	3	0
Leveraging existing monitoring resources	*Initial National Policy Needs*	0	2	1	0	3	0	0
International/national privacy	*Initial National Policy Needs*	0	0	1	0	2	1	0
Policy and technology transfer in support of continuity/sustainability	*Other*	0	0	0	0	0	0	0
Use economic data as proxy (e.g. purchase pattern change)	*Other*	0	1	3	2	2	2	0
Need community-based observing partnerships	*Other*	0	1	0	1	0	2	0
Landscape stability/instability	*Physical Conditions*	14	3	1	10	1	1	7
How to monitor biological attributes	*Physical Conditions*	3	8	0	2	2	1	0
Infrastructure	*Physical Conditions*	2	3	4	2	0	10	0
Natural disturbances	*Physical Conditions*	2	0	2	0	2	0	0
Robust near-term climate models	*Physical Conditions*	0	3	1	0	3	1	0
Hydrological conditions	*Physical Conditions*	0	2	2	0	2	1	0
Local moisture conditions	*Physical Conditions*	0	1	2	1	4	0	0
Weather variables	*Physical Conditions*	0	2	0	1	0	3	0
Changes in atmosphere (e.g. methane, CO2)	*Physical Conditions*	0	2	0	1	2	0	0
Year-round lake monitoring	*Physical Conditions*	1	0	0	1	0	0	0
Coastal ocean	*Physical Conditions*	0	1	1	0	0	1	0
Use existing reporting systems, if available (who do these data go	*Public Health*	7	3	2	8	5	1	1

		Pareto/N3 Counts						
		Criticality			Time Frame			
{ELICITED INPUTS}	*Quadrant*	Critical	Importan	Helpful	<1 Year	1-5 Years	5+ Years	Highest
to?)								
Village nurse & clinician & health aide reports through systematic reporting system	*Public Health*	7	2	1	5	4	1	6
Use proxy data (e.g. OTC meds purchased) & economic indicators	*Public Health*	1	2	6	2	5	6	1
Arctic investigation service w/CDC - AK native tribal health consortium	*Public Health*	0	5	3	3	2	1	0
Positive side of non-lethal pathogenesis: immune system training	*Public Health*	1	1	4	1	2	5	0
Include "idiopathic" systems (physical & mental - psych.)	*Public Health*	1	1	3	1	4	1	0
Include movement data for patient (incl. demographics, etc.)	*Public Health*	0	3	1	0	2	0	0
Zoonotic disease spread	*Wildlife Monitoring*	13	4	0	12	0	0	0
Population or migration changes of organisms (fish, caribou, etc.)	*Wildlife Monitoring*	4	6	1	2	10	0	0
Microbiological indicators affecting landscape conditions & responding to conditions	*Wildlife Monitoring*	1	5	2	3	0	5	0
Monitoring through social media ("Facebook fish") might be untrustworthy	*Wildlife Monitoring*	0	1	7	1	2	4	0
New growth/movement of species	*Wildlife Monitoring*	0	0	3	0	1	0	0
Hyperspectral or other indicators of poor plant health (net primary productivity)	*Wildlife Monitoring*	0	0	2	0	1	3	0
Sickness or death	*Wildlife Monitoring*	0	1	0	1	0	0	0
Predicting wildlife population/migration changes	*Wildlife Monitoring*	0	1	0	0	0	2	0