Environmental Impacts on The Performance of Pavement Foundation Layers – Phase I

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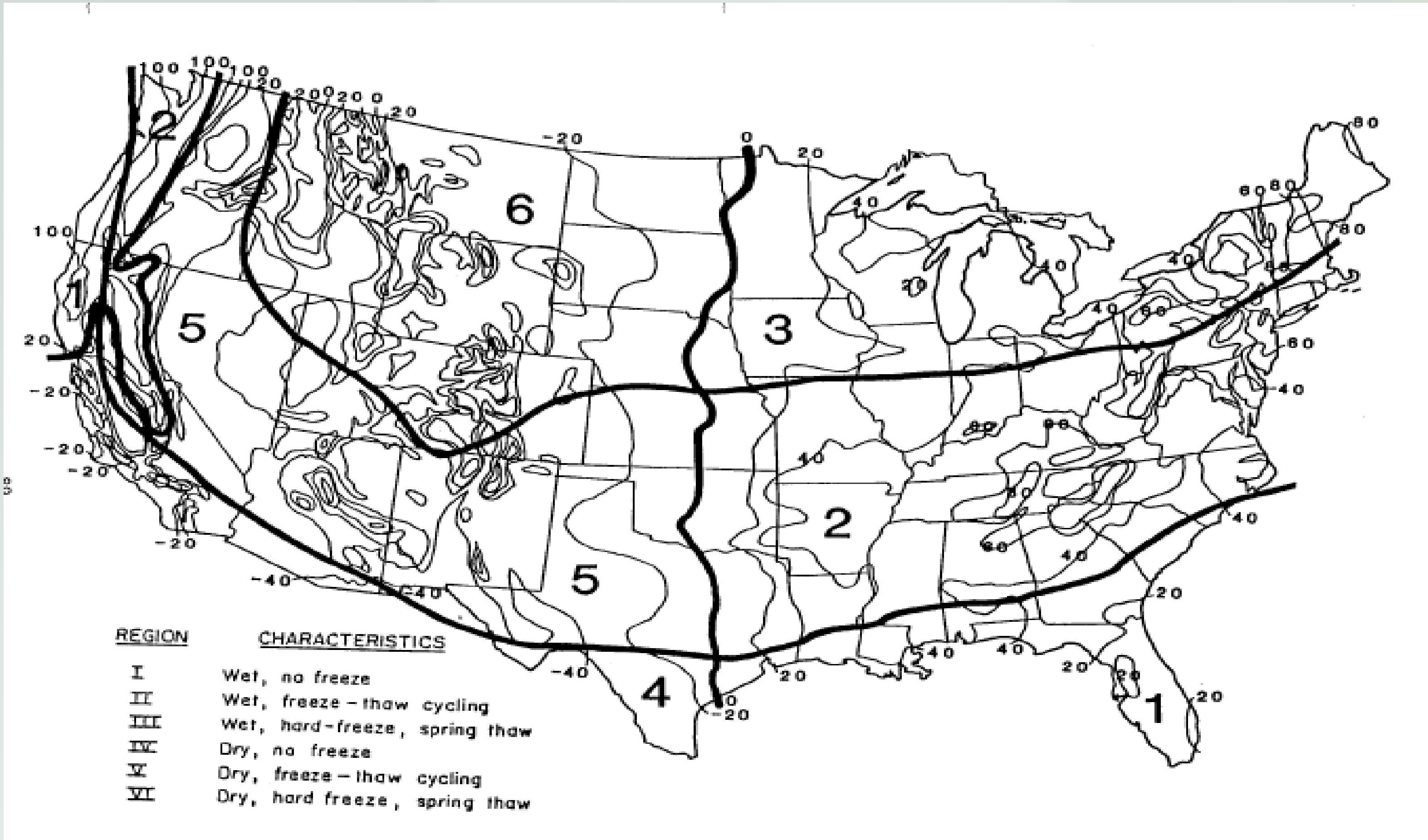
NRRA Members (Agency Partners)

- MnDOT
- Caltrans
- MDOT
- Illinois DOT
- LRRB
- MoDOT
- WiscDOT
- Iowa DOT
- Illinois Tollway

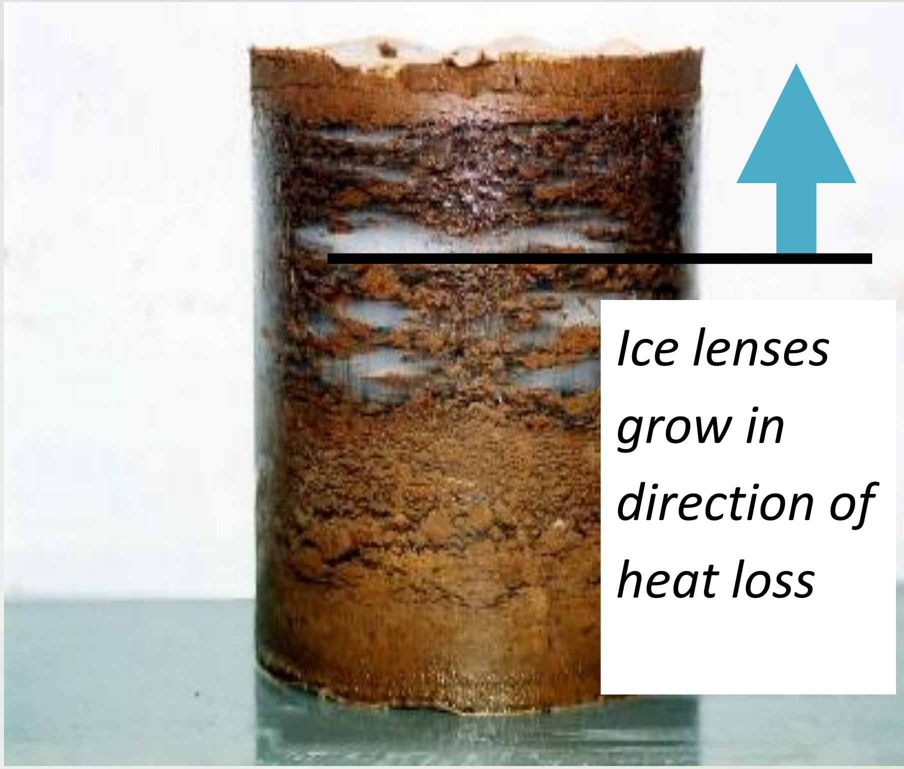
NRRA Members (Industry Partners)

- Aggregate and Ready Mix
  (Association of MN)
- APA
- Braun Intertec
- CPAM
- Diamond Surface Inc
- Flint Hills Resources
- IGGA
- MIDSTATE
  (Reclamation and Trucking)
- MN Asphalt Pavement Association
- Minnesota State University
- NCP Tech Center
- Road Scanners
- University of Minnesota-Duluth
- University of New Hampshire
- MATHY
- 3M
- Paviasystems
- Michigan Tech
- University of Minnesota
- NCAT
- GSE Environmental
- HELIX
- Ingios
- WSB
- Cargill
- PITT Swanson Engineering
- INFRASENSE
- Collaborative Aggregates LLC
- American Engineering Testing, Inc.
- CTIS
- ARRA
- 1st
- O-BASF
- North Dakota State University
- All States Materials Group

PROBLEM STATEMENT



PROBLEM STATEMENT



PROBLEM STATEMENT

Freezing

Thaw Weakening

Ice Lensing → Frost Boil | Rutting | Potholes

https://myferndalenews.com/frost-boils-reason-emergency-road-restrictions_55759/

https://porthawkesburyreporter.com/spring-weight-restrictions-partially-lift

SEASONAL LOAD RESTRICTION (SLR)

Avoid additional loads

- Keep the damage minimum
- Organize heavy vehicles/ keep the adverse effect minimum

(Image: patch.com)

Determining SLR:

- Subsurface Instrumentation
- In-situ Stiffness Testing
- Modeling

IMPACTS OF FREEZE-THAW CYCLES UNDER ROADS

- *Water in soil freezes and* ***expands***
- *During spring-thaw, melted water and infiltrated water trapped above the zone of frozen subgrade* ***– strength loss*** *under heavy loading*
- *Seasonal Load Restrictions – applied to* ***avoid/reduce damages***
- ***Prediction*** *of Freeze-Thaw Cycles – Monitoring systems & Computational Models*

INSTRUMENTATION

- Instrumented with an array of:
  - Soil Moisture
  - Soil Matric Potential
  - Temperature

- Weather Station to measure climate data
  - On site
  - Road Weather Information Systems (RWIS)
  - Environmental Sensing Stations
  - Modern Era Retrospective Analysis for Research and Applications (MERRA)

OBJECTIVES

Develop a Data Driven Model to Predict the Frozen Soil Depths & Freeze-Thaw Durations

- **Inputs:**
  - Climate data (precipitation, relative humidity, percent sunshine, temperature, & wind speed)
  - Layer thicknesses
  - Material type
- **Output**
  - Number of freeze-thaw cycles at specific depths
  - Duration of freezing and thawing
  - Frost depth

Overview of Research Plan

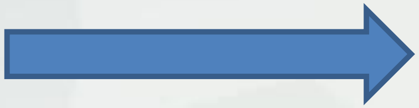
- **Task 1** – Initial Memorandum on Expected Research Benefits and Potential Implementation Steps
- **Task 2** – Field Data Collection
- **Task 3** – Modelling Analyses
- **Task 4** – Final Report

Task 1 - Initial Memorandum on Expected Research Benefits and Potential Implementation Steps

Benefit category	How?
Construction Savings	*Designing pavement foundations by taking freeze-thaw effect into account*
Operation & Maintenance Saving	
Decrease Engineering/Administrative Cost	*Friendly use program delivery could minimize the engineering cost for pavement foundation design*

IMPLEMENTATION

1. Final Report
   - Organized database
     - Climate Data
     - Performance Data
     - Material Data
   - User-Friendly Modelling Program

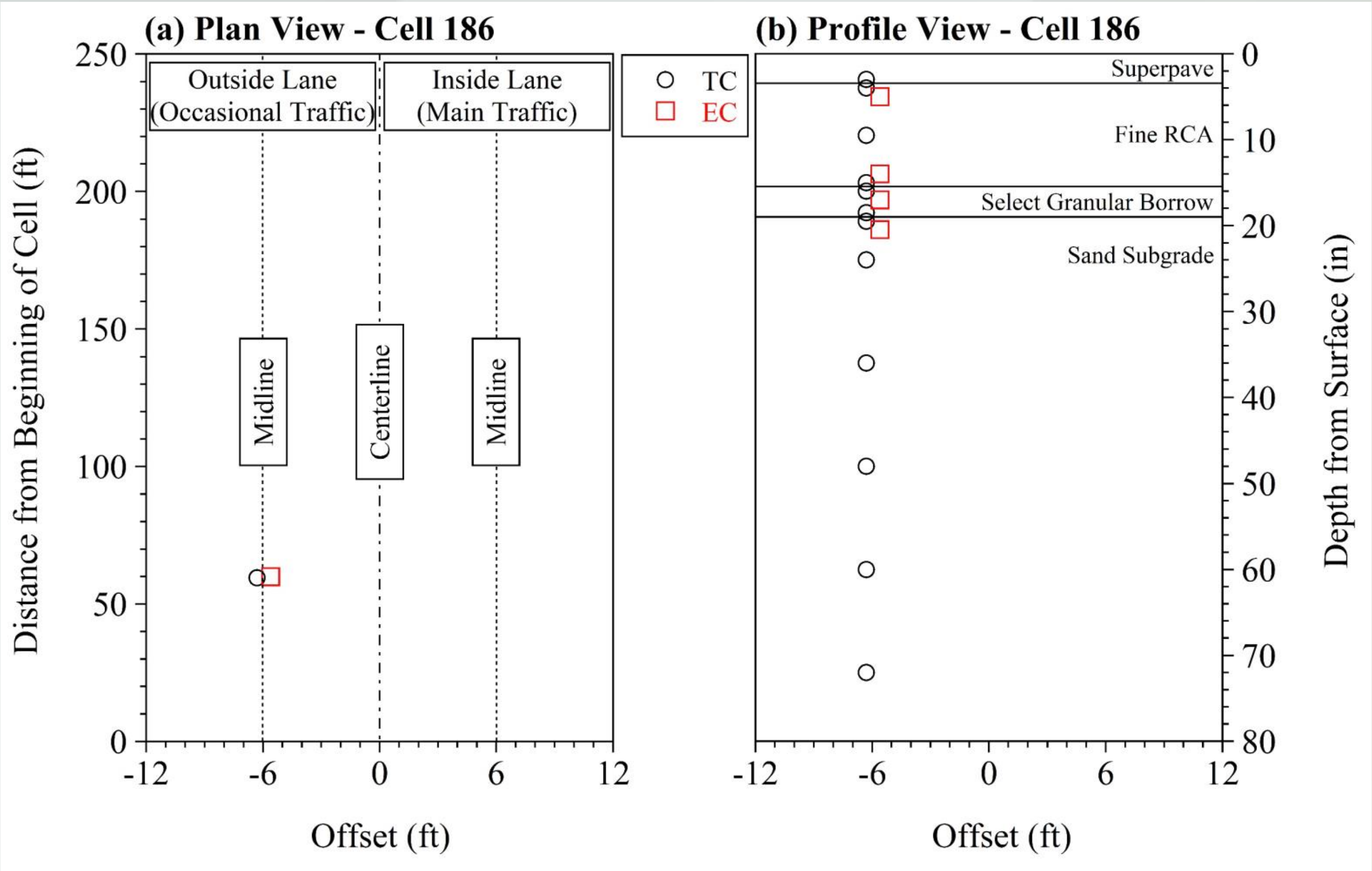


TASK 2 – FIELD DATA COLLECTION

List of data that will be collected:

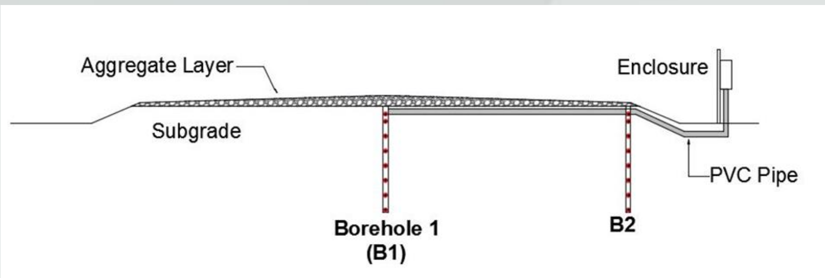
- Climate Data
  - Air temperature
  - Percent sunshine
  - Precipitation
  - Wind speed
  - Relative humidity
- Soil Data
  - Material data
  - Temperature
  - Water content
  - Matric suction
- FWD Elastic Modulus
  - Elastic modulus

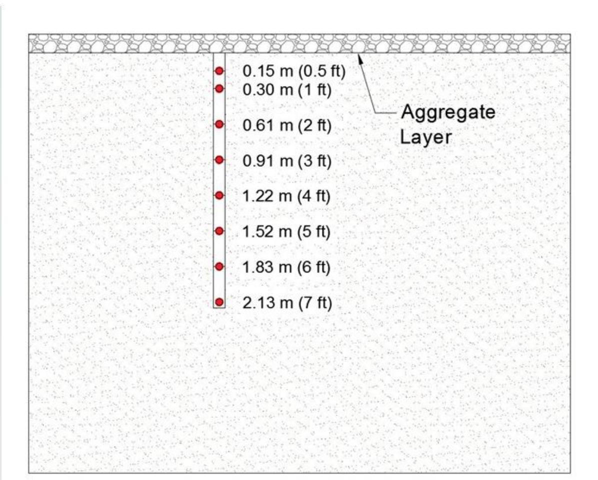
SENSOR LOCATIONS

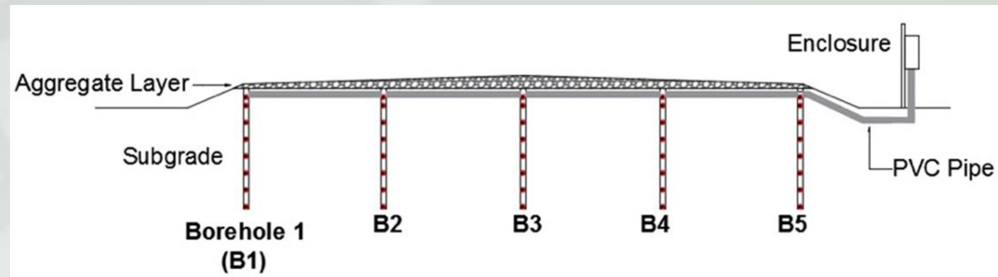


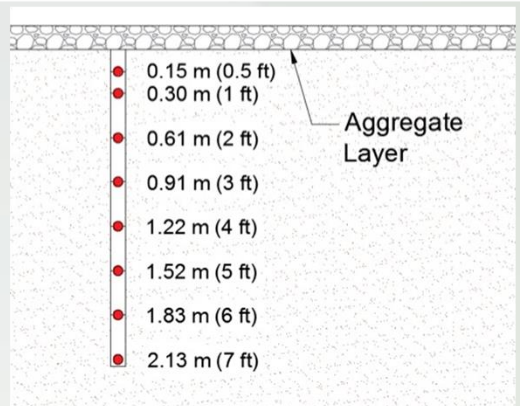
TC = Thermocouple
EC = Moisture probe

TASK 2 – FIELD DATA COLLECTION









Task 3 – Modelling Analyses

Modeling Objectives:

Develop a **tool** that can be used to assess/predict the freeze-thaw behavior of roadways

- Simple
- Stand-alone
- For any location (where soil profile and weather data are available)

Output needed:

- number of freeze thaw cycles at certain depth
- frost depth isotherms over time

Modeling Approaches

Two types of modeling approaches to consider:

Physics-based modeling (“white box”)

Data-driven modeling (“black box”)

What is the appropriate approach to consider?

Different approaches towards modeling:

Physics-Based Modeling

based on physical principles and relationships between variables; described with a set of mathematical equations with variables that have physical meaning

Inputs: Many input (or assumptions) required; some may or may not be known

Pros: better at extrapolation, limited historical data required

Cons: significant knowledge of all physical properties and interactions; slower (higher computational intensity)

Data-Driven Modeling

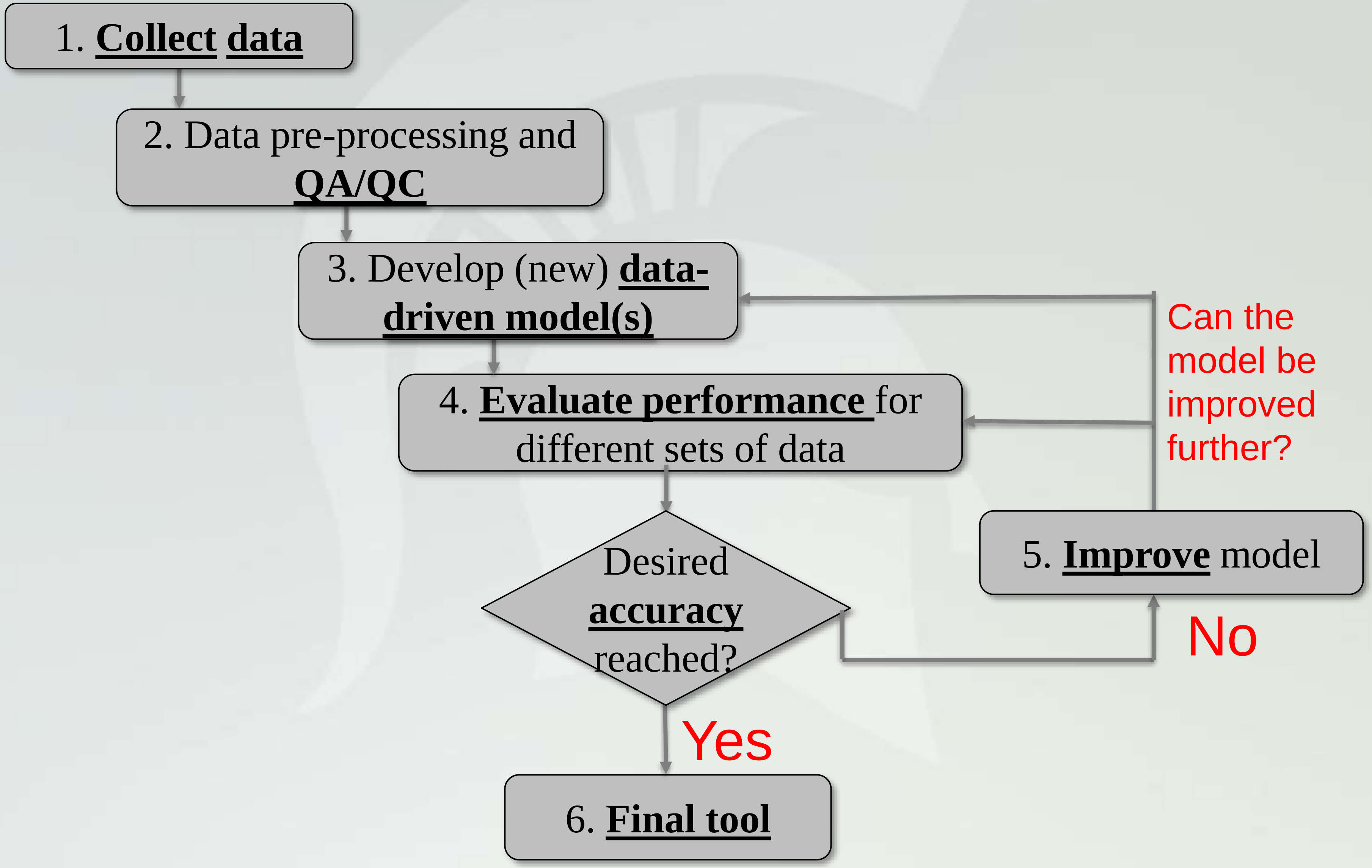
Statistical or machine learning based; uses historical data to develop a quantifiable relationship between inputs and outputs

Inputs: whatever data is available (*and ultimately found to be significant*)

Pros: lower computational intensity; no knowledge of physical properties or interactions required

Cons: worst (typically) at extrapolation outside of bounds of original data; needs larger training dataset to create and validate

Tool Development Process: *Workflow*



Step 1. Collect data: *Data Needs*

Most important requirements for data-driven modeling are:

- large(r) input datasets, which will be split into:
  - In-sample (to create the model)
  - out-of-sample (to validate the model)
- diversity of conditions (e.g. hot/cold, wet/dry, etc..)

Data needed (ideally):

- Weather data (close or near to site)
- Soil profiles/characteristics (thermal/moisture)
- Historical temperature at different depths
- A range of sites/locations of data collection

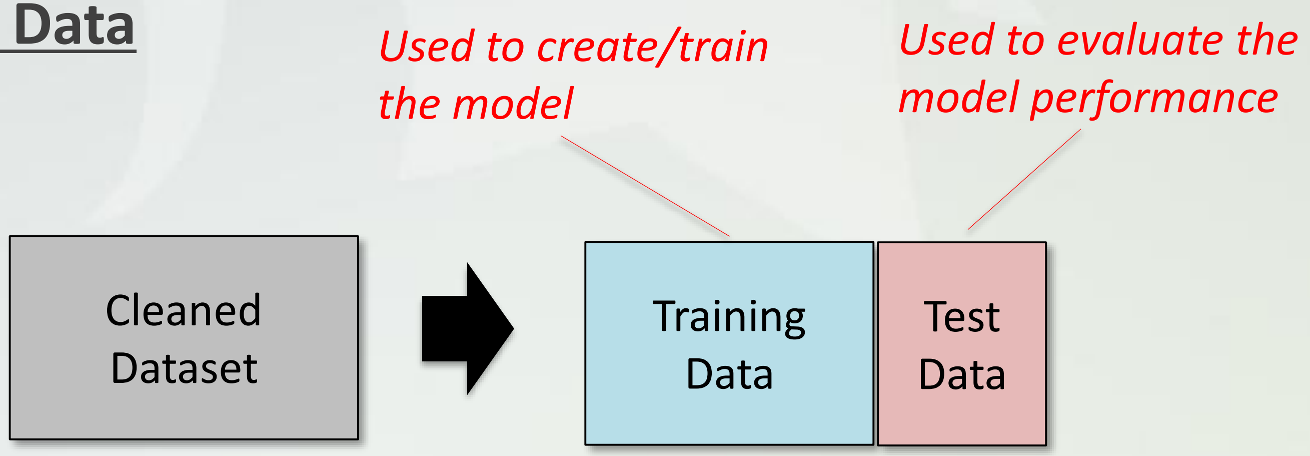
Step 2. Data Pre-Processing:

QA/QC: Types & Handling of Missing Data:

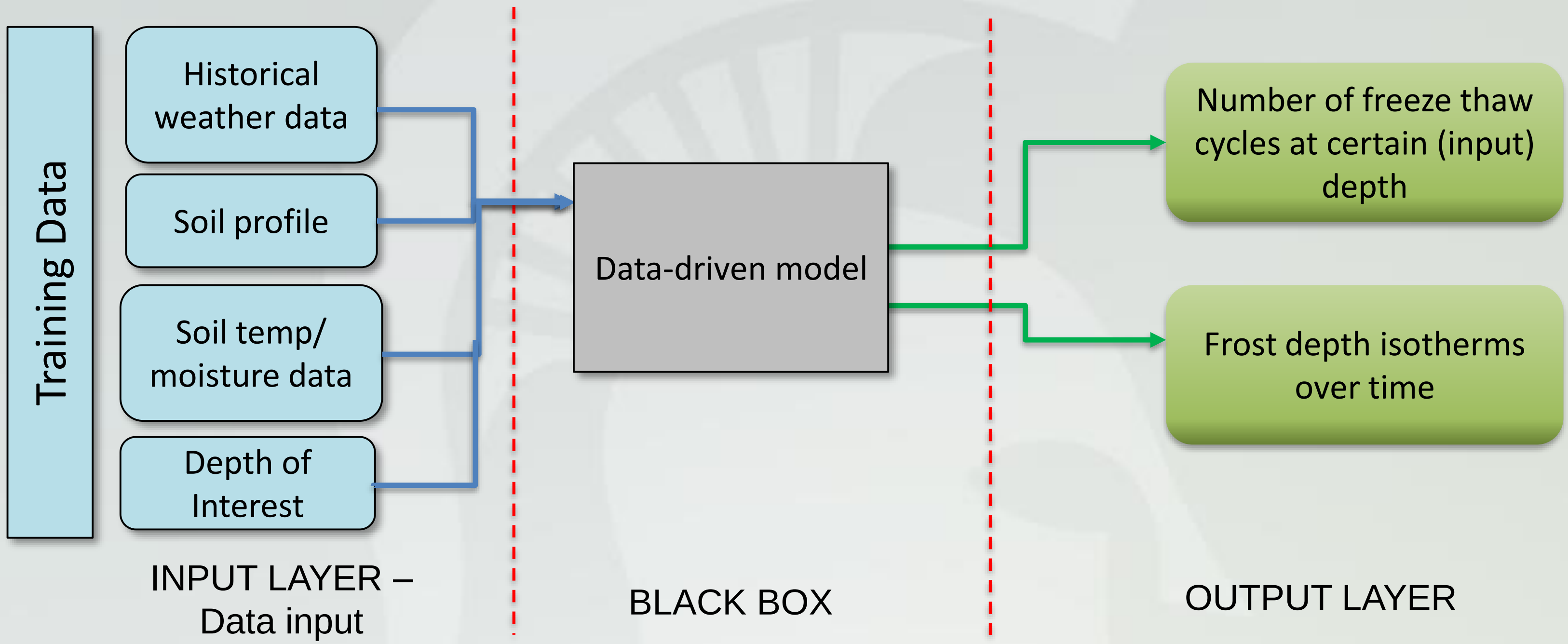
1) Short spans (less than 10 hrs)
   - → Impute data (fill it in) based on trends in surrounding data
   - → forward fill method

2) Long spans (more than 10 hrs in this dataset)
   - → Remove the time periods with missing data

Division of Data



Step 3. Develop data-driven models: *Process*



Layout of model development process

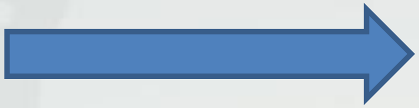
Step 3-6. Refine Model: *Progressive Improvement*

Stepwise/Regression models → Neural network models → Deep learning models

Example sequence from simple to complex modeling to determine relative improvement in performance

TASK 4

Draft/Final Report



Linear regression models:

- Initially, a simple model has been selected, and then sequentially proceed towards the complex models.
- Linear regression model has been selected as the starting point. After that forward stepwise regression method has been implemented to evaluate the significant input variables.

Soil temperature	Regression coefficients				Regression intercept
	AirTemp	Rain	RH	Wind	
TC_1	1.04	0.19	-0.07	-0.59	12.13
TC_2	1.02	0.18	-0.05	-0.69	10.51
TC_3	0.92	0.02	0.05	-0.86	4.49
TC_4	0.84	0.02	0.08	-0.77	2.42
TC_5	0.83	0.03	0.09	-0.75	2.38
TC_6	0.81	0.06	0.09	-0.72	2.37
TC_7	0.80	0.07	0.09	-0.71	2.41
TC_8	0.76	0.12	0.09	-0.66	2.59
TC_9	0.66	0.14	0.04	-0.41	4.93
TC_10	0.60	0.11	0.09	-0.54	2.88
TC_11	0.39	0.08	0.10	-0.40	5.49
TC_12	0.47	0.04	0.09	-0.41	3.44

Linear regression models:

- To use linear regression, first 50000 data has been used for training and rest 9522 data has been used for test dataset.
- The error in training dataset for all the temperature values are shown below.

Linear regression models:

- The errors for test data are shown in the following figure.
- The range of the errors vary significantly.

Forward stepwise regression models :

- To evaluate the impact of all the input parameters, forward stepwise regression method has been used. The result of the study are shown below:

Temperature node	Significant inputs
TC_1	Air temperature, Relative humidity, Wind speed, Precipitation
TC_2	Air temperature, Relative humidity, Wind speed, Precipitation
TC_3	Air temperature, Relative humidity, Wind speed
TC_4	Air temperature, Relative humidity, Wind speed
TC_5	Air temperature, Relative humidity, Wind speed
TC_6	Air temperature, Relative humidity, Wind speed
TC_7	Air temperature, Relative humidity, Wind speed
TC_8	Air temperature, Relative humidity, Wind speed
TC_9	Air temperature, Relative humidity, Wind speed
TC_10	Air temperature, Relative humidity, Wind speed
TC_11	Air temperature, Relative humidity, Wind speed
TC_12	Air temperature, Relative humidity, Wind speed

Questions for TAC :

- What is the level of accuracy desired?
- Any other outputs or inputs preferred
- Excel based?

SCHEDULE

Task No.	Months							
	1	2	3	4	5	6	7	8
1								
2								
3								
4								

PRODUCTS & DELIVERABLES

- Quarterly progress reports as required
- Draft final report
- Final report
- Technology transfer brief
- A copy of the executive final presentation
- User friendly modelling program

AGENCY ASSISTANCE

- Access to related data from MnROAD
  - Site selection
  - Temperature data
  - Water content data
  - Elastic modulus data
  - Weather data