Optimizing mine water and mine waste management using machine learning approaches (and data you already collect)

Presented By

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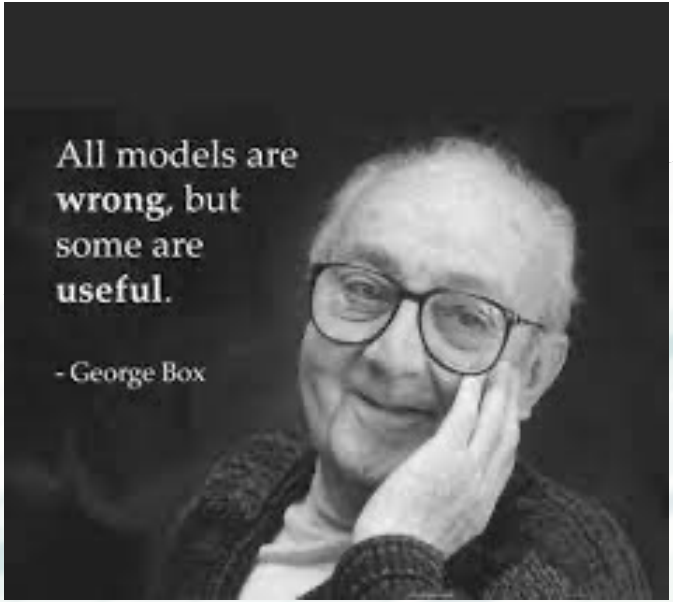
Agenda

- Introduction to machine learning concepts
  - How can the predictive power of multi-stakeholder datasets be used to provide **useful** solutions
- Case examples
  - Water management
  - Mine material management



Information and the Mine Life Cycle

Global Information Standard for Tailings Management
Principle 2, Requirements 2.1 and 2.2

NI 43-101
Form 43-101F

Mineral Exploration → Development → Production → Closure

ICMM Integrated Mine Closure Good Practice Guide
Tool 2 – Monitoring, Measuring and Inspections

Baseline Studies

Environmental Assessment

Permitting

- Geological setting, mineralization, deposit type
- Mineral resource estimate and geological model
- Mine plan, mining method and production rates
- Mineral processing flow sheet and recovery estimates
- Detailed site characterization including data on climate, geomorphology, geology, geochemistry, surface and groundwater quality, hydrology, hydrogeology, geotechnical parameters and seismicity

Province of British Columbia, Canada Joint Application Requirements for MA/EMA Permits

Environmental Performance Monitoring

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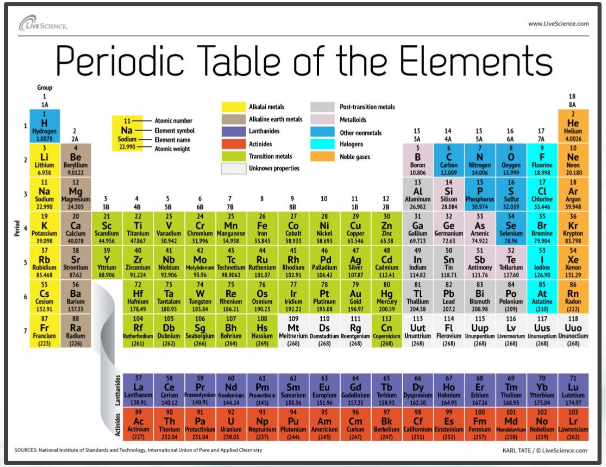
Assay Data is Highly Underleveraged

Drill core assay collected throughout the mine project life cycle



Water quality data collected throughout the mine project life cycle

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Machine Learning 101

Advanced Data Analytics

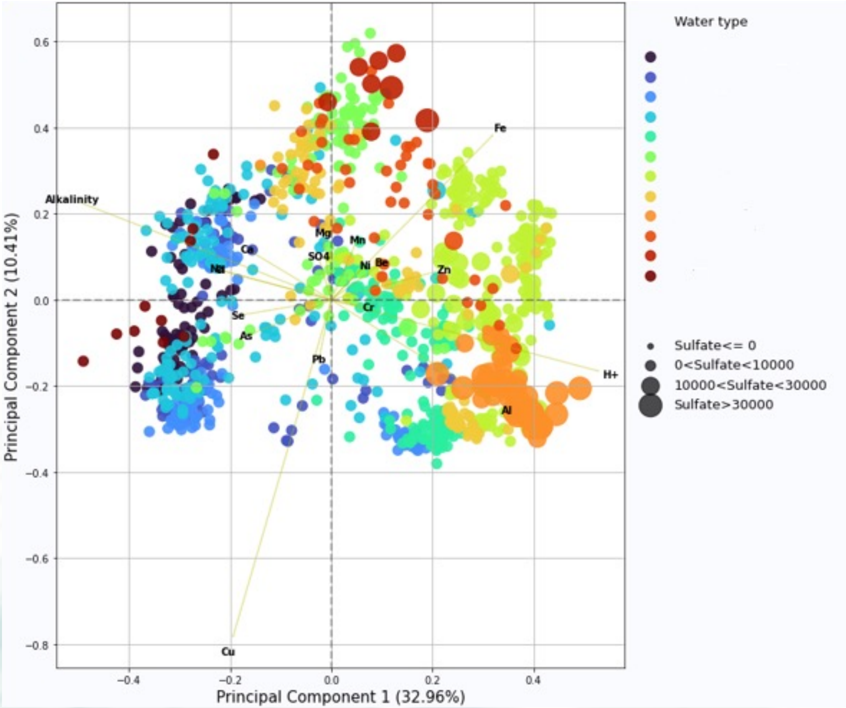
IBM's Definition…

"Machine learning is a branch of artificial intelligence (AI) and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy."

- Provide insights from deep datasets that aid business decision making
- Data-driven alternative to mechanistic models

Introduction to Classification vs. Domaining

- Unsupervised Machine Learning
  - Identify multivariate assay signature of groups of environmentally related samples (domains) that have been **extensively characterized** (e.g., ABA, XRD, short-term leach, HCT)
  - Exploratory data analysis (EDA) using tools such as principal component analysis, multivariate clustering etc.
- Supervised Machine Learning
  - Predict water and material domains (target variable) based on assay data (predictor variable) alone



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Value Proposition: Mine Material and Mine Water Management

- Uncharacterized water/material samples can be rapidly classified using assay data only (including new data collected for on-going assay programs)
- Water Management
  - Rapid identification of baseline vs. impacted, ARD vs. AMD
  - Process water management
  - Design and operation of water treatment and mitigation systems
  - Compliance monitoring programs: early warning, location of future wells
- Materials Management
  - More accurate segregation and estimation of material volumes
  - “Mine-to-mill” optimization:
    - Mill, leach, short-term PAG, long-term PAG, waste, construction etc.
    - Multiple decision points: orebody, blast, shovel, fleet, belt, waste facility

Industry Applications
Mine Water Management

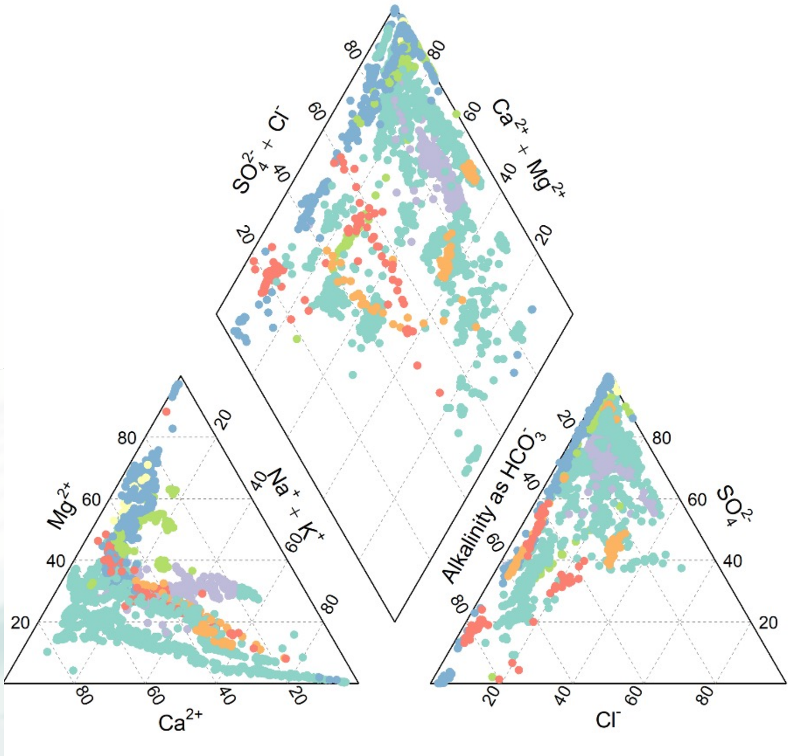
Mine Water Management

- **Case study:** impacted mine site going into closure after 40+ years of operation

- **Objective:** inform on-going compliance program
  - Identify pre-mining impact and baseline
  - Identify mining impact associated with various facilities
  - Assess extent of natural attenuation
  - Assess risk of future exceedances
  - Rapid classification of new water quality data
  - Evaluate analytical suite
  - Inform future monitoring well placement

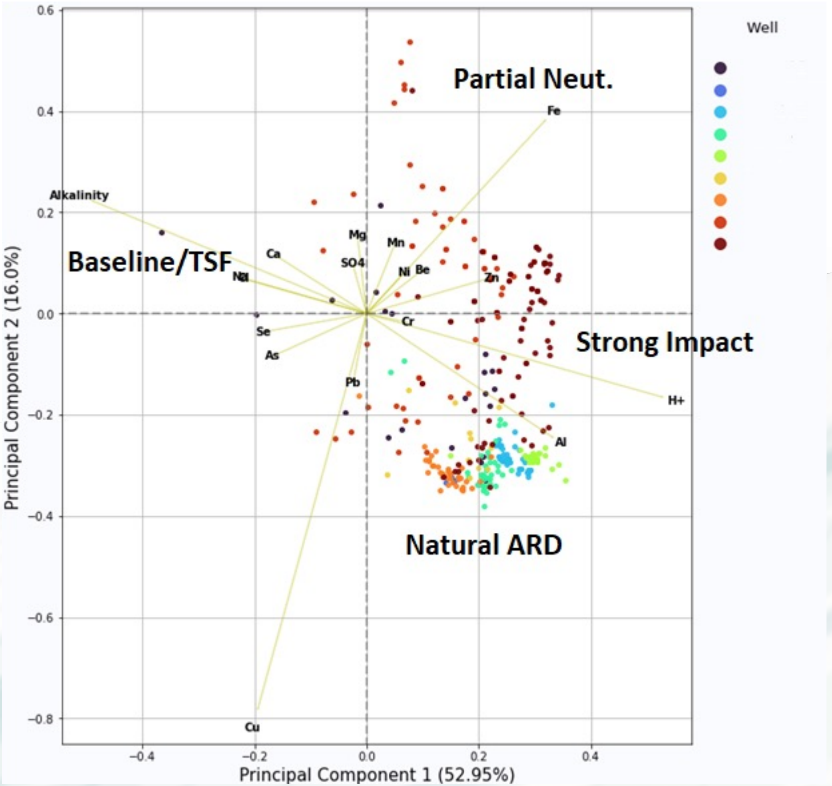
Approach

- Detailed, multivariate analysis of all historic site water quality data
- Unsupervised
  - Time series diagrams (Python)
  - Time-based chemical component post maps (QGIS)
  - Major ion classification – Piper (R)
  - PCA (Python)
- Supervised ML (proposed)



Results

- Clear domains:
  1. Pre-mine AMD
  2. Pit/WRF impact
  3. Peripheral attenuation
  4. Baseline/TSF

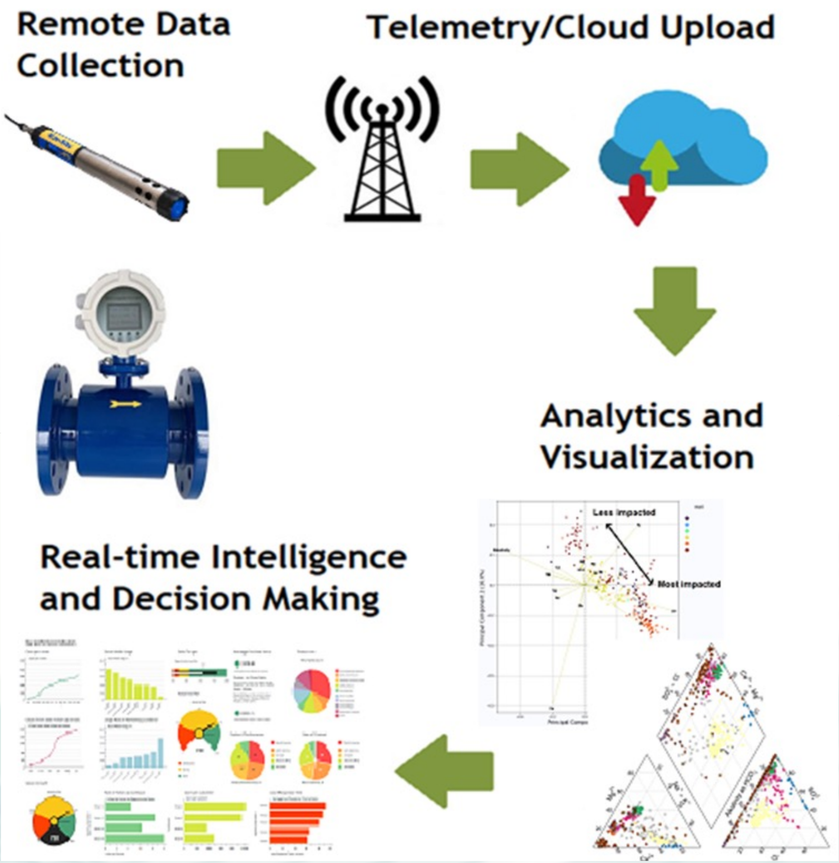


Lessons Learned

- Areas of success
  - AMD vs. ARD, various sources of mine impact, baseline
  - Provides insight on attenuation (sorption and neutralization halo)
  - New water quality could be rapidly domained
- Areas of challenge
  - Overlapping domains (TSF/baseline) and evolving water quality
  - Additional work needed to evaluate future risk
- Recommendations for change
  - Data collection practices
    - Consistent analyte suite (think beyond compliance)
    - Start w/ larger suite and widdle down over time
  - Eliminate certain monitoring wells, replace with others

Water Case Study

Long-Term Sitewide Water Quality Management



- Industry 4.0
- IoT Framework
- Benefits
  - Streamline data collection, management and analysis
  - Intelligent analytics
  - Enhanced, (near) real-time decision-making
  - Water quality forecasting

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Industry Applications
Mine Material Management

Mine Material Management

- **Case study:** mine waste model for a project that is working on an integrated mine plan
- **Objective:** Develop a block model capable of estimating mine material volumes for a geologically and environmentally complex ore deposit
  - Key issues: acid rock drainage and metal leaching (several parameters, including metals and oxyanions – e.g., selenium)
- **Available Data:**
  - Ore resource model and preliminary mine plan
  - Geologic model – extensive drill core descriptions, well defined lithologies and alterations
  - Assay Data
    - Geochemical Dataset (n = 1000s) **detailed dataset** acid rock drainage and metal leaching potential; material reactivity and lag times to onset of geochemical threshold conditions
    - Exploration dataset (n = 10,000s) **deep dataset** comprehensive solid phase analysis

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Approach

Geochemical Interpretation - TIC NP/AP classification criteria

Geochemistry dataset (1000s samples): TIC NP (total inorganic carbon) and AP (sulphide)

Exploration assay dataset (10,000s samples): ICP metal scan – no TIC NP

Environmental Domaining

Geological characteristics – lithology / alteration

Geochemical characteristics (ML/ARD)

Proxy Analysis

Continuous: multivariate approach to calculate AP and TIC NP

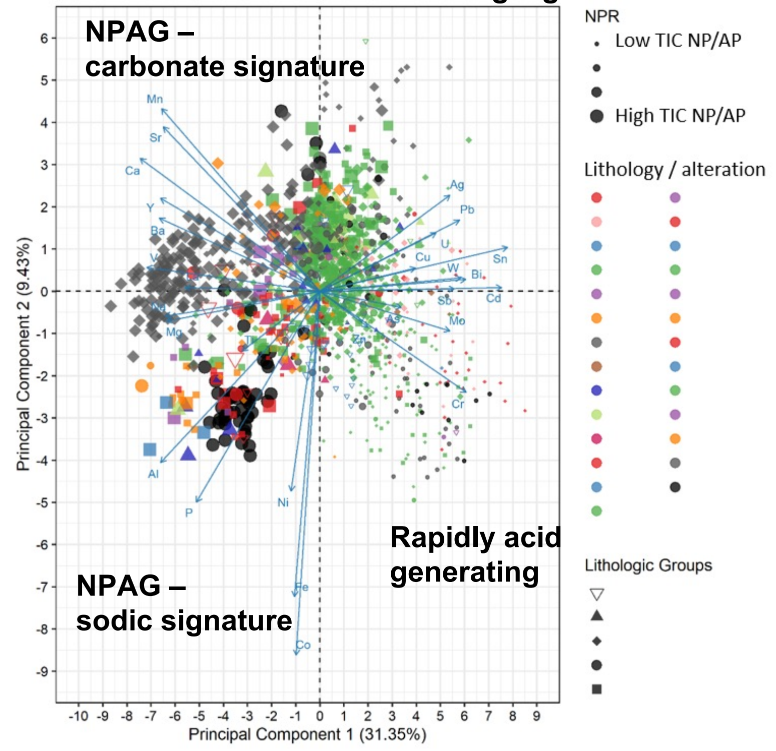
Categorical: predict environmental domain for each sample

Mine Waste Block Model

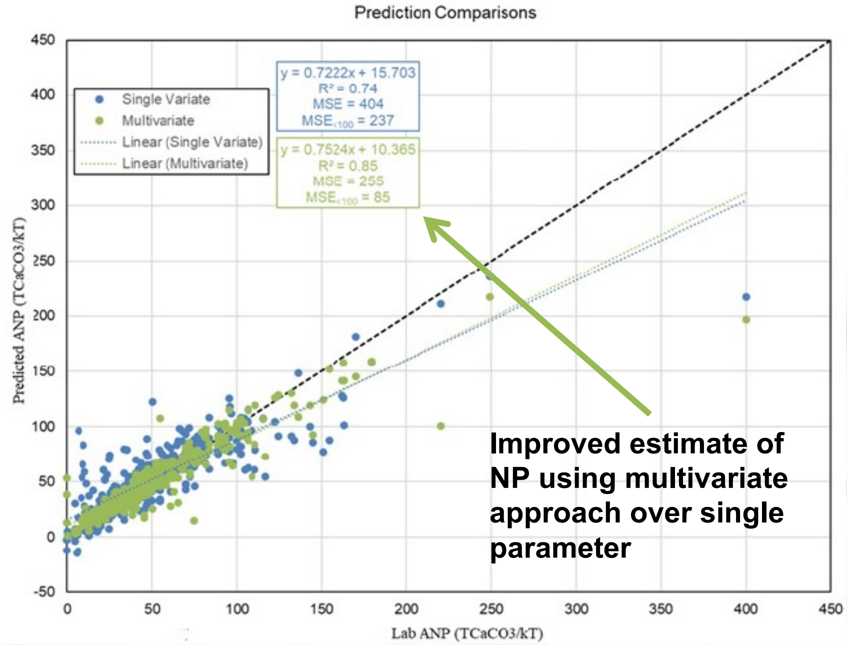
Variography followed by kriging with additional controls

Results

Domaining



Proxy Analysis



Improved estimate of NP using multivariate approach over single parameter

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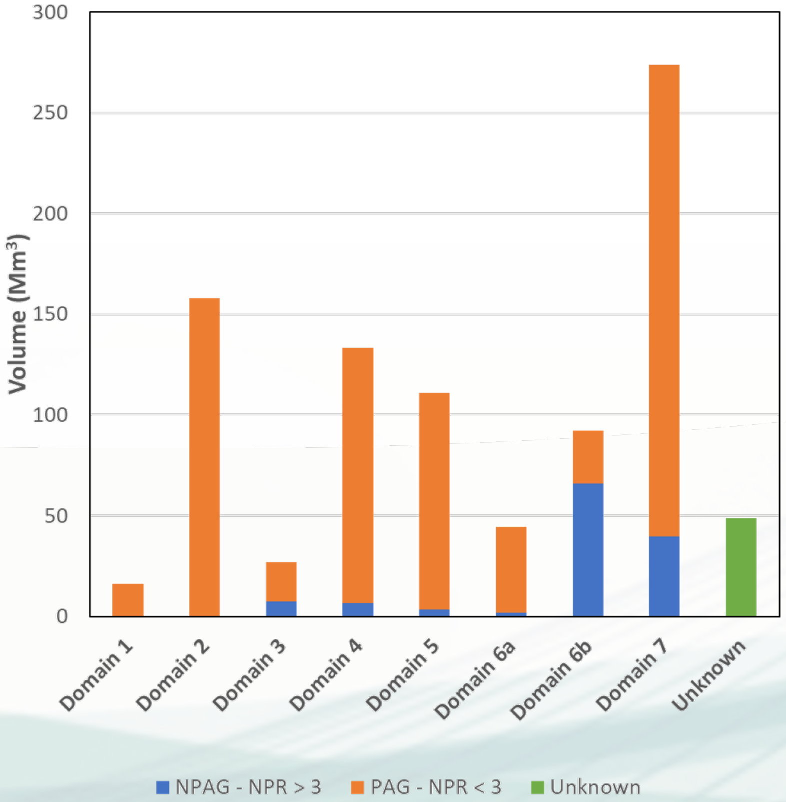
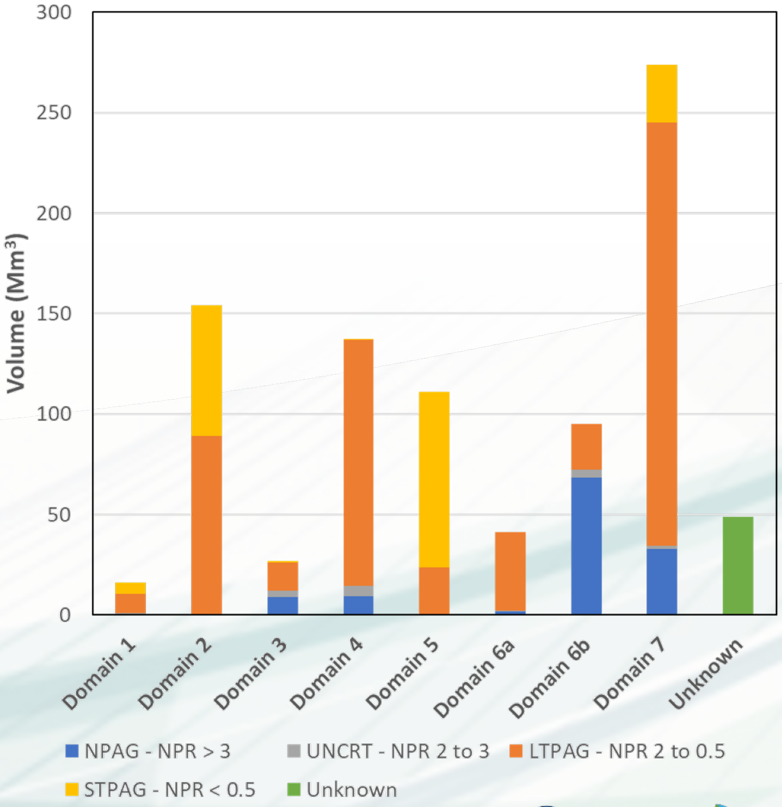
Results





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Stakeholders and Applications

- Client team – process group – metallurgical process
- Subject matter experts – ML/ARD
- Client team - exploration geology – geological interpretation
- Subject matter experts – statistical evaluation and machine learning
- Subject matter experts – block model development
- Client team – projects group – mine plan
- Subject matter experts and client team – mine waste facility design
- Client team - environmental group – site-specific environmental management plans

Applications

"Designer" mine wastes and mine waste management solutions

Circularity – Design with the end in mind

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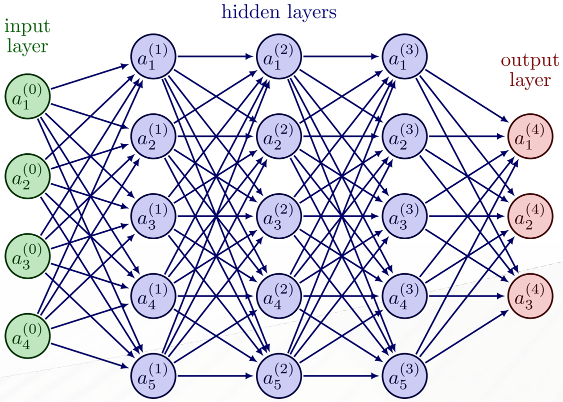
What next?

Mechanistic vs. Data-driven Models

- Statistical learning pros (**Mechanistic cons**)
  - Does not require understanding of process
  - Model predictions improve with ‘experience’
  - Computationally/effort efficient (high initial effort)
  - Spot relationships in data that are ordinarily difficult to identify
  - **Useful for:** process optimization and scale-up
- Mechanistic pros (**Statistical learning cons**)
  - Facilitates understanding of process
  - Large volumes of data not necessarily required
  - Not limited to calibration space
  - Model predictions improve with understanding
  - **Useful for:** rapid evaluation of conceptual model alternatives to quantify uncertainty



PHREEQC

Visual MODFLOW

GoldSim

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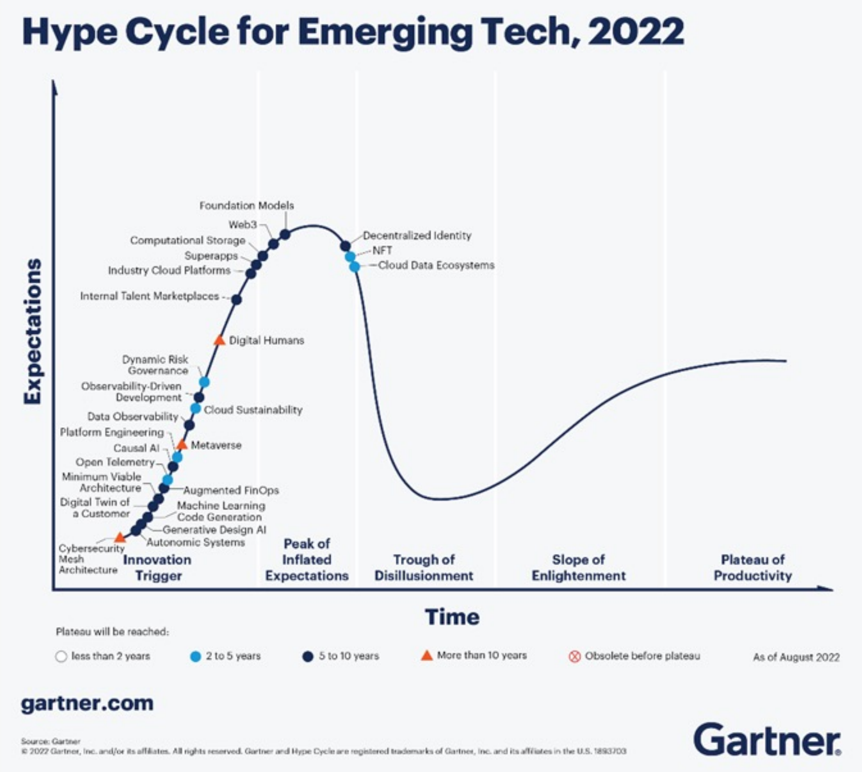
Keys to Machine Learning Success

- Scalability (start small – low-hanging fruit)
- Establish trust and involve all key stakeholders
- Don’t overhype/sell
- Clearly define objectives
- Well developed conceptual model
- Data quality should be high, and data predictive- use EDA as a feedback loop to additional data collection
- Careful benchmarking and value demonstration



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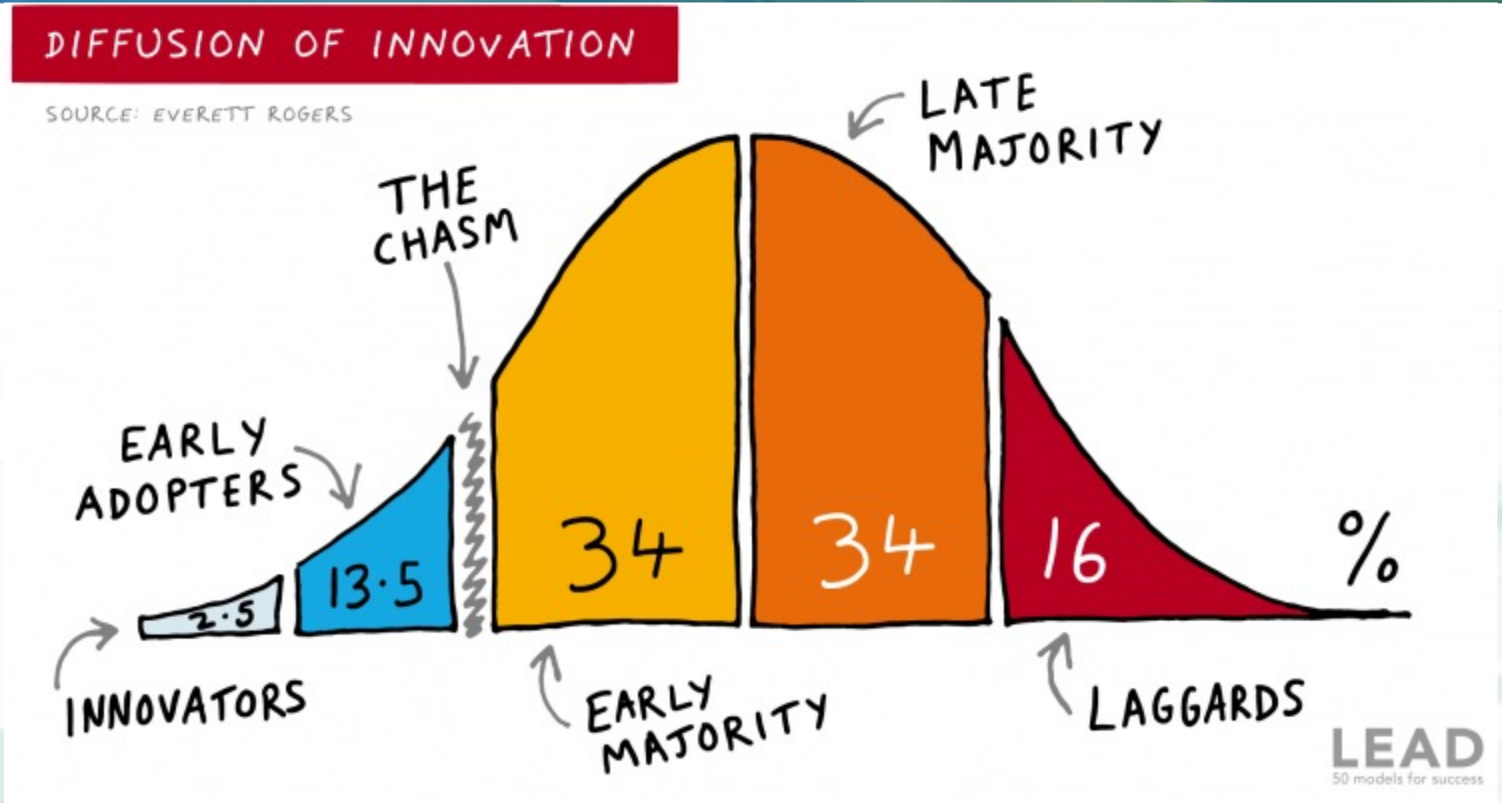
Bridging the Divide



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Thank you

Data Science: Getting Started

- Students
  - Learn to script (R/Python)
  - Geoscience domain expertise is most important
  - Consider data science boot camps
  - Competitions: Unearthed, Kaggle etc.
- Professionals
  - Look for opportunities to augment existing projects with data science components
  - Develop an internal data science strategy
  - Provide continued education opportunities, esp. to senior staff
  - Outsource missing components to specialty firms
  - Continue to fund R&D
  - Develop a data-driven culture including organization-wide data collection practices