PIPELINE SPILL MODELING TO SUPPORT VALVE PLACEMENT OR OPERATION DECISIONS

National Academy of Sciences - Criteria for Installing Automatic and Remote-Controlled Shutoff Valves on Existing Gas and Hazardous Liquid Transmission Pipelines (Meeting 6)

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rpsgroup.com

MAKING COMPLEX EASY

Jeremy Fontenault
Director, RPS – Ocean Science

- Background in Natural Resources and GIS
- 11 years of experience in pipeline spill modeling
  - on land and in water spill modeling
  - Land-based releases from pipelines, facilties, tanks, rail cars, etc.
  - HCA Analysis
  - Valve placement and optimization studies
  - Model development/enhancements

RPS Overview

- Leading global professional services firm, founded in 1970
- Ocean Science and Technology division based out of South Kingstown, RI
- Environmental scientists, software developers, and engineers
- Serve a diverse range of clients in the Energy, Environment, and Government sectors
- Environmental modeling services

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RPS Pipeline Experience

Services

- Trajectory, fate, and effects modeling
- Release volume estimation
- Valve optimization
- Full-Scale exercise development/support
- Incident Command System (ICS) Training/Support
- Monitoring
- Subject matter expert advice
- Legal/hearing support
- Engagement
- Data management

Assessments

- High Consequence Area (HCA) Analysis
- Emergency Flow Restricting Device (EFRD) Analysis
- Environmental Impact Assessments (EIA)
- Ecological and Human Health Risk Assessments (EHHRA)
- Oil Spill Response Plans (OSRP & COSRP)
- Risk Assessments
- Contingency Plans
- Net Environmental Benefit Analysis (NEBA)
- Spill Impact Mitigation Assessments (SIMA)
- Natural Resource Damage Assessments (NRDA)

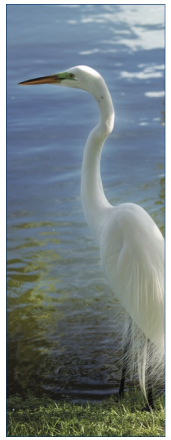
Agenda

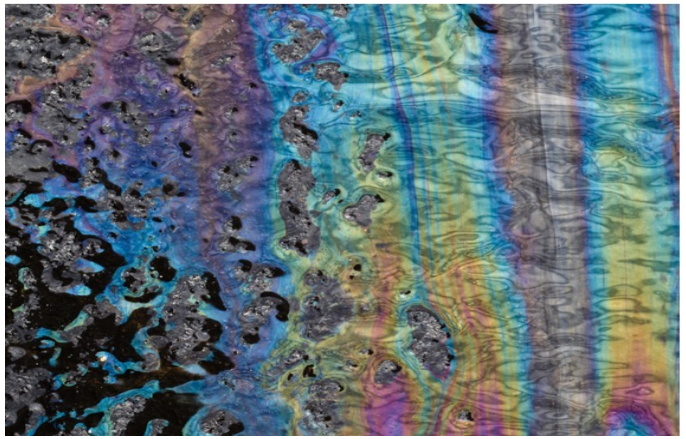
- Spill Modeling Overview
- RPS Spill Modeling Services
  - Liquid Spill Plume Modeling – OILMAPLand
  - Vapor Dispersion, Fire, and Explosion Modeling
- High Consequence Area (HCA) Analysis
- Emergency Flow Restricting Device (EFRD) Analysis
- Q&A

Spill Modeling

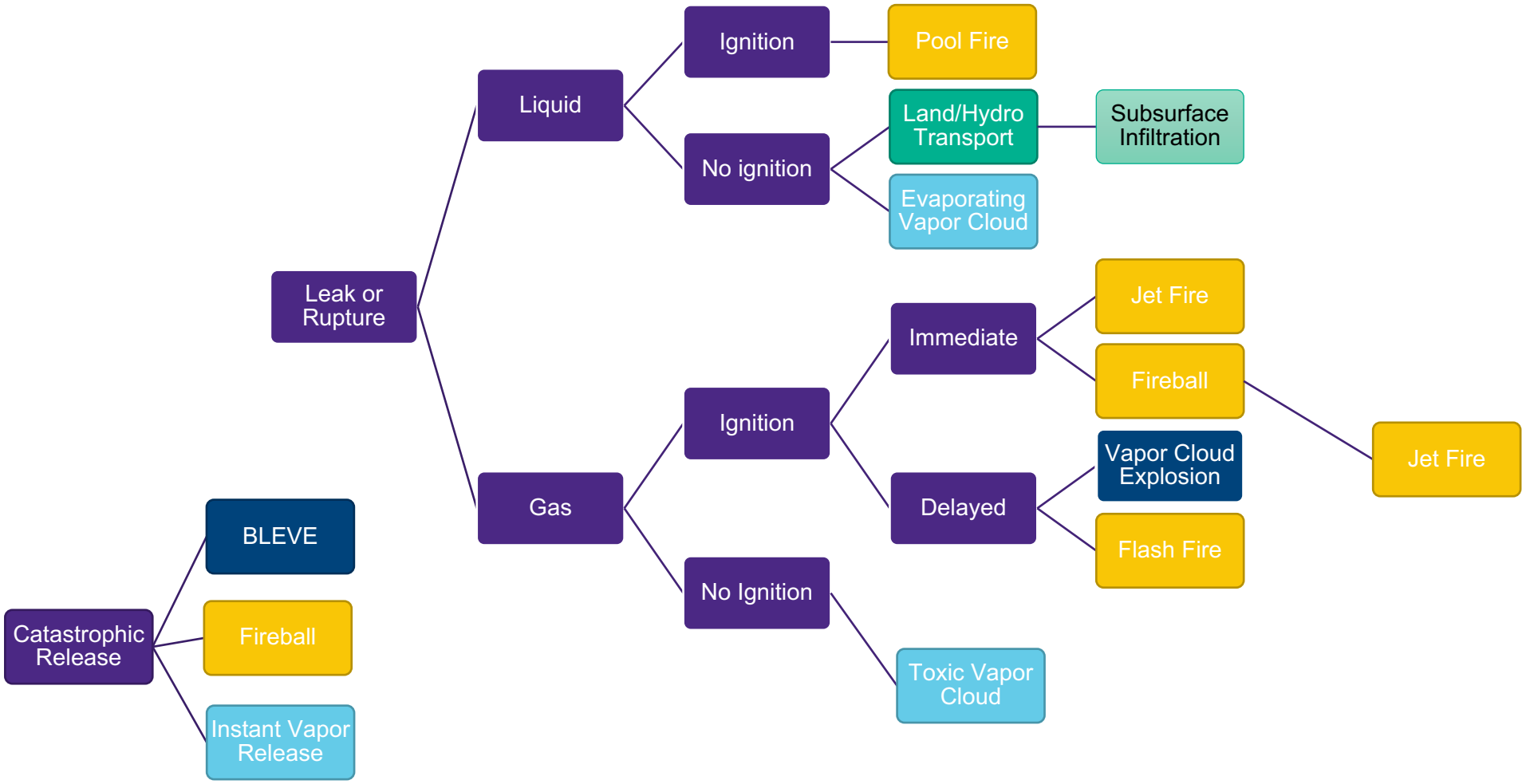
Modeling Helps Answer 3 Main Questions:

1. **Trajectory** – where will the release product travel in the environment?
2. **Fate** – how will the product behave and weather in the environment?
3. **Effects** – What biological/socio-economic resources may be impacted and how?

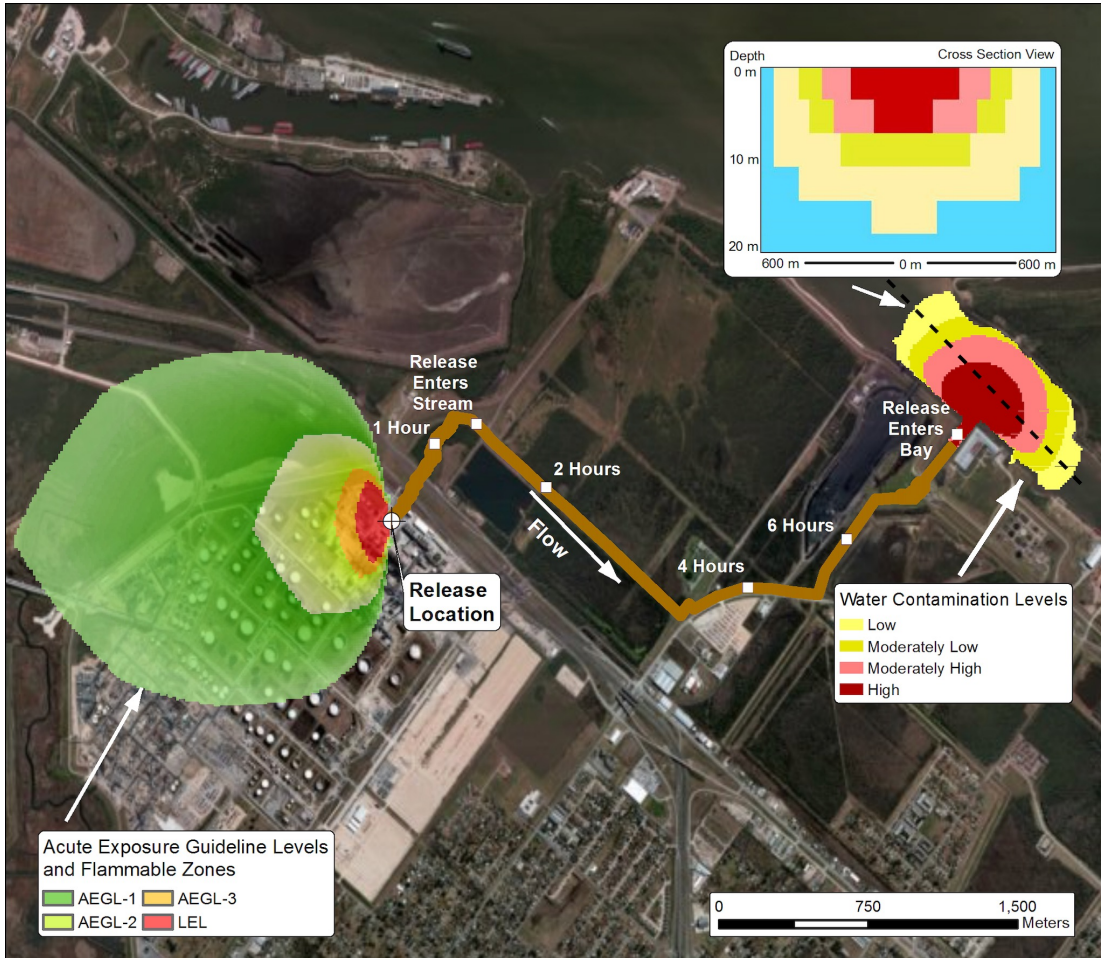


Release Consequence Scenarios

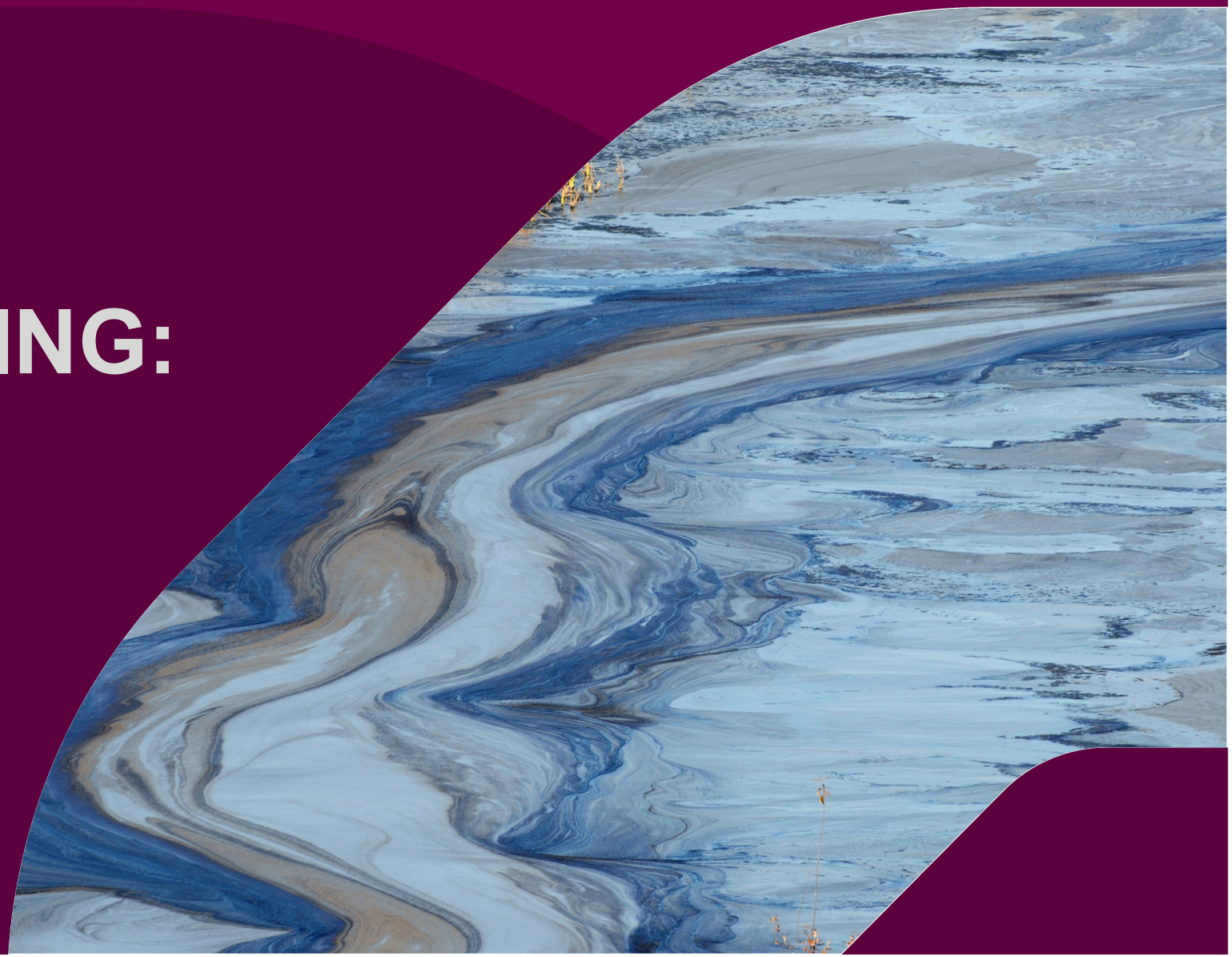


RPS Spill Modeling Services

- Overland Liquid Release Modeling - **OILMAPLand**
  - Release volume prediction
  - Overland and in water 2D trajectory and fates
- In Water Modeling – **OILMAP** / **SIMAP** / **CHEMMAP**
  - Advanced 3D modeling in water
  - Inland waterways and offshore
  - Biological effects and response analysis options
- In Air Modeling
  - Atmospheric dispersion modeling for highly volatile liquids and gas
  - Fire and Explosion modeling



LIQUID SPILL PLUME MODELING: OILMAPLand

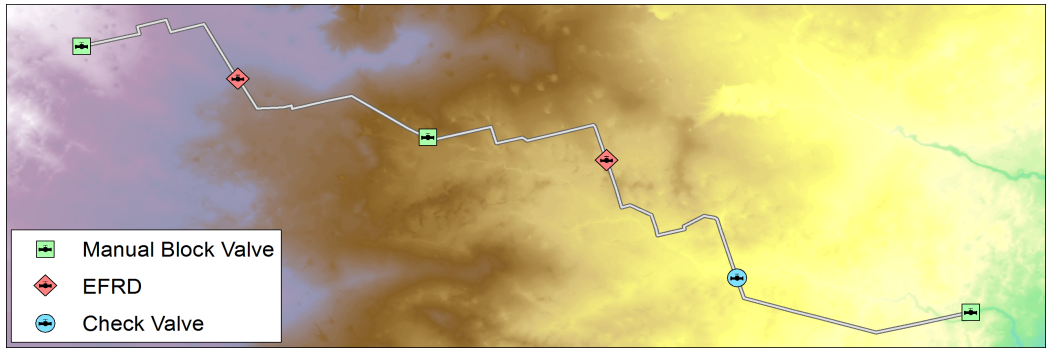


OILMAPLand Overview

- Predicts the transport and fate of spilled oil over the land surface and in surface water networks.
- 2D simulations
- Integrated into standard GIS Software
- Capable of simulating releases along an entire pipeline route, or individual locations (i.e., tank facilities)
- 3 Main Modules:
  - Release volume calculation
  - Overland spill model
  - Surface water spill model

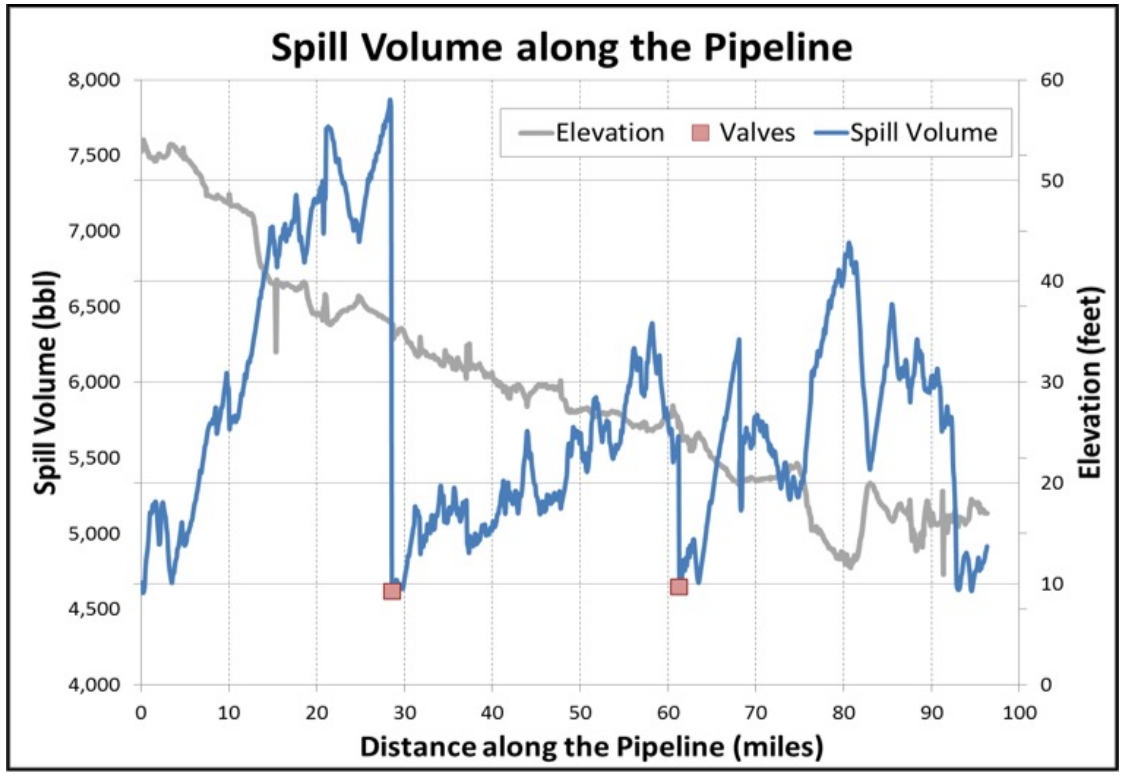
OILMAPLand - Release Volume Calculation

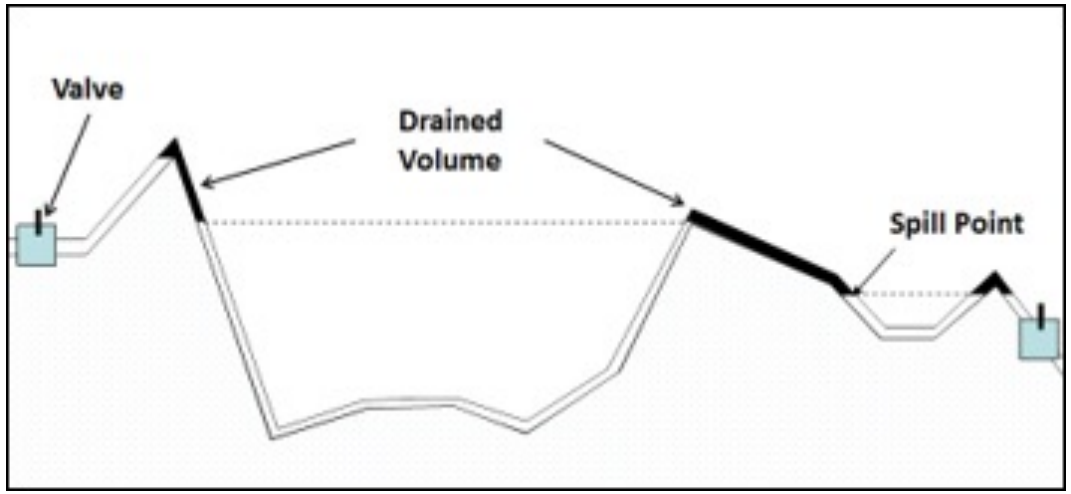
- Release Type:
  - **Full-bore Rupture (FBR)** – guillotine type break in the line, hole equal to inside diameter
  - Can simulate smaller leaks (user specified hole size)
- Release locations:
  - Interval along the pipeline
  - Specified location(s)
- Inputs:
  - Properties of transported product
  - Diameter/wall thickness
  - Flow rate
  - Timing – leak detection, reaction, pump shutdown
  - Valves – location, operation type, closure timing
  - Elevation profile of the pipeline



OILMAPLand - Release Volume Calculation

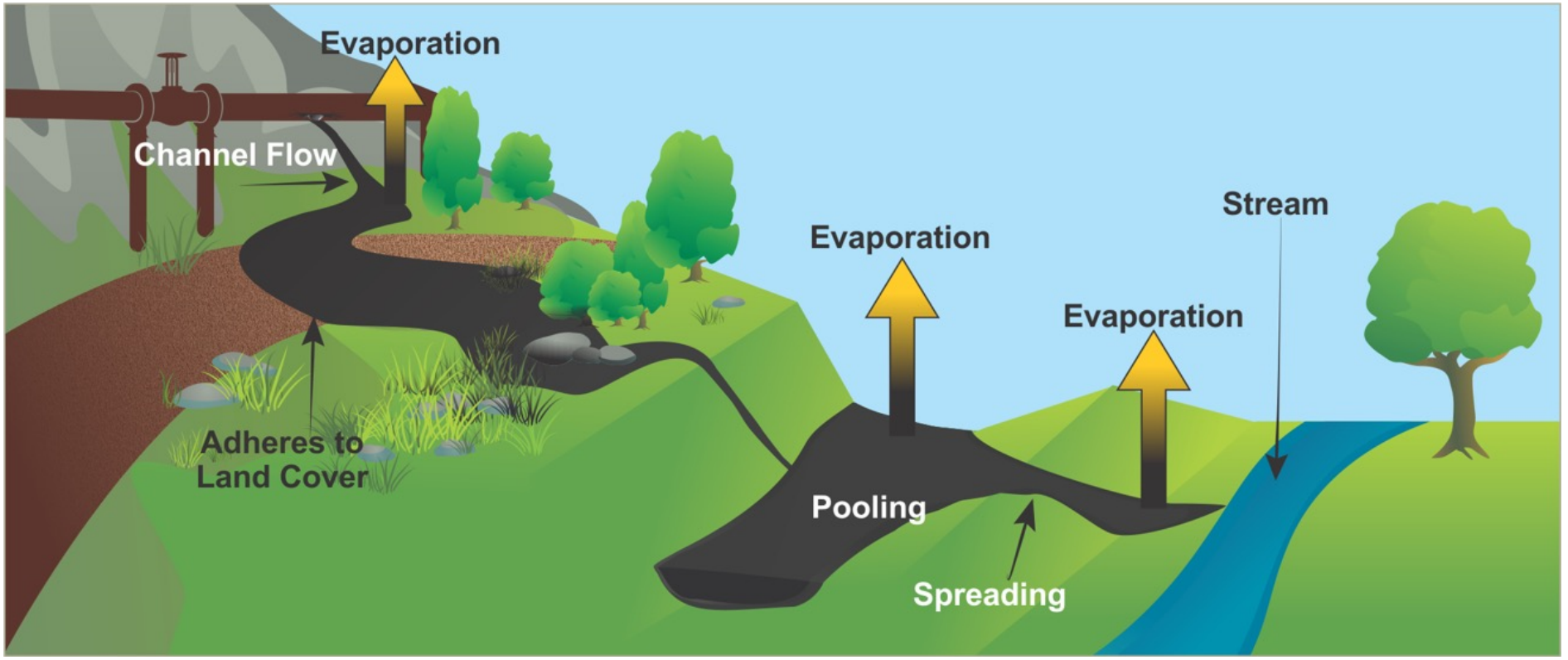
Total Release Volume = Pumped Volume + Pre-Isolation Drainage Volume + Post-Isolation Drainage Volume





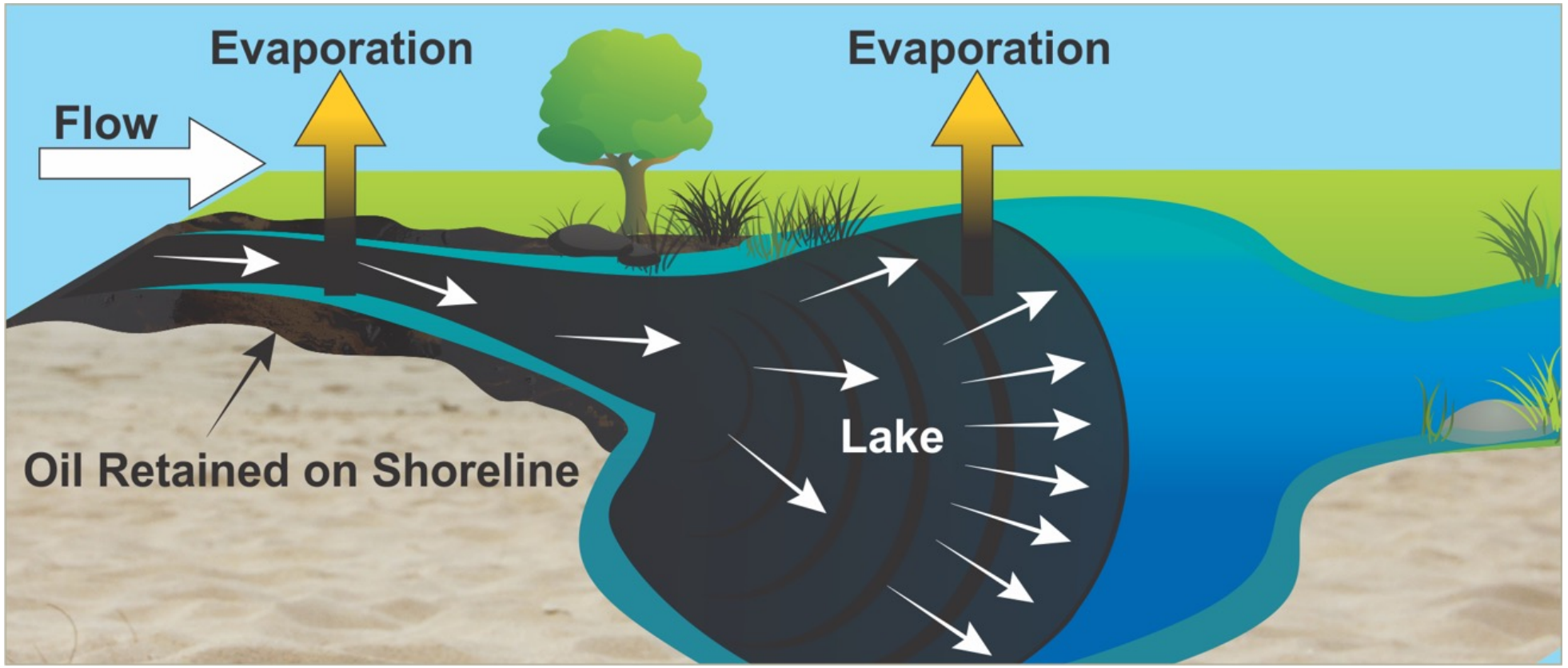
Overland Modeling

- Overland Flow
- Surface Adhesion
- Pooling
- Evaporation



Surface Water Modeling

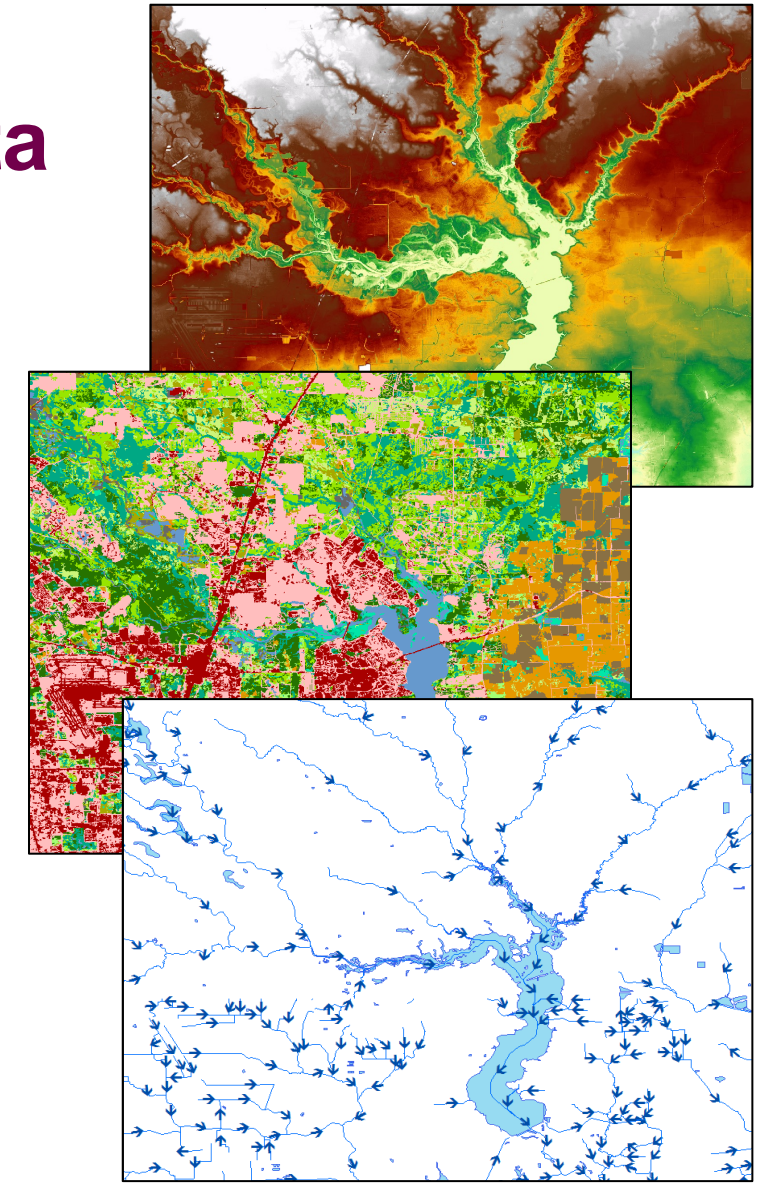
- Downstream Movement
- Shoreline adherence
- Spreading in waterbodies
- Evaporation



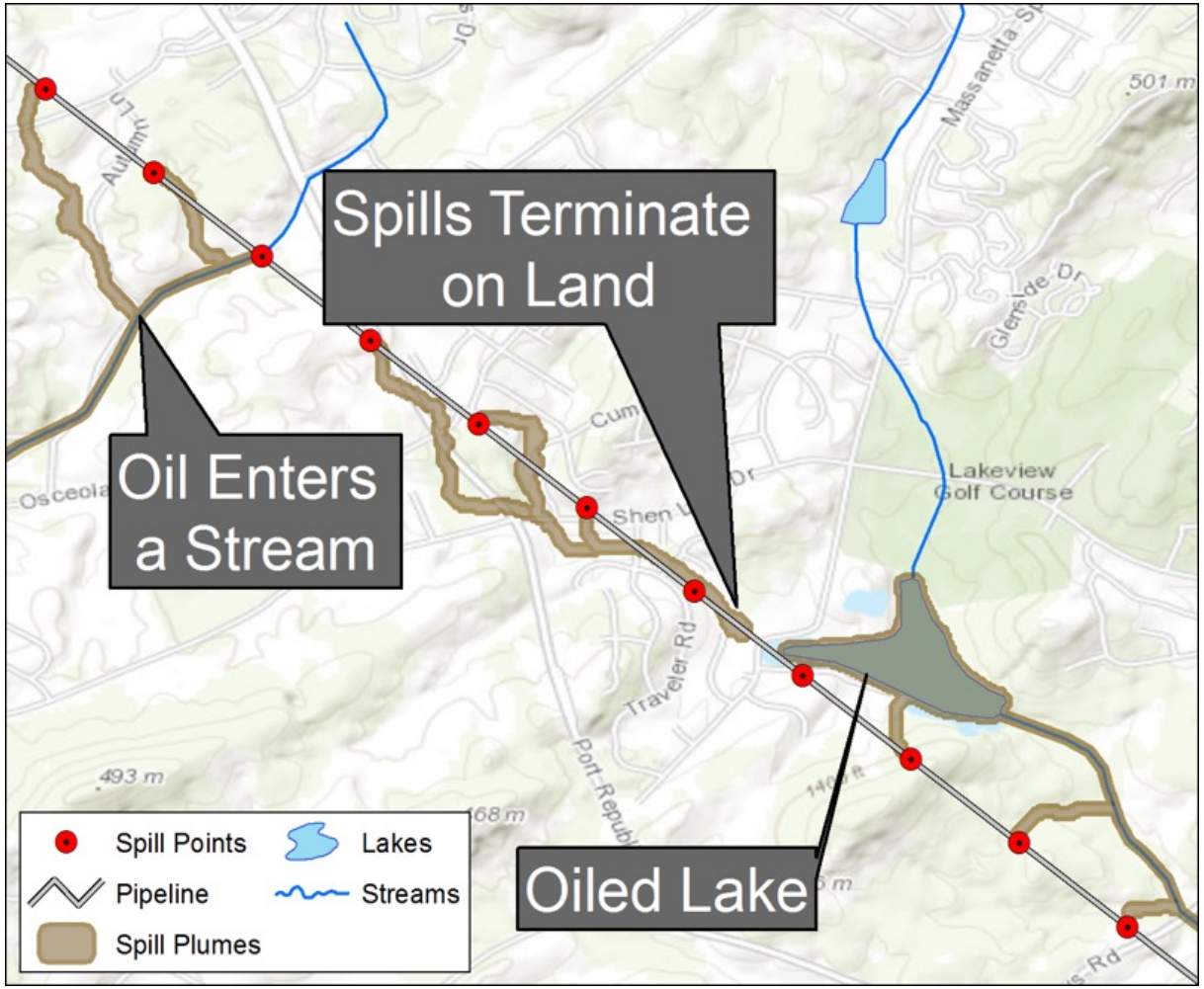
OILMAPLand Plume Modeling Input Data

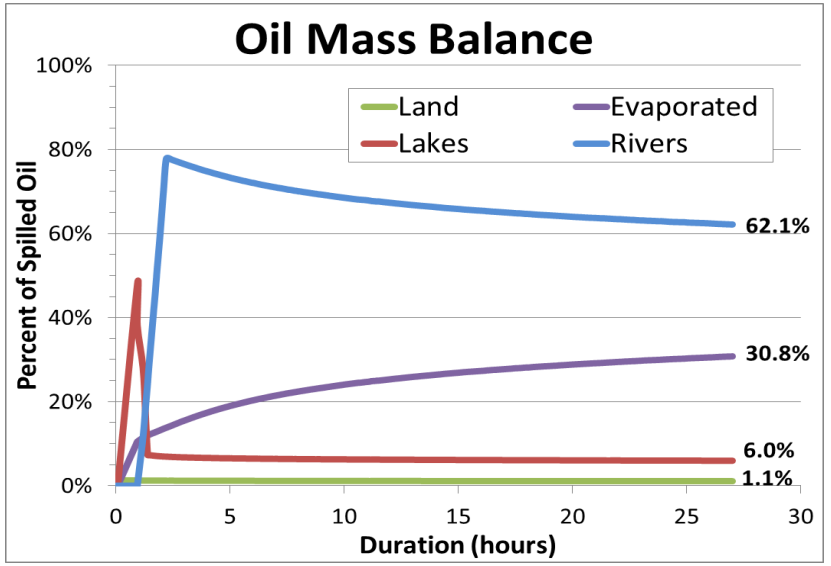
- **Land Elevation – Digital Elevation Model (DEM)**
- **Land Cover – Land cover grid**
- **Surface Water – Networked streams and lakes**

- Environmental Data – air temperature, wind speed
- Oil Characteristics – physical and weathering properties
- Release Locations
- Simulation time limit options



OILMAPLand Output – High Level

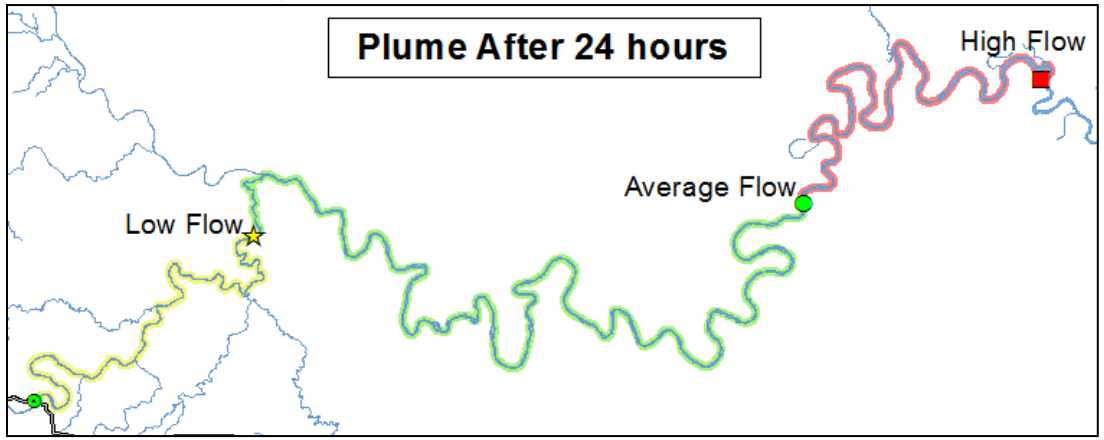


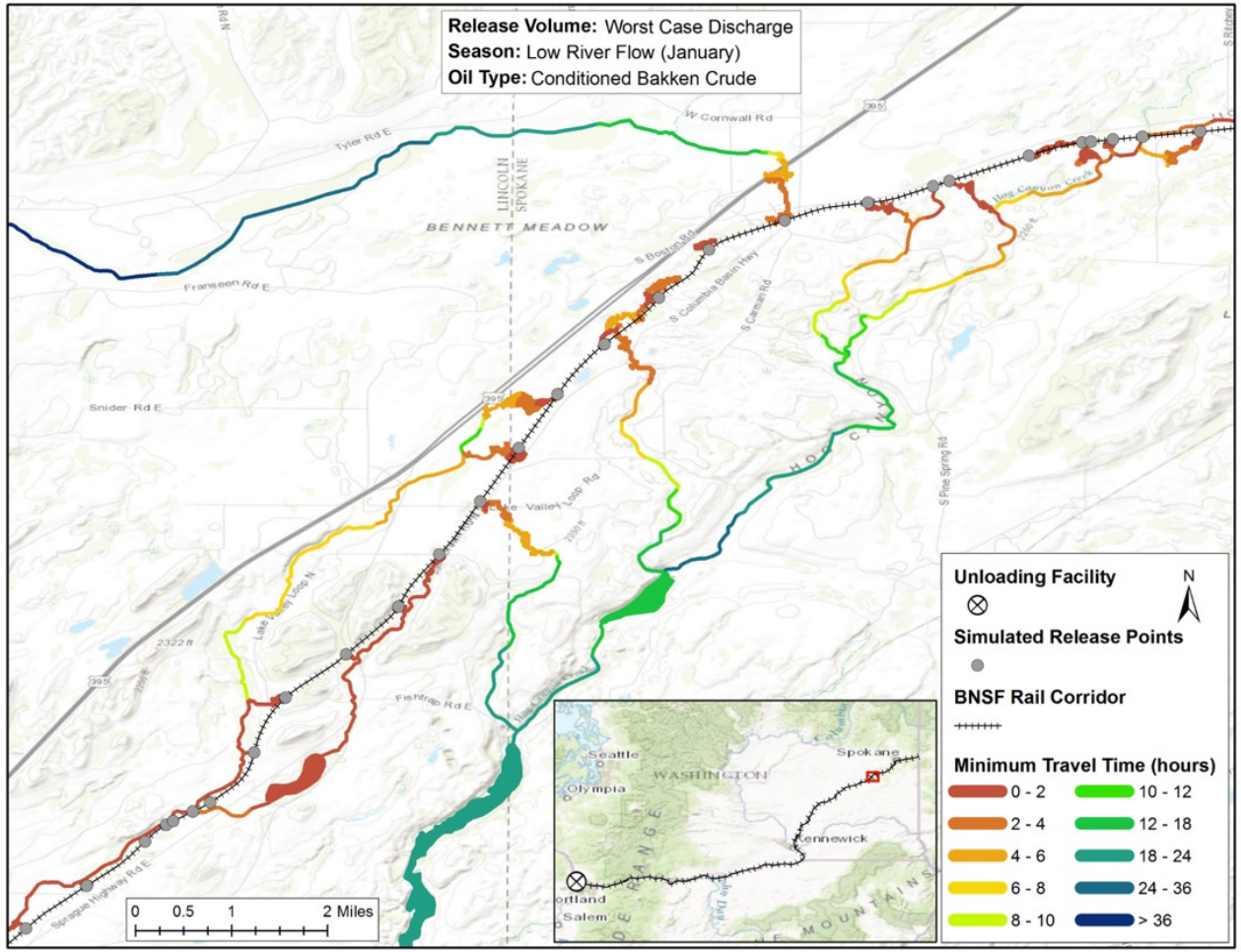


Spill Num	Volume (m^3)				
	Land	Evaporated	Rivers	Lakes	Total
1	9.92	3.35	172.20	0.00	185.47
2	6.93	4.70	220.30	0.00	231.94
3	7.05	5.00	229.00	0.00	241.04
4	7.12	4.92	225.40	0.00	237.44
5	7.44	4.45	212.80	0.00	224.69
6	24.81	4.62	189.50	0.27	219.20
7	25.54	4.34	182.80	0.28	212.96
8	24.55	4.04	174.90	0.29	203.77
9	24.58	3.91	169.50	0.29	198.28
10	23.47	3.72	165.30	0.30	192.78

OILMAPLand Output – Timing

- Predict the timing of spilled product first reaching a location
- Response Planning:
  - Timing to consider response timing needs, plan equipment location, and other strategies
  - Assess environmental conditions/seasonal variability

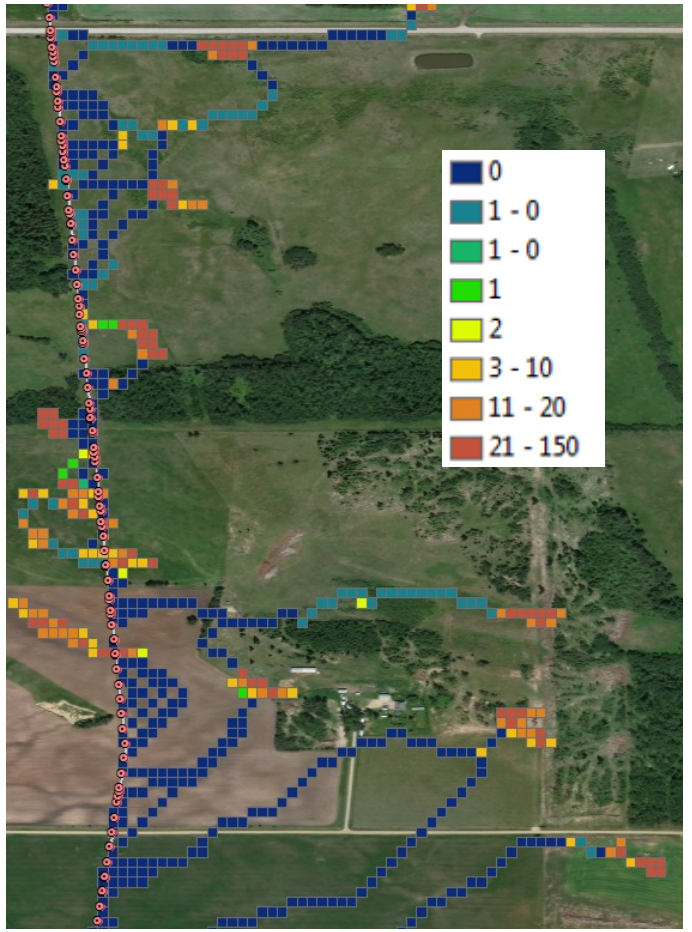




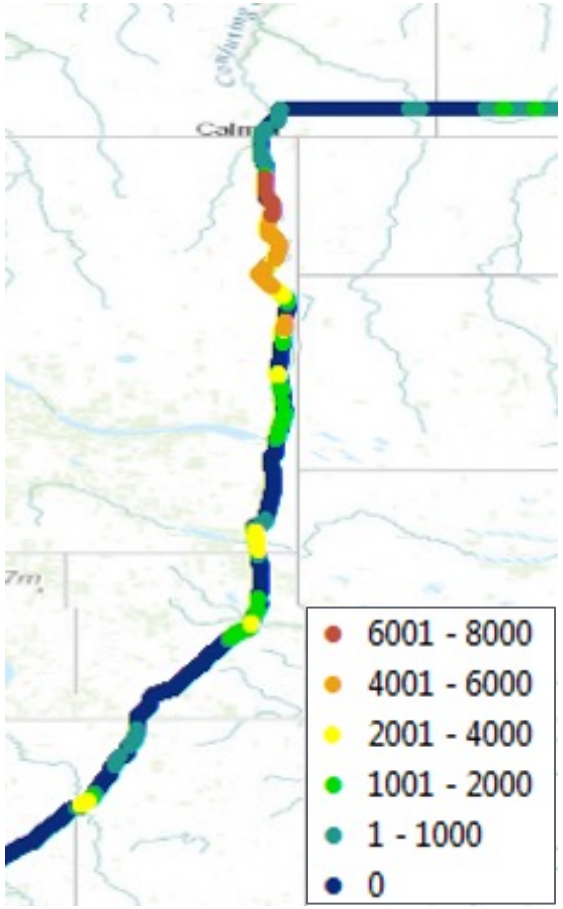
OILMAPLand Output – Volume in Environment

- Estimate the environmental consequence of a spill for use in advanced Risk Assessment
  - Volume of oil remaining on the land surface – pooled in depressions or adhered to the surface
  - Volume of oil reaching water or specific watercourse
  - Length of a watercourse impacted
  - Volume evaporated (total or over time)
  - And more…

Volume Remaining on Land



Volume Reaching Water



VAPOR DISPERSION, FIRE, AND EXPLOSION MODELING

Models Used and Products Assessed

Primary Models Used:

- **Complex Hazardous Air Release Model (CHARM)**
  - Release characterization from pressurized vessels
  - Jet fire radiation
  - Pool fire radiation
  - Pool evaporation
- **EPA SLAB Model**
  - Vapor dispersion – denser-than-air gases
- **EPA/NOAA ALOHA Model**
  - Vapor cloud explosion
  - Vapor dispersion

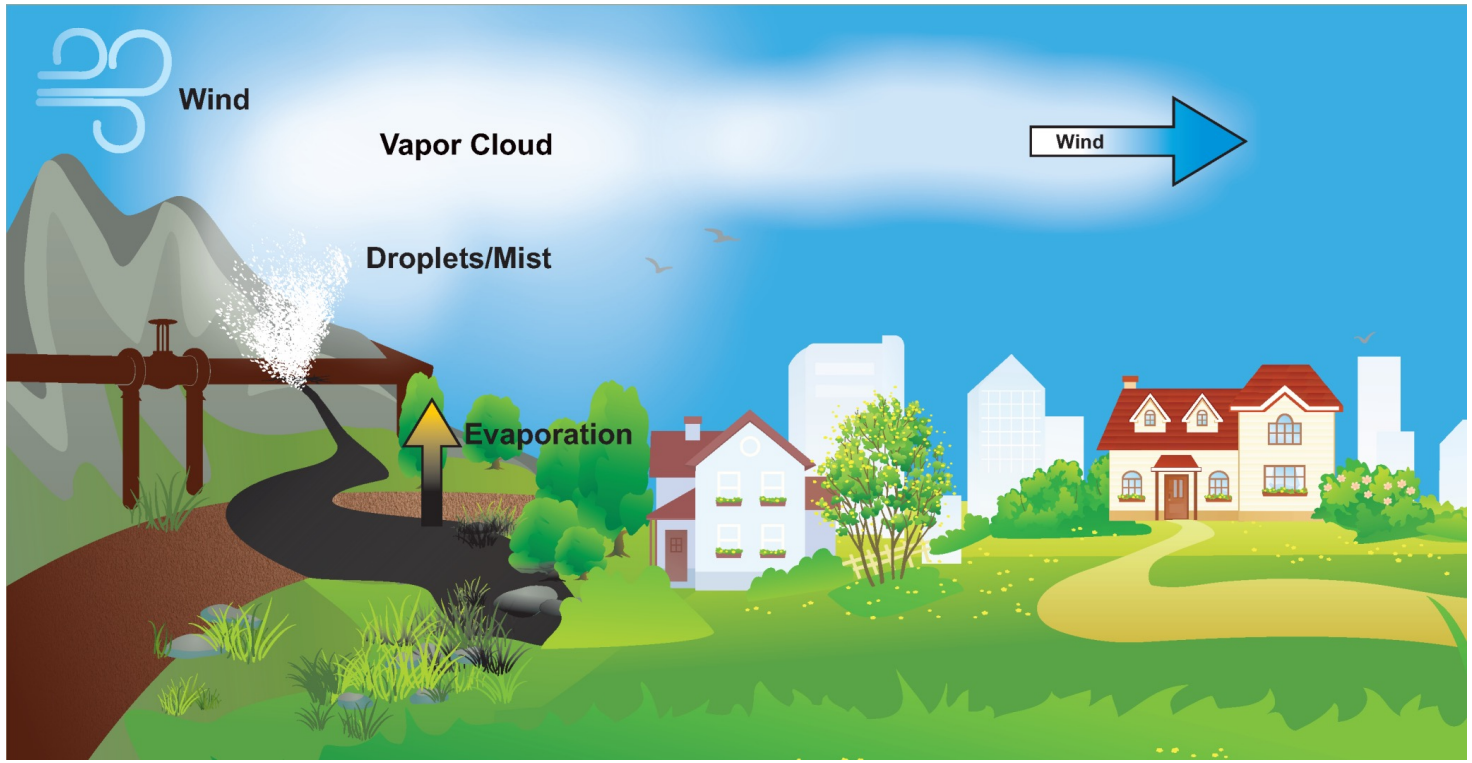
Products Assessed:

- Highly Volatile Liquid (HVL) Hydrocarbons / High Vapor Pressure (HVP)
- Natural Gas (Methane)
- Carbon Dioxide (CO_2)
- Ammonia
- Hydrogen
- And other chemicals

Highly Volatile Liquid (HVL) Pipelines

May need to consider consequences of both liquid and vapor released

- Products transported as liquids, but released as vapor or combination of liquid and vapor
  - OILMAPLand can be used for liquid plume modeling
  - Other models used to assess vapor dispersion, and other potential consequences

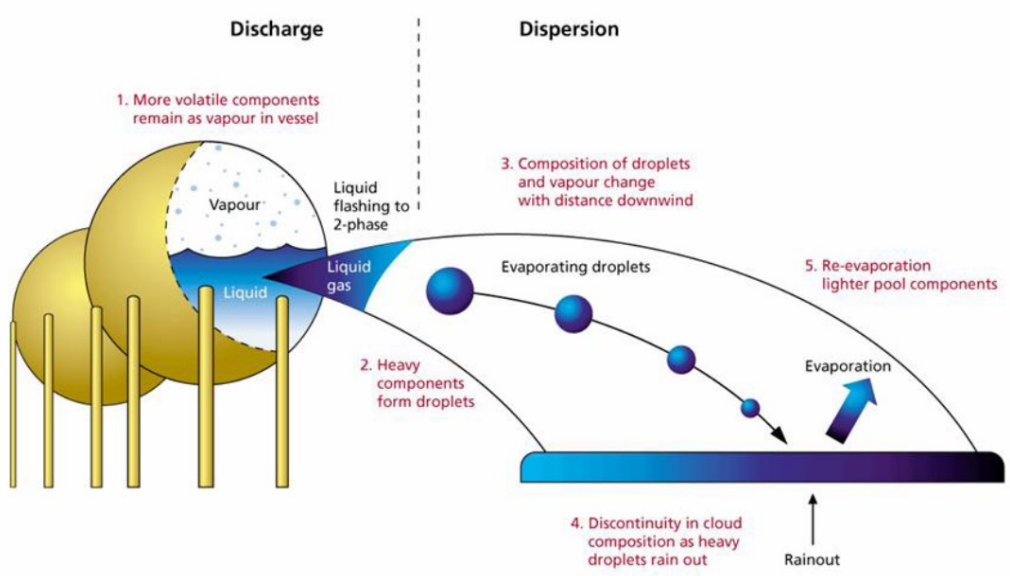


Process:

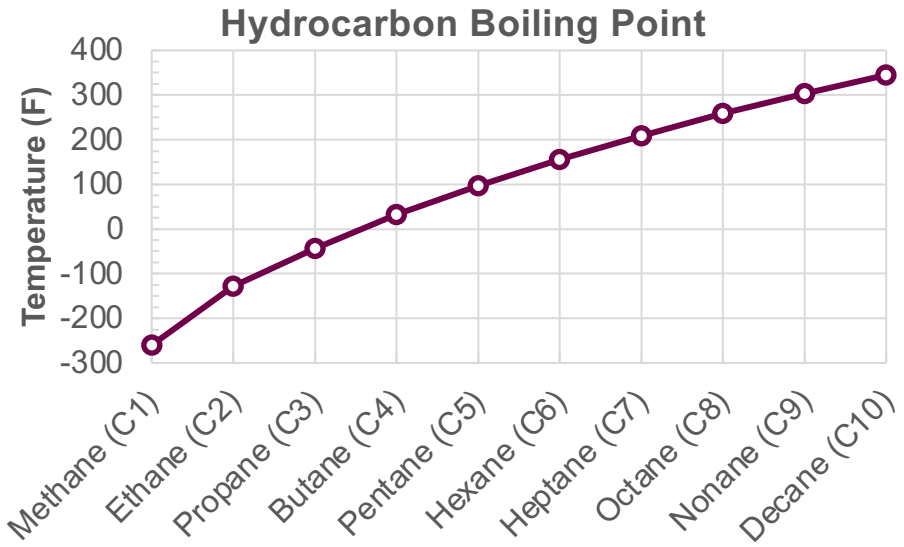
1. Analysis of the HVL composition
2. Characterize the release conditions
3. Assess the potential consequences related to various HVL release hazards

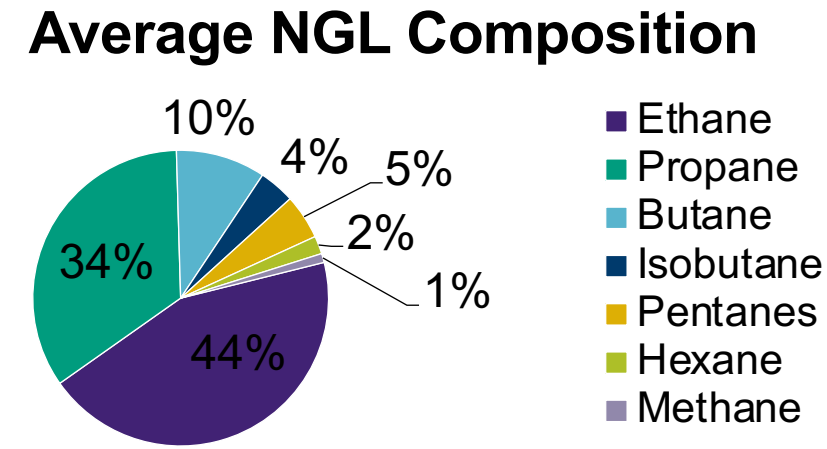
HVL Composition

- Products are typically composed of multiple hydrocarbon chemicals, in varying quantities
- Different physical properties - will behave differently when released



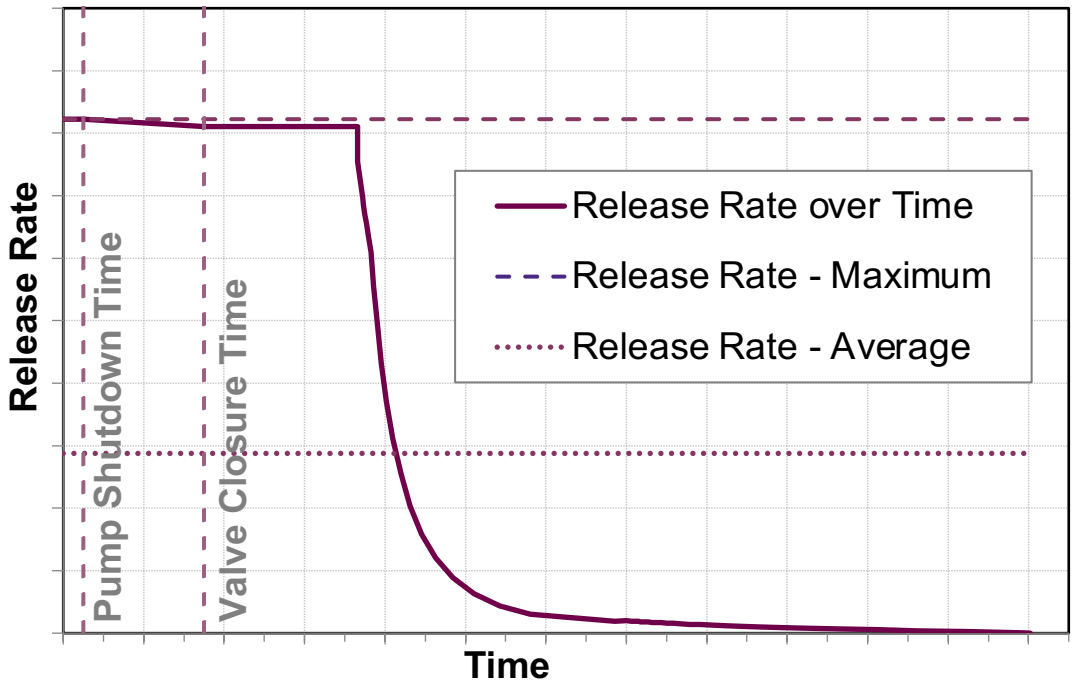
Source: DNV GL https://www.dnv.com/Images/Phast-flier_tcm8-56726.pdf





Release Characterization

- Physical state of the release hydrocarbons
  - Amount of liquid, droplets/mist, vapor
- Predict the release rate over time
  - Maximum release rate
  - Average release rate over a period of time
- Factors Considered:
  - Storage/ambient pressure and temperature
  - Timing: detection/response, pump shutdown, valve closure
  - Size of the hole
  - Volume available to be released (length/diameter of the pipeline or isolated segment)



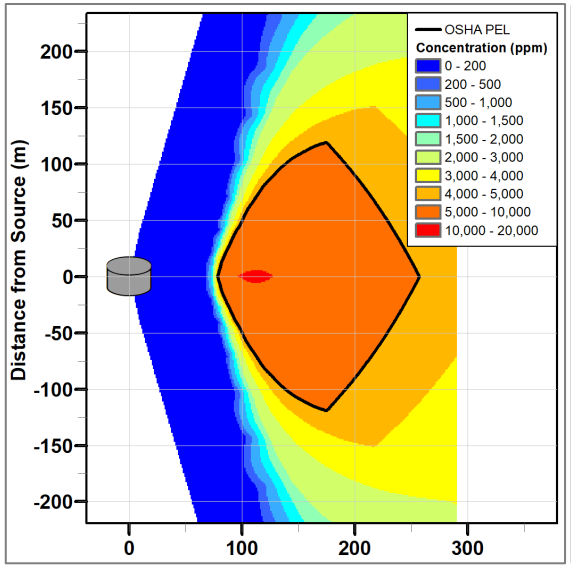
Vapor Dispersion - Thresholds of Concern

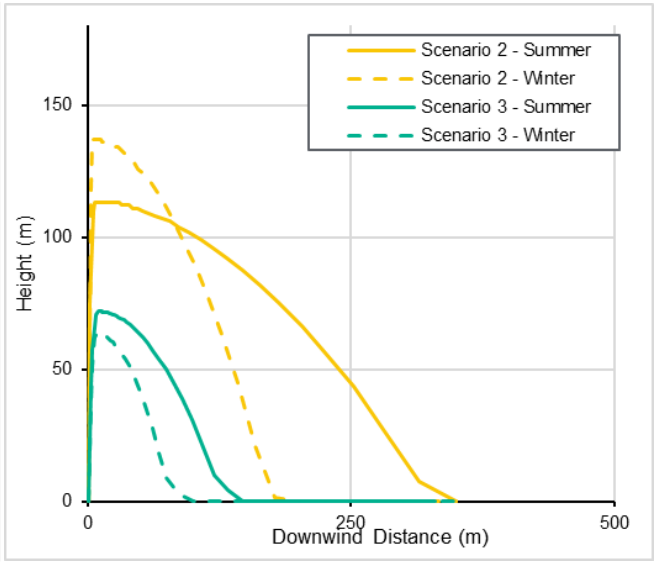
- Lower Explosive Limit (LEL)
  - Concentration threshold at which the vapor could catch fire if there were an ignition source

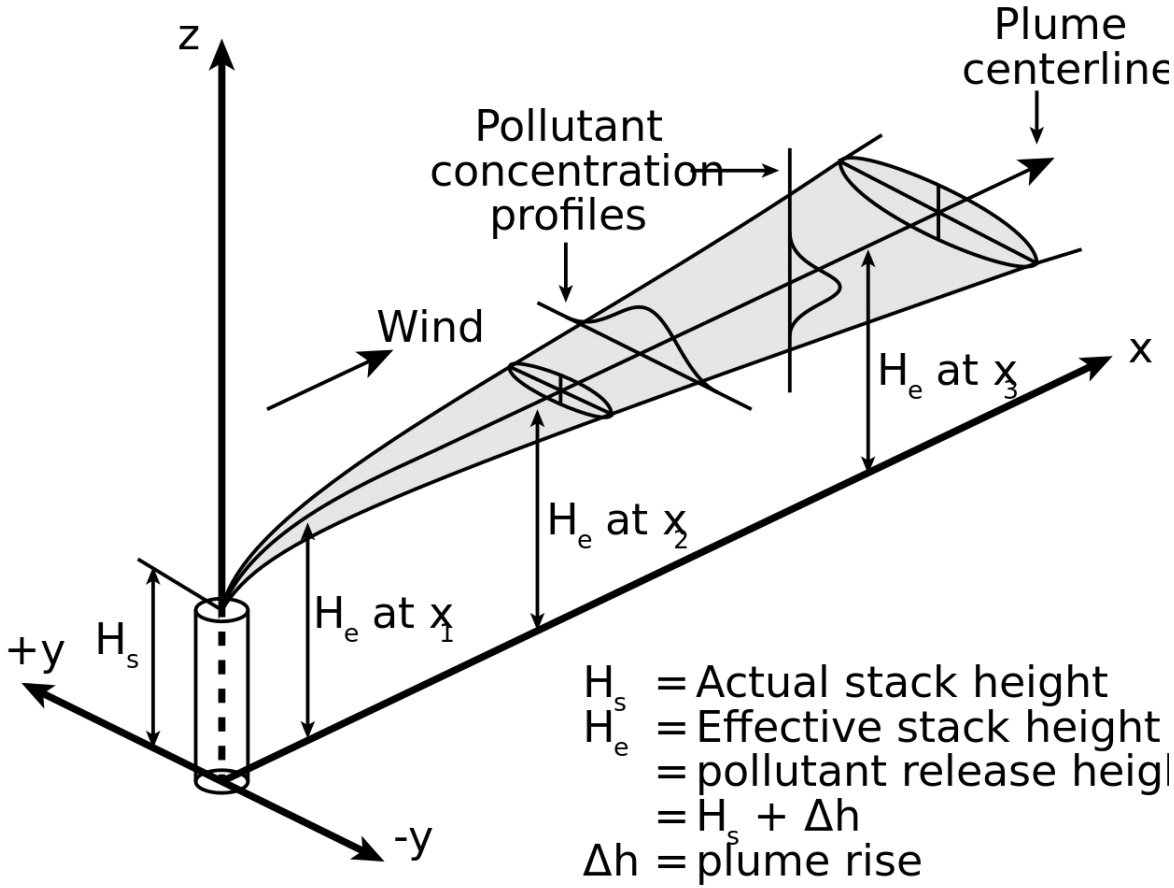
- Health Risk Thresholds
  - Concentrations exceeding these for a **defined time period** (10, 30, or 60 minutes) can cause toxic effects
    - Level 1 – reversible effects (discomfort, irritation, etc.)
    - Level 2 – irreversible effects, long-lasting effects, impaired ability to escape
    - Level 3 – life-threatening effects or death

Vapor Dispersion

- Simulates plume concentration and extent:
  - Concentration along plume centerline
  - Concentration cross section – plume dimensions
  - Height of maximum concentration

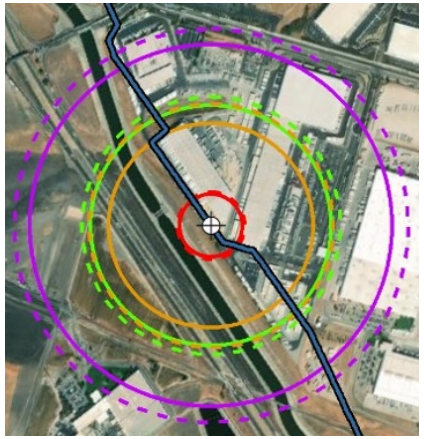


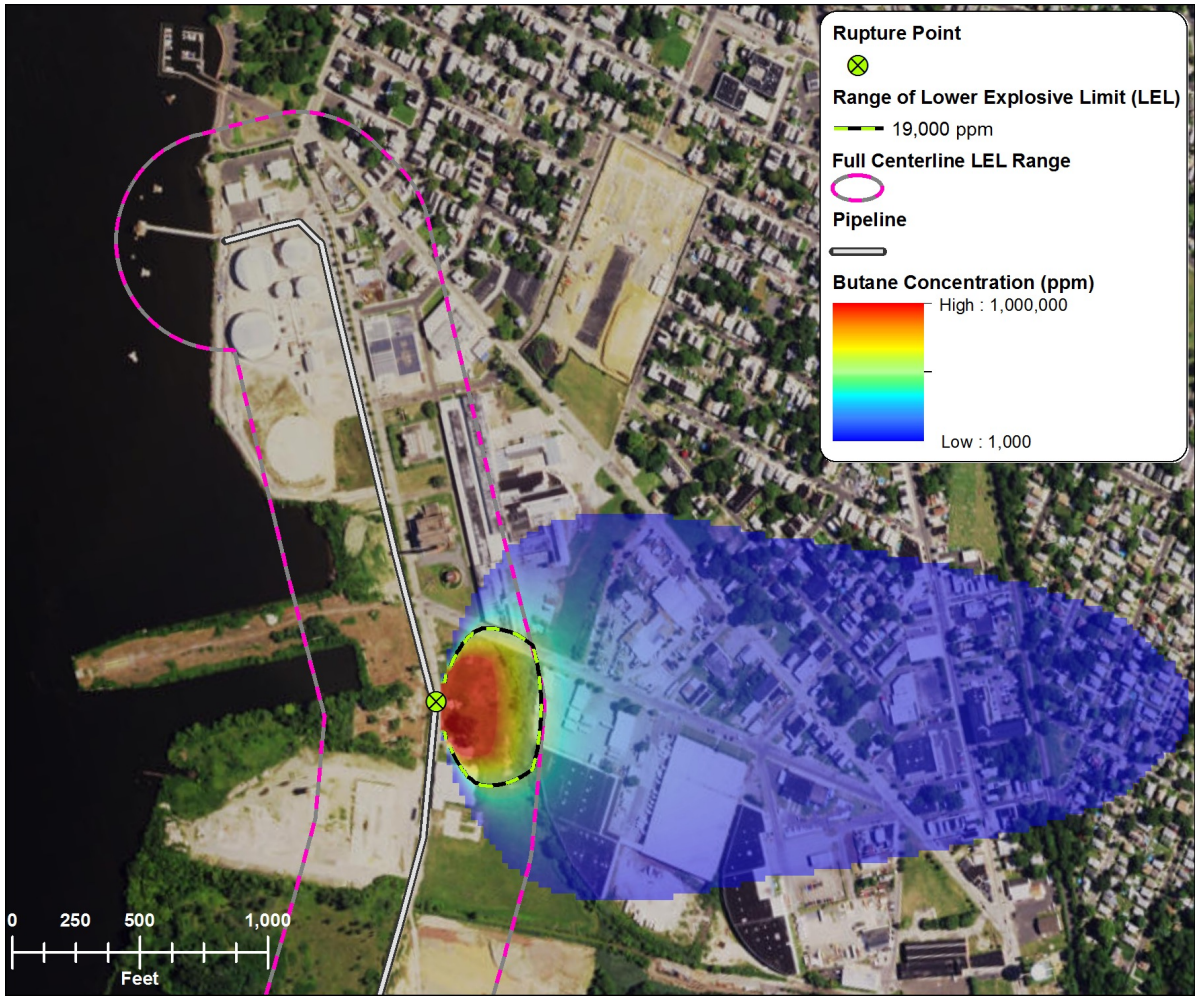




Vapor Dispersion Interpretation

- Assume:
  - release could be transported in any direction (wind)
  - release could occur anywhere along that pipeline segment
- Identify maximum distance by threshold (or overall)
- Can buffer the pipeline by this distance to define impact area.





Jet/Pool Fire Analysis

- **Jet Fires**
  - Ignited, continuous release from pressurized vessel. Can assess vertical or horizontal jets.

- **Pool Fires**
  - Ignited vapors above a pool of flammable liquid.

- Assess impacts from thermal radiation away from flames.
- Thresholds based on probability of mortality over a specific exposure period

Explosion Analysis

- **Vapor Cloud Explosion**
  - Vapor above the explosive limit concentration ignited
  - Unlikely, but can have significant impact

- Assess impacts resulting overpressure (shock wave)
- Impact severity can be related to damage to buildings, building collapse, or mortality

Bradley, D., Chamberlain, G.A. and Drysdale, D.D., 2012. Large vapour cloud explosions, with particular reference to that at Buncefield. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *370*(1960), pp.544-566.

HIGH CONSEQUENCE AREA (HCA) ANALYSIS

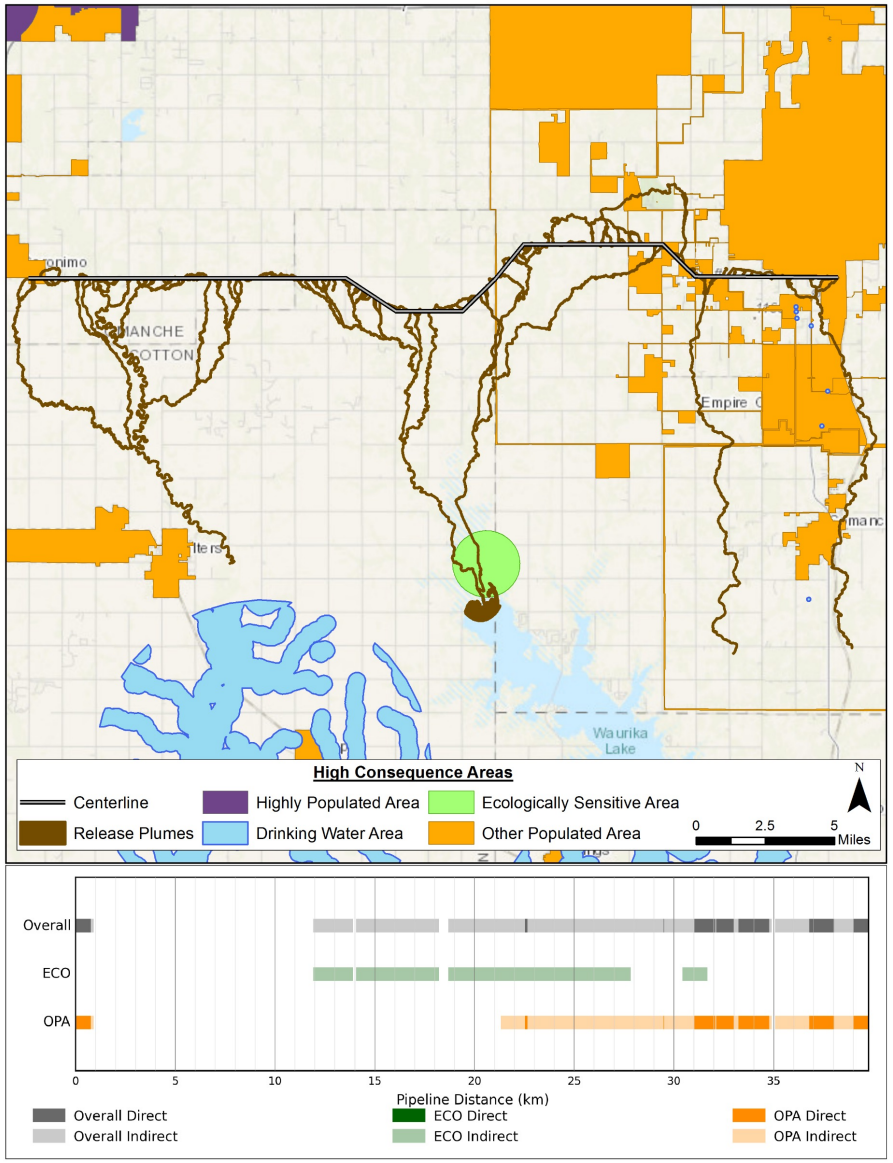
HCA Analysis

- Using results from plume modeling, asses impacts to nearby receptors
- HCAs:
  - PHMSA National Pipeline Mapping System (NPMS):
    - High Population Areas (HPA)
    - Other Population Areas (OPA)
    - Commercially Navigable Waterways (CNW)
    - Drinking Water (DW)
    - Ecologically Sensitive Areas (ECO)
    - Coastal Ecological Unusually Sensitive Area
  - Supplemental HCAs or other Areas of Interest (AOI)
- Impacts Summarized as:
  - Direct: Pipeline crosses the HCA
  - Indirect: Resulting release plume can reach the HCA

HCA Analysis

- **Liquid Plumes** – does the spill plume overlap with an HCA?
- **Vapor Dispersion** – are any HCAs within a distance from the pipeline where a threshold is exceeded?

- Develop HCA “could-affect” segments and summarize at various levels by count and mileage:
  - Direct vs Indirect
  - HCA category
  - Individual HCA



EMERGENCY FLOW RESTRICTING DEVICE (EFRD) ANALYSIS

EFRD Analysis - Introduction

- Emergency Flow Restricting Device:
  - Automatic shutoff valve (ASV)
  - Remote-controlled valve (RCV)
  - Check Valve

- Importance:
  - Swiftness of shutdown
  - Reduce amount of product released
  - Protect High Consequence Areas (HCAs)

- Requirements
  - Assess if there are benefits from adding EFRDs, in terms of reducing impacts to HCAs

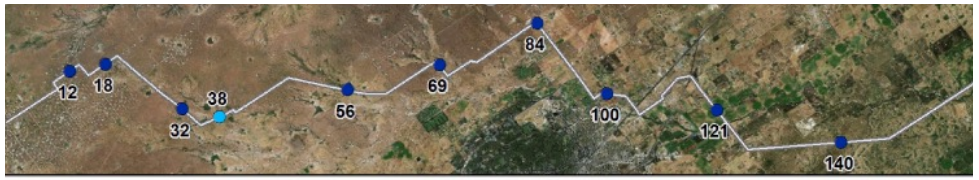
EFRD Analysis - Approach

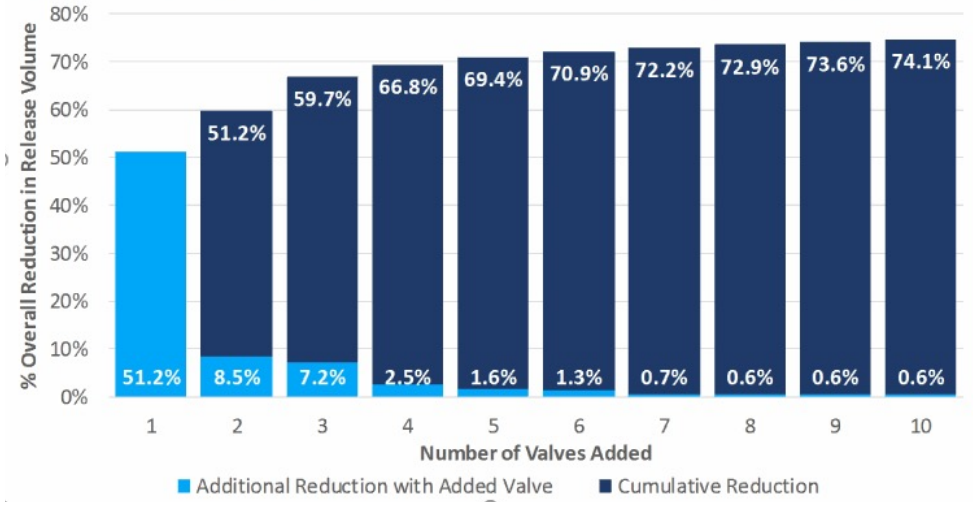
- Approaches:
  - Optimization – maximum reduction of potential release volume or impacts
  - Targeted Assessment – assess volume/impacts for specific scenarios
  - Upgrade Analysis – test upgrading existing manual valves

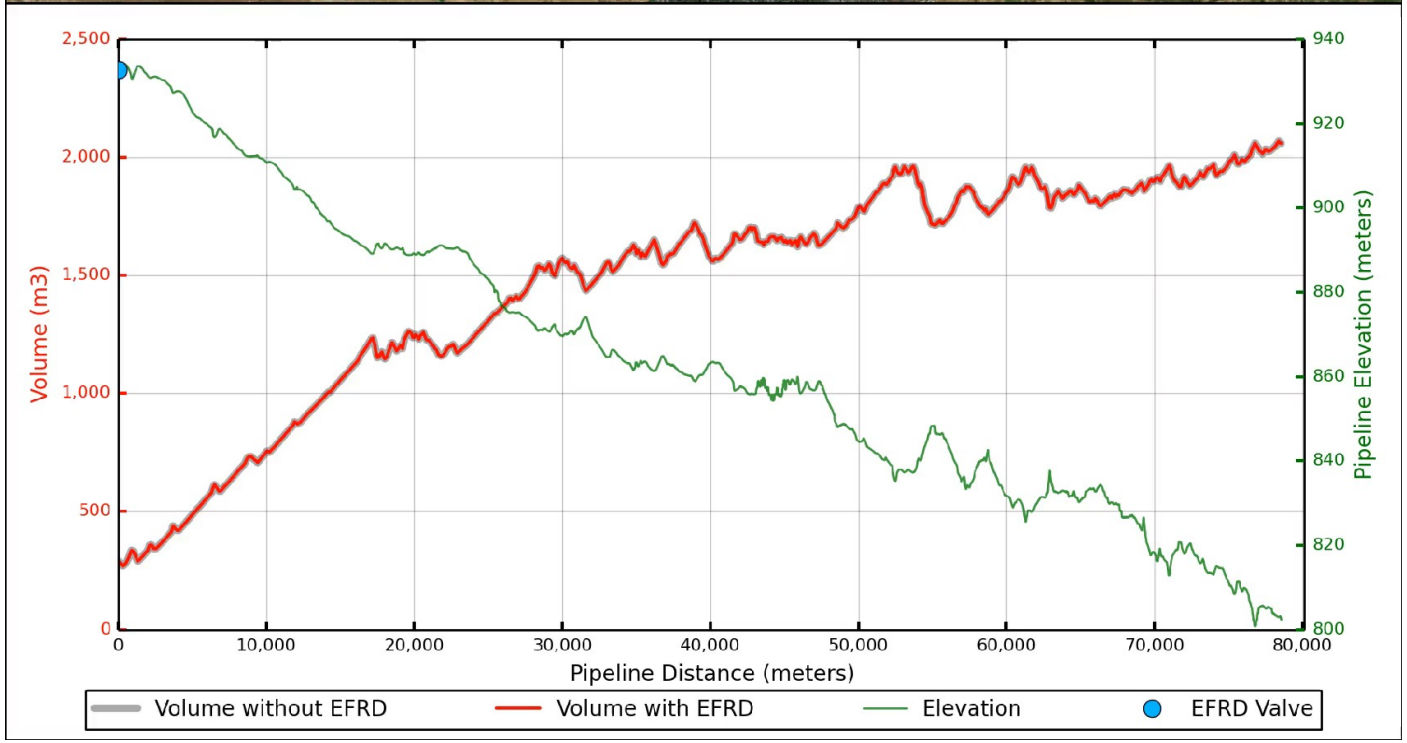
- Ways to Quantify Benefits:
  1. Reduction in amount of product released
     - Overall
     - HCA segments
  2. Reduction in HCA impacts:
     - Shorter HCA segments
     - Fewer HCAs impacted
  3. Less product reaching HCA (volume of liquid, vapor concentration, fire radiation, etc.)

EFRD Analysis – Liquid Releases

- Optimization of pipeline with no valves
- Automated analysis – hypothetical valves at interval along the pipeline
- Assess overall volume reduction

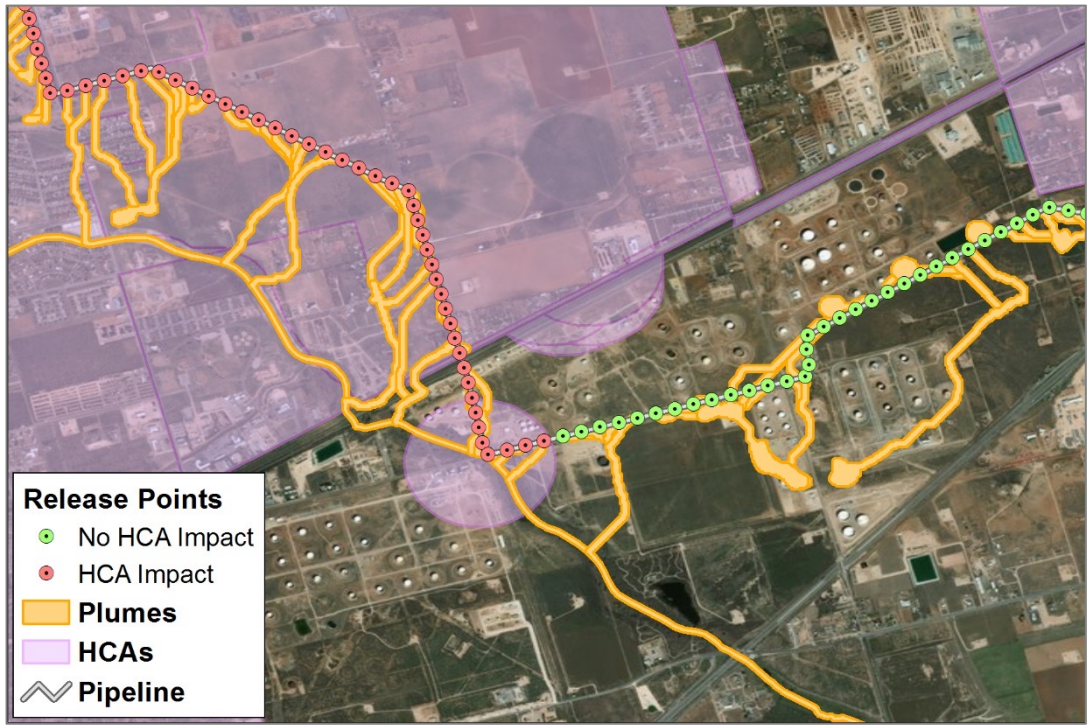


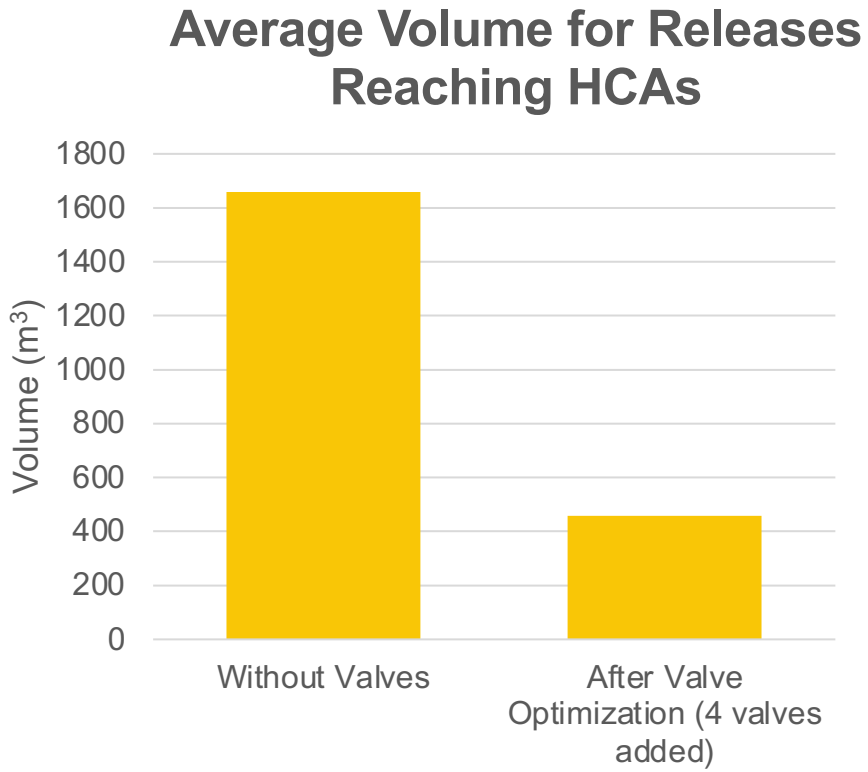




EFRD Analysis – Liquid Releases

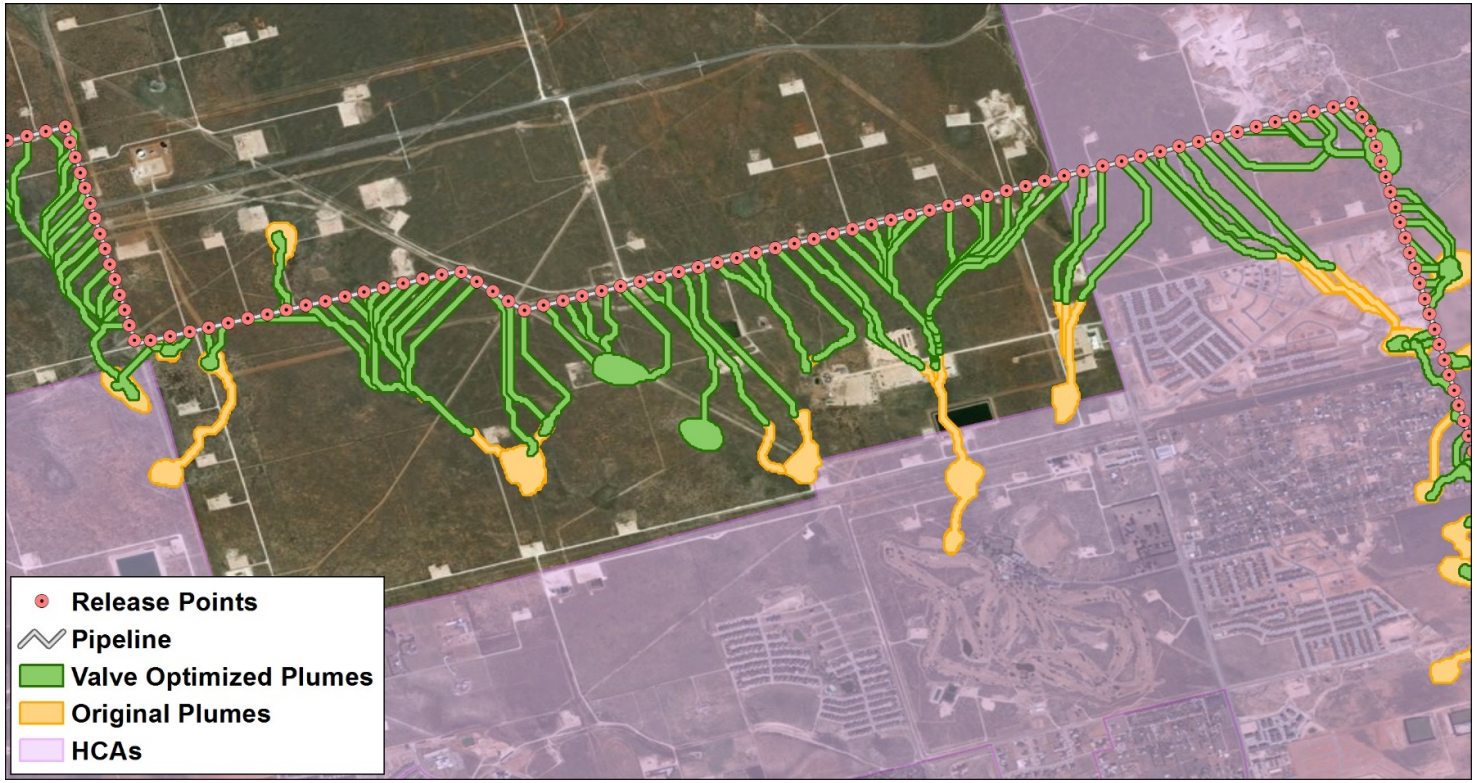
- Another metric could be to look at the release volume for those locations where an HCA could be impacted





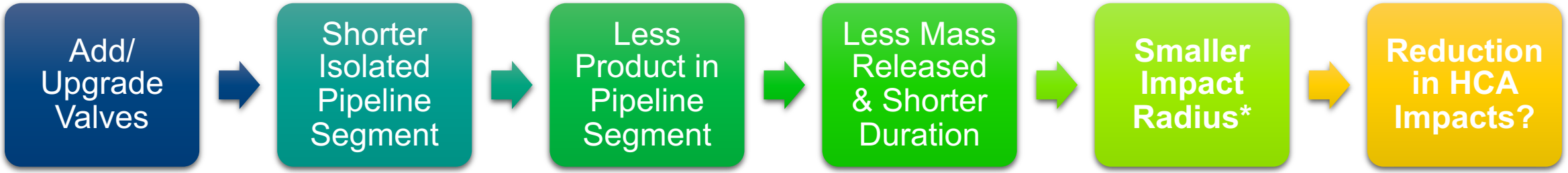
EFRD Analysis – Liquid Releases

- Assess reduction in HCA impacts
- Requires multiple plume modeling scenarios using different volumes



EFRD Analysis – HVL/Gas Releases

- Unlike liquids, terrain is less of a factor in a vapor release



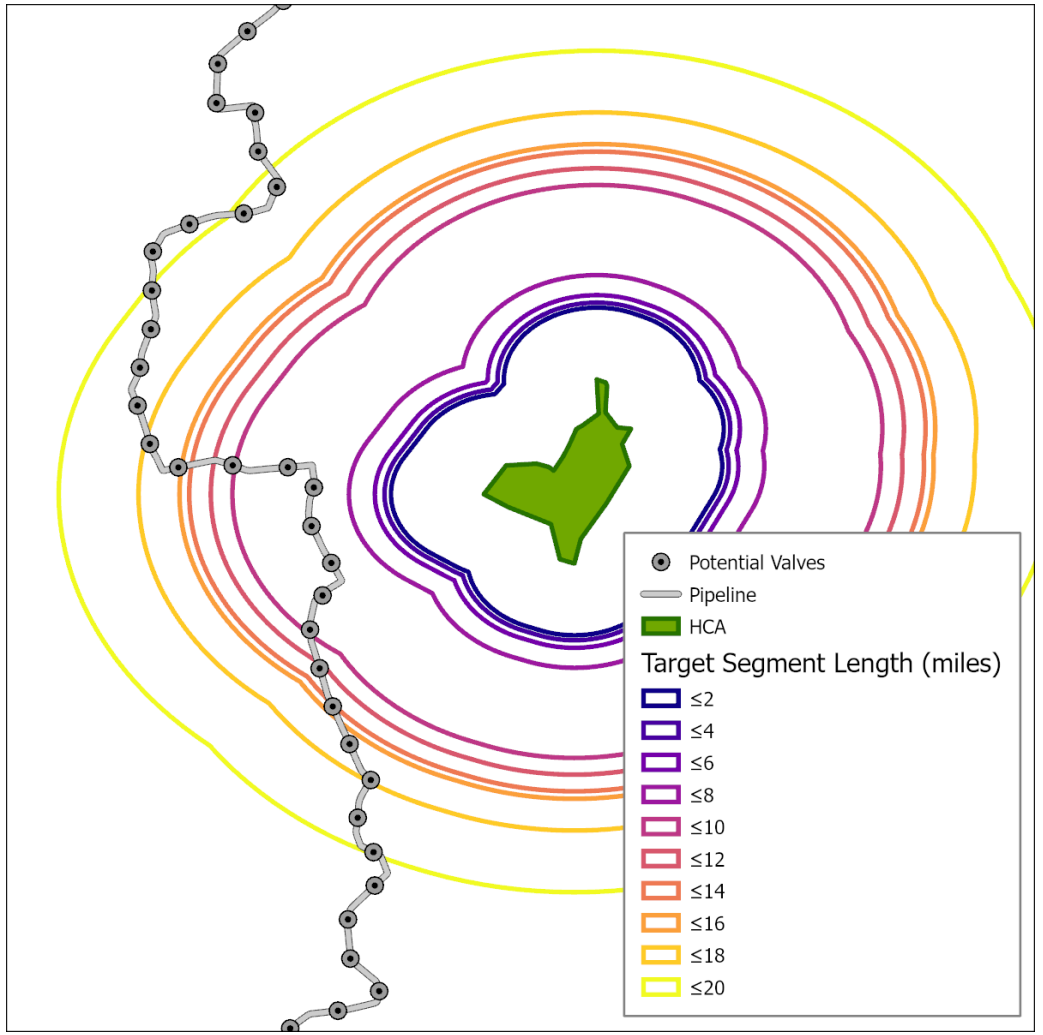
*** Not true for all hazards or all pipelines**

- Fire/Explosion impacts are worst immediately following the release.
  - Impacts are typically assessed based on that. Impacts could occur over a shorter time and decrease more rapidly though.
- Shorter pipelines may not benefit as release duration may be shorter than isolation time.

EFRD Analysis – HVL/Gas Releases

HCA Focused Approach

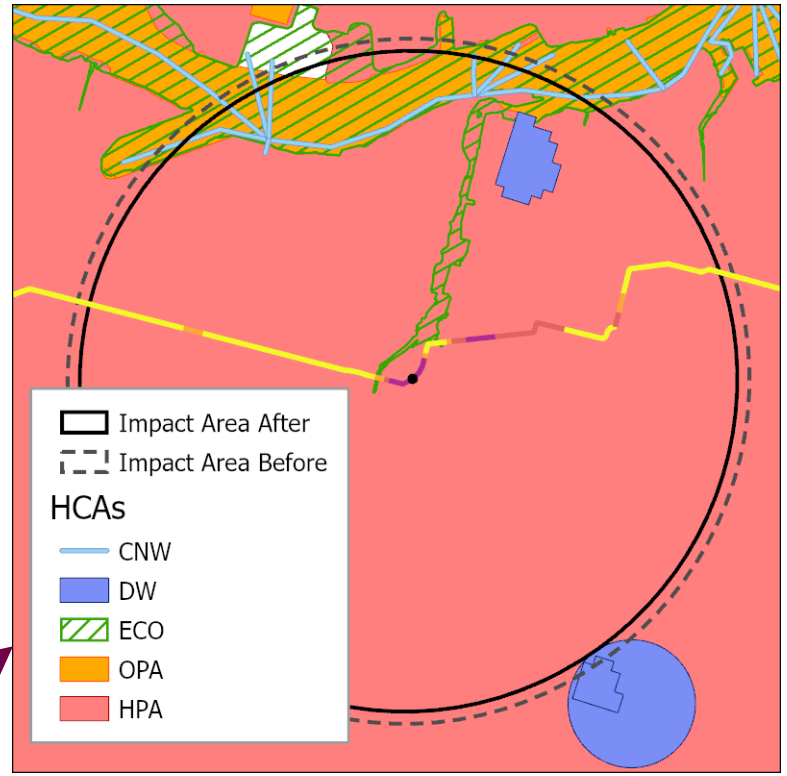
1. Define a set of potential valve locations (interval or targeted locations)
2. Buffer HCAs by each possible impact radius (based on various pipeline segment length scenarios)
3. Assess location of pipeline relative to HCA buffers
4. Manually select possible EFRD locations to create new segments that will reduce HCA impacts

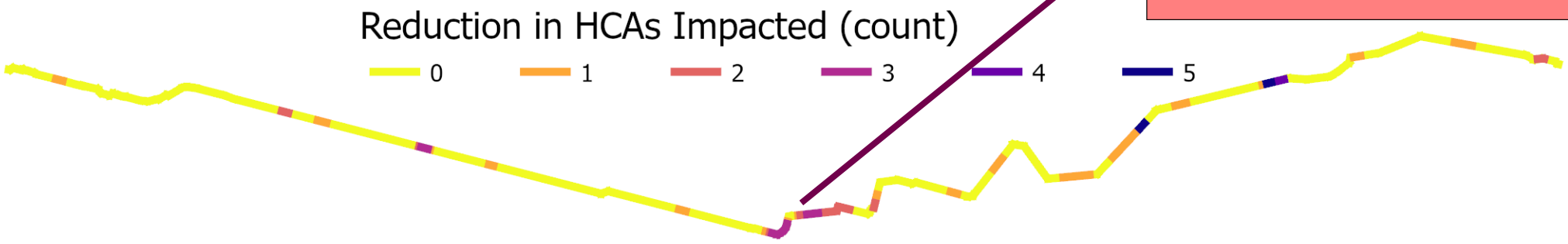


EFRD Analysis – HVL/Gas Releases

Pipeline Focused Approach

1. Identify a target impact radius (based on response timing, or minimum valve spacing)
2. Divide the pipeline into smaller segments
3. Identify potential changes in HCA impacts, by segment, if that impact radius is achieved
4. Target EFRDs where the most significant HCA reductions are possible





Conclusions

- Consequence modeling is used to understand the potential impacts of a release.
- Modeling can assess different valve scenarios to:
  - Quantify the benefits of adding EFRDs
  - Determine the best type of valve to reduce impacts
  - Identify the best location for valves
- Making informed valve decisions requires an understanding of the potential consequences and how valves can change them.

QUESTIONS

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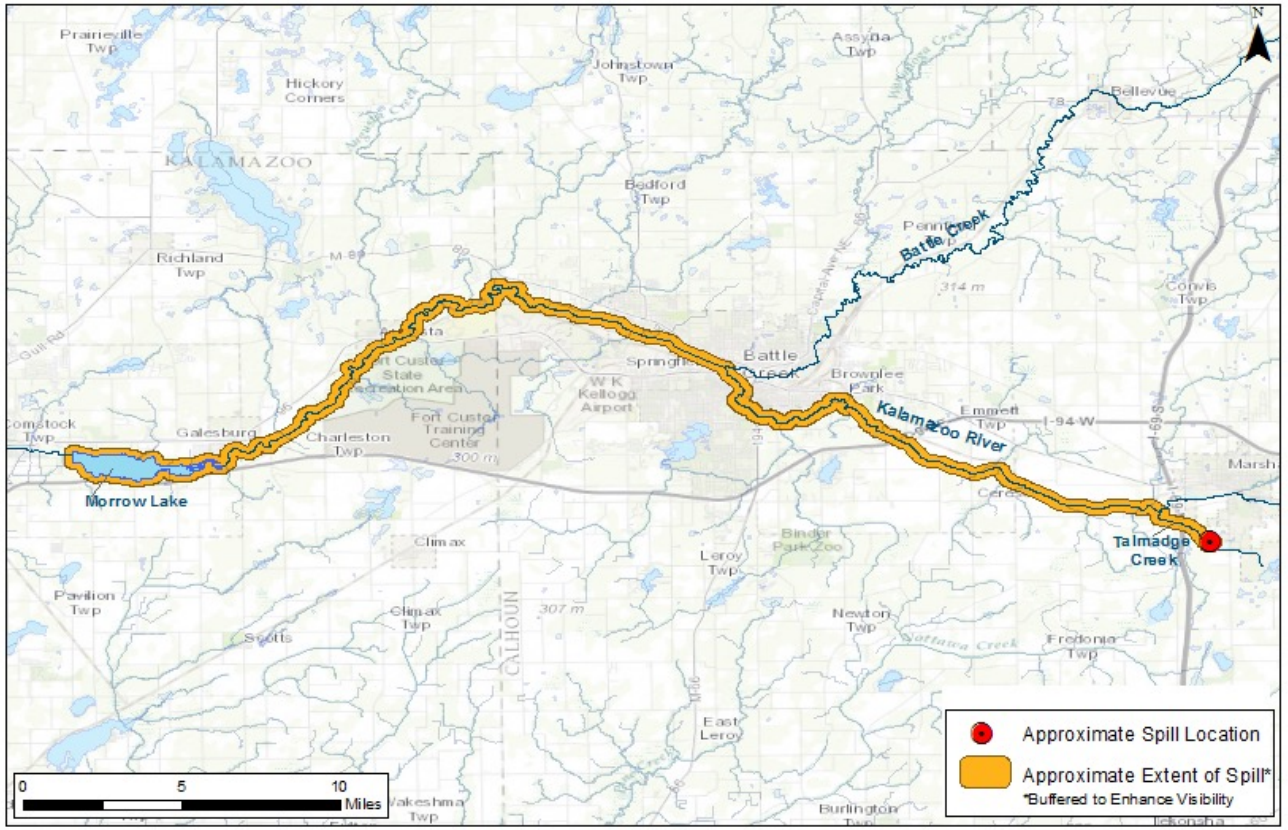
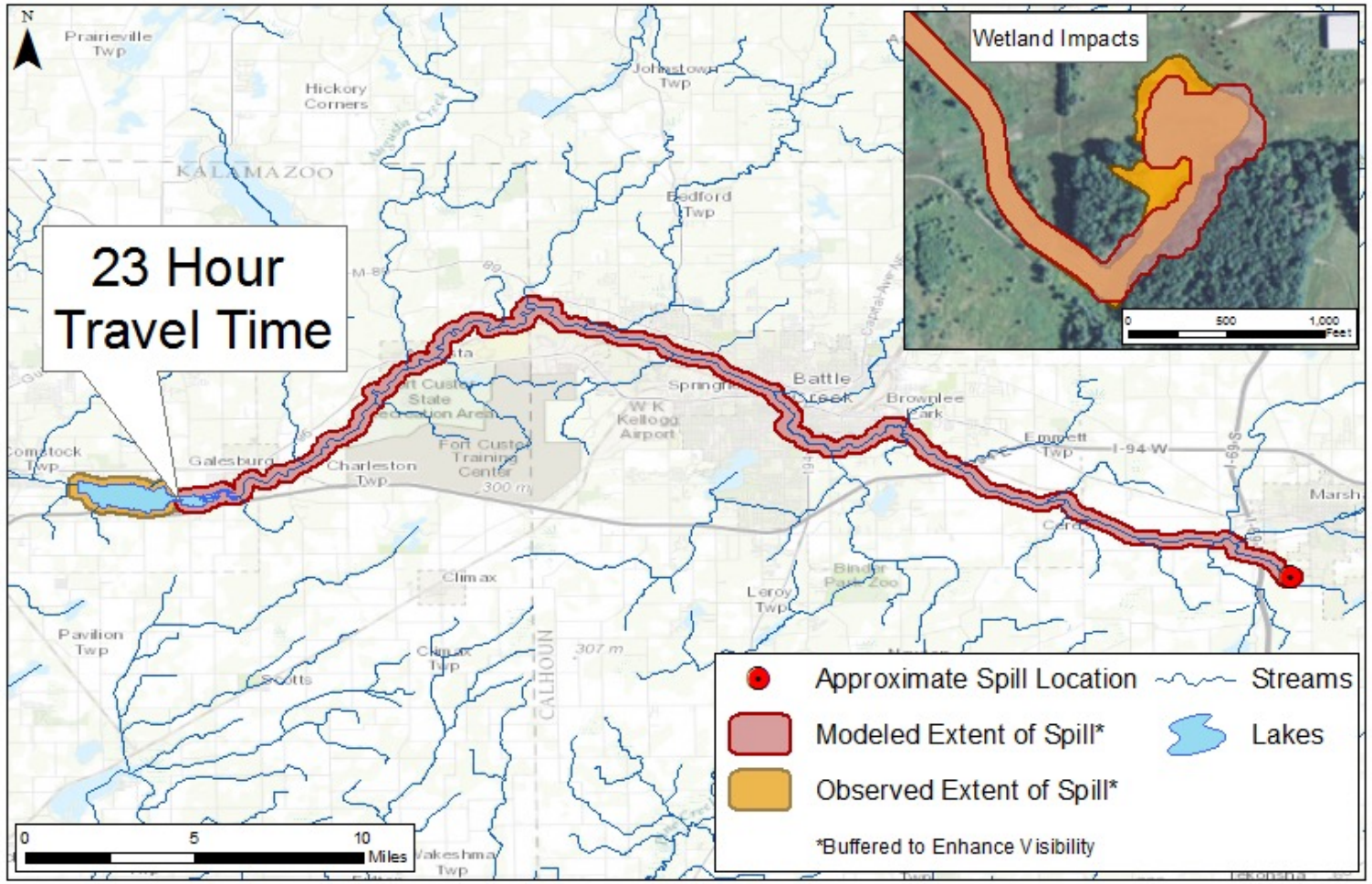
OILMAPLand Validation – Example #1

- 20,000 bbl crude oil spill into the Kalamazoo River
- During a high flow condition



OILMAPLand Validation – Example #1



OILMAPLand Validation – Example #2

- 5,000 – 7,000 bbl heavy crude oil spill in Arkansas
- Spill traveled through a neighborhood, eventually reaching a small creek and lake.

OILMAPLand Validation – Example #2