

An Evaluation of the Potential for Ground Water Contamination by Transport of Petroleum Products over the Rathdrum Prairie Aquifer

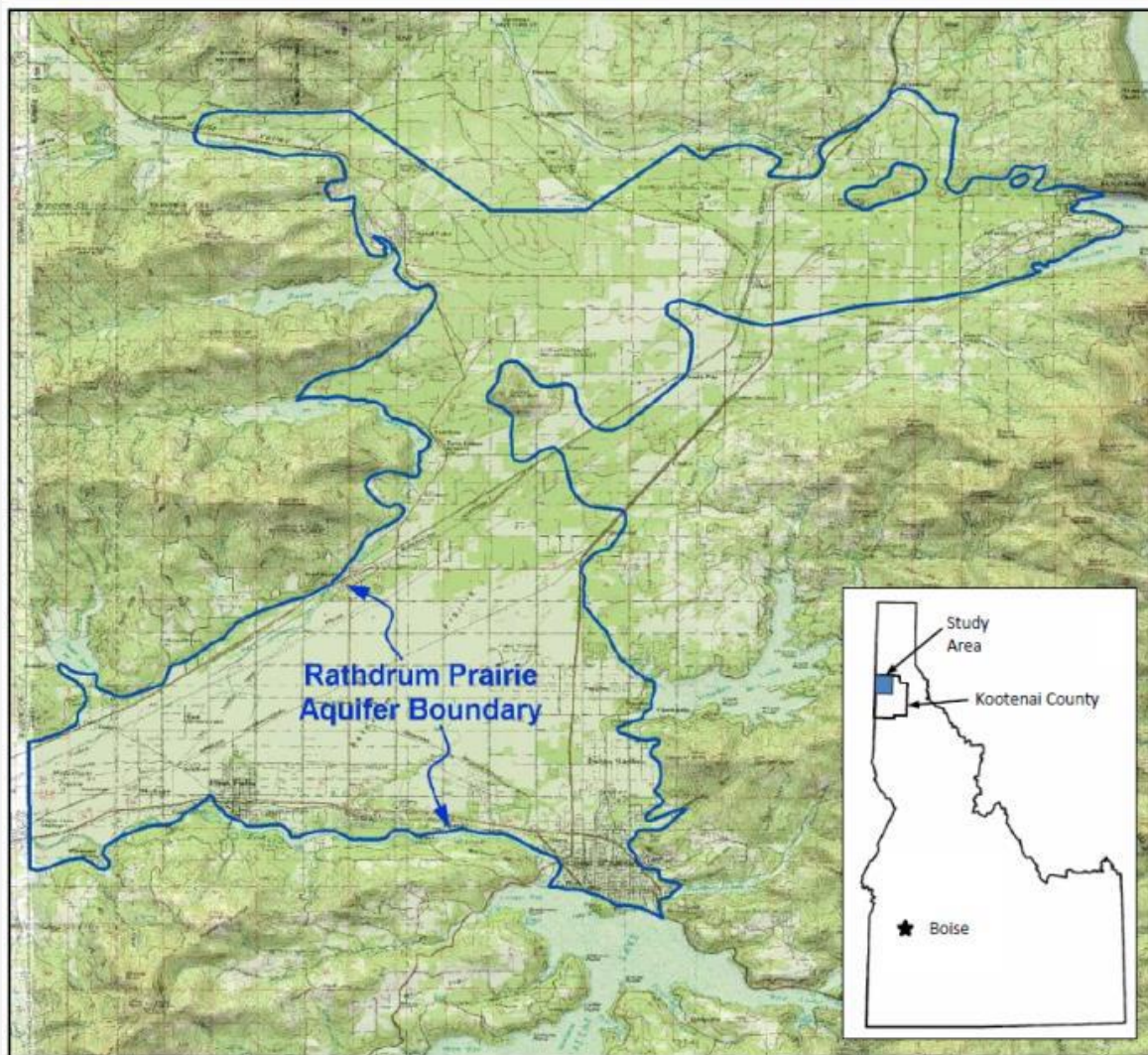


RPA Petroleum Transport

- Study Area
- Petroleum Types and Transport
- Volumes Transported Over the RPA
- Dakota/US Transport of Crude Oil
- Historical Releases
- Petroleum Properties
- Fate & Transport Models
- Model Results

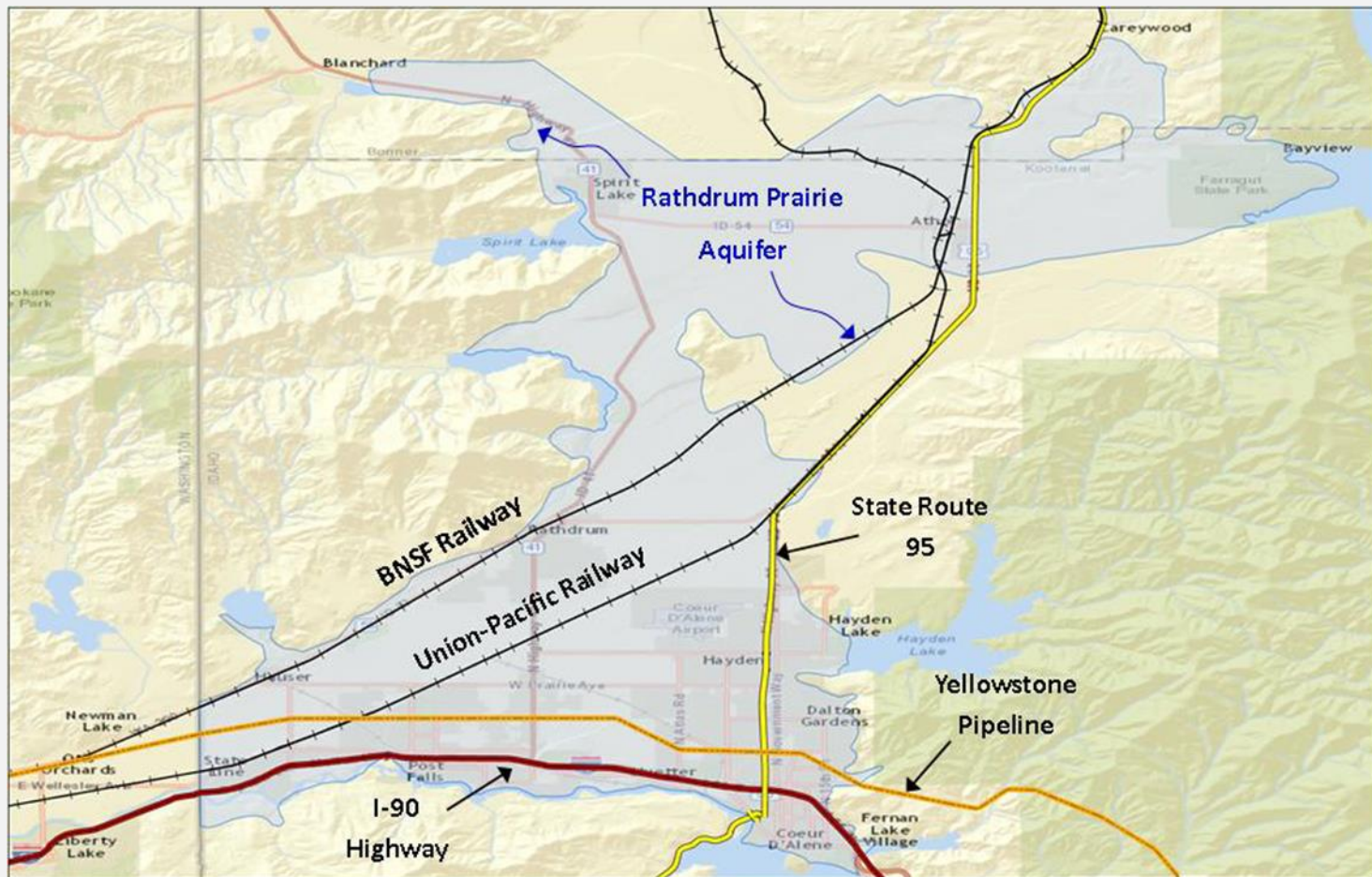


Study Area



Petroleum Types and Transport

- Truck Transport of Gasoline and Diesel
- Rail Transport of Bakken Crude Oil and Ethanol
- Pipeline Transport of Various Refined Petroleum Products

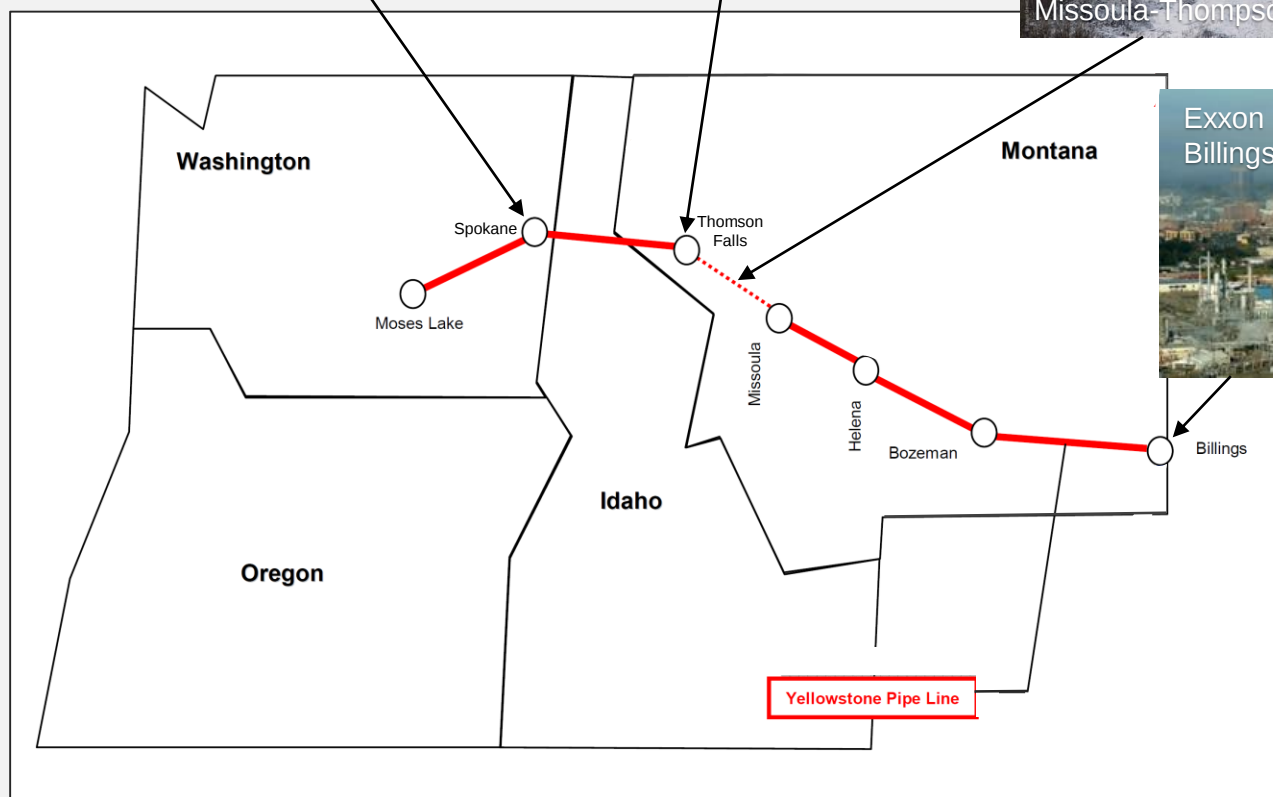


Petroleum Types and Transport – Truck Transport

- Transport refined petroleum from distributor to retail outlet
- Tanker trucks carry approximately 1,000 to 9,000 gallons
- Main routes for distribution I-90 and SR-95
- Volume Estimate
 1. Weigh Stations – ITD information not sufficient to determine volume
 2. Retail Petroleum Taxes (\$0.32/gal) – Idaho State Tax Commission
fuel is taxed at distributor not retail outlet. Could not isolate to Kootenai County
 3. Number of Registered Vehicles – ITD database with number of registered vehicles for each county

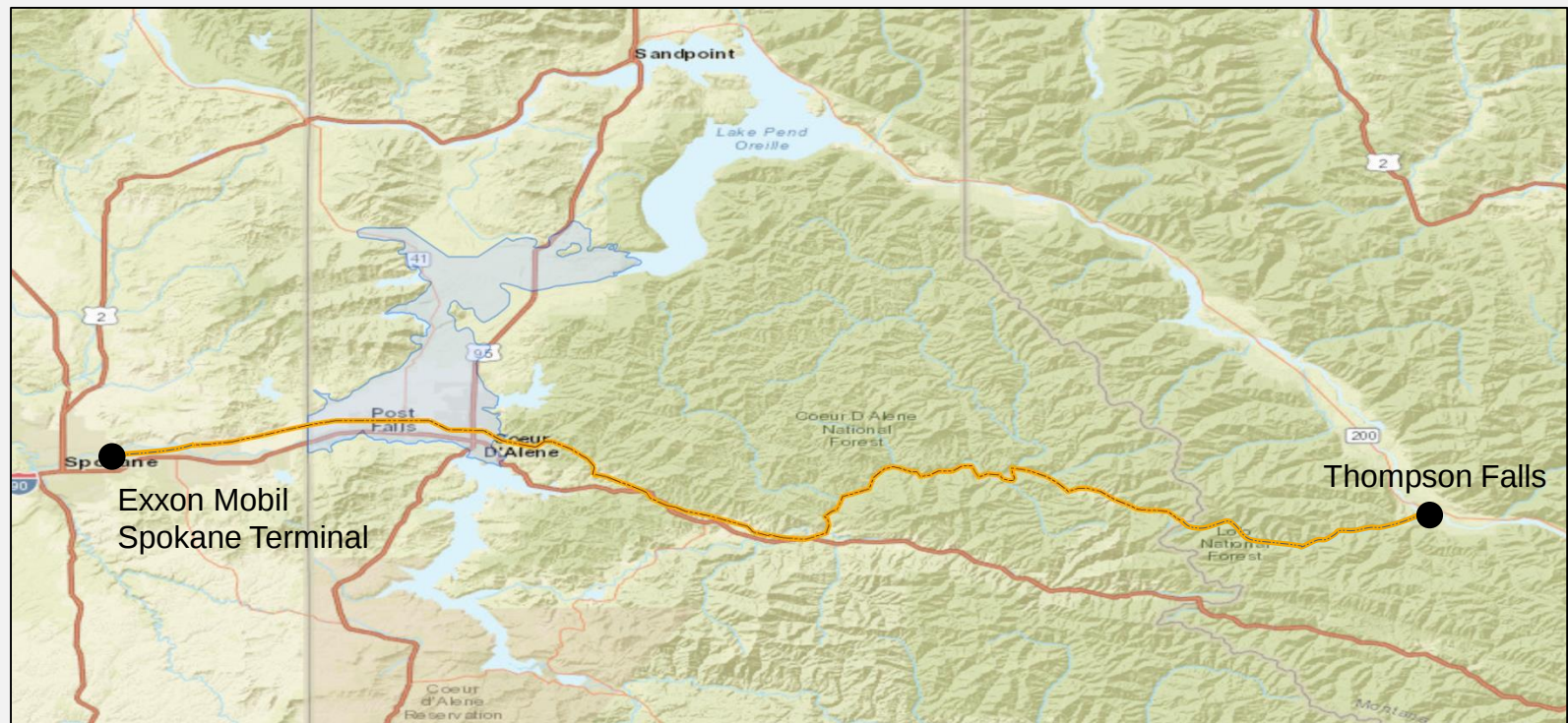
Gallons per year = Number of registered vehicles * EPA est. of miles driven per year / EPA est. of mpg
= 77,981,194 gallons per year
= 213,647 gallons per day

Petroleum Types and Transport – Yellowstone Pipeline

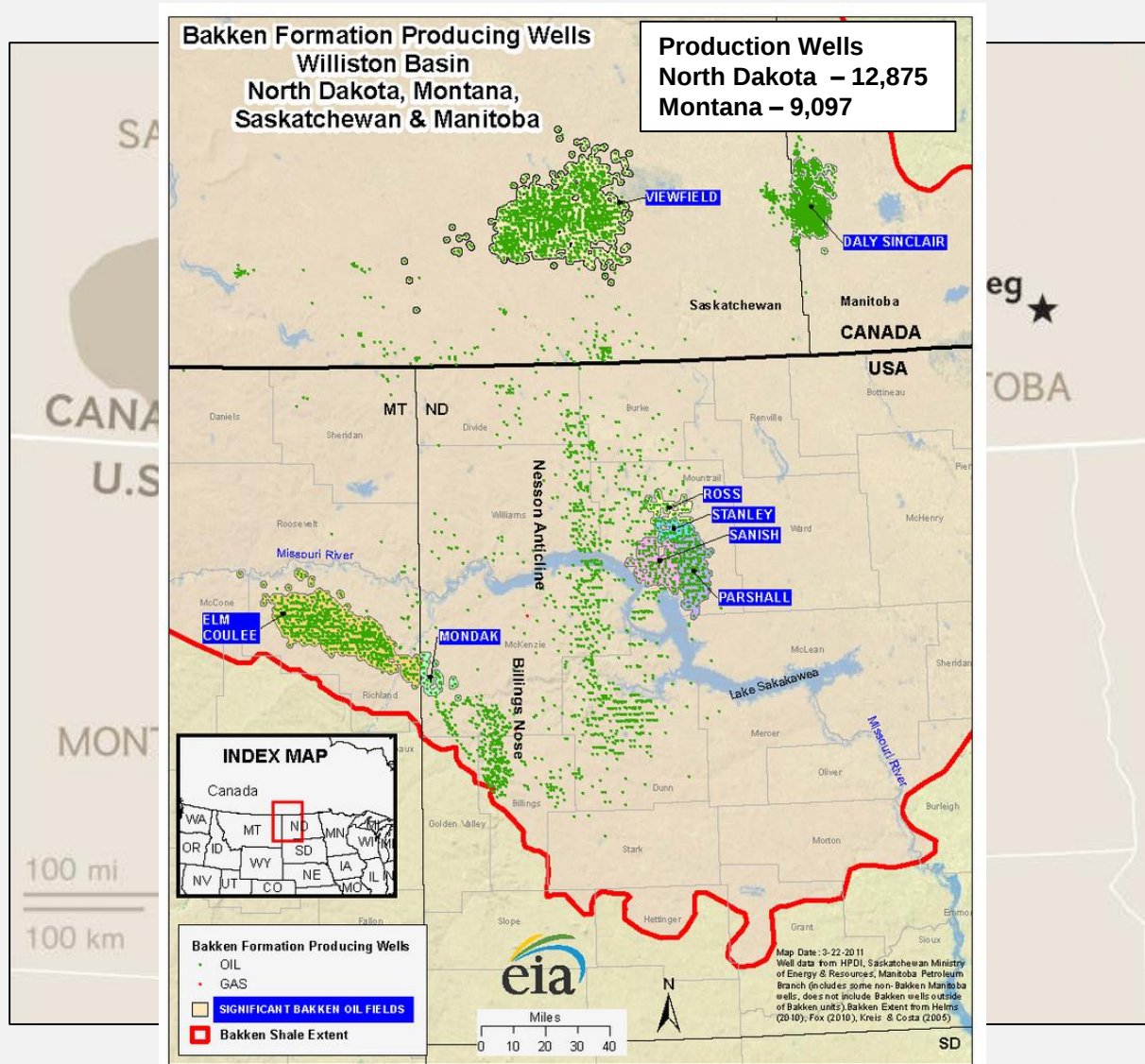


Petroleum Types and Transport – Yellowstone Pipeline

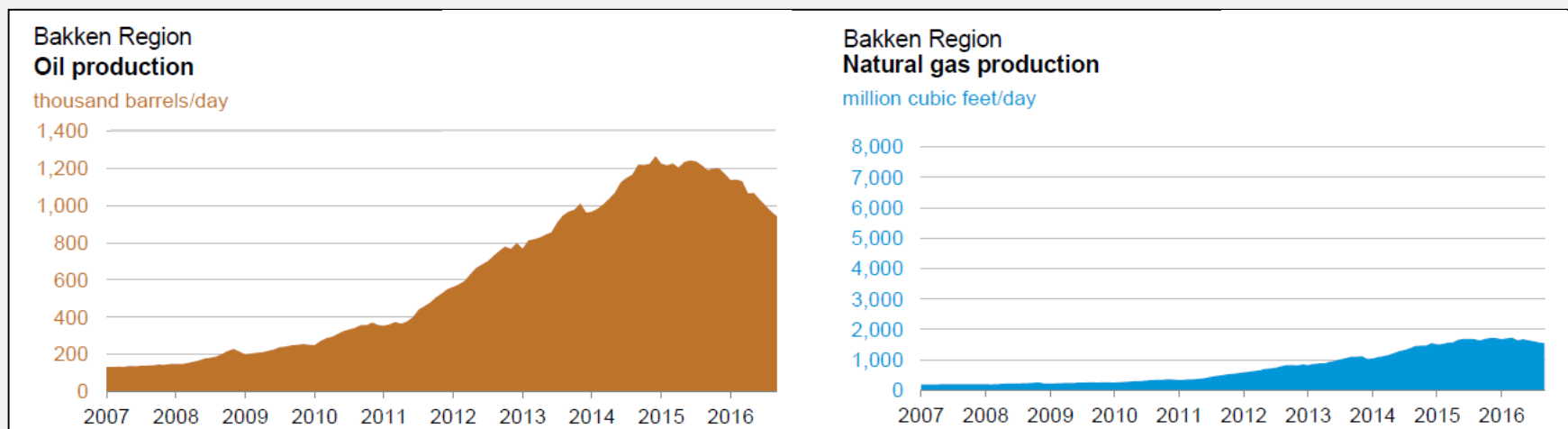
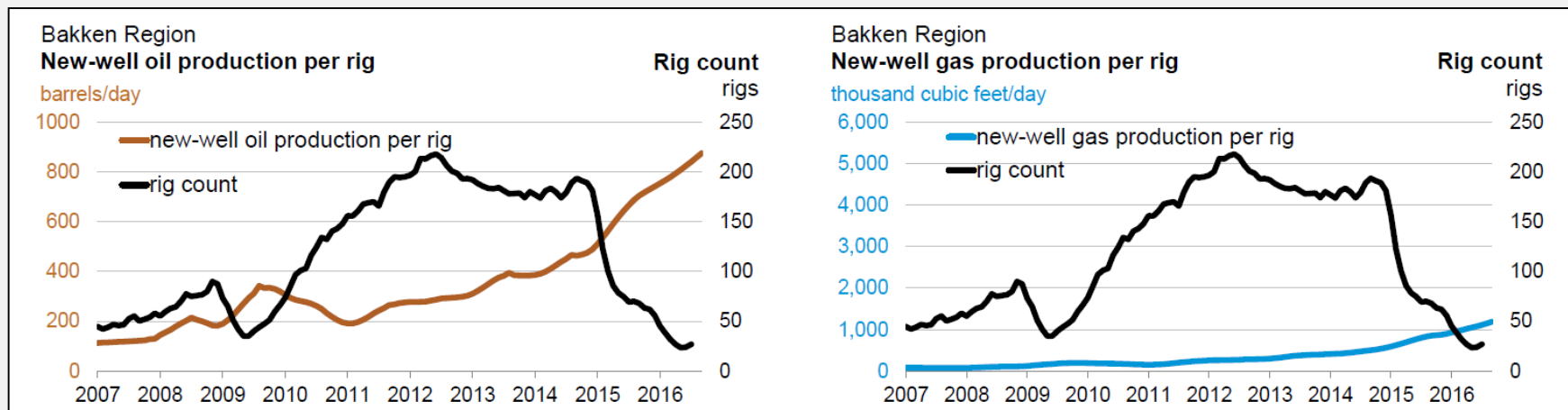
- Constructed in 1954
- Buried 10 – Inch Diameter Steel Pipe
- Operates at $\approx$ 900 psi
- Crosses over the 14 miles of the RPA
- Transports gasoline, diesel & jet fuel
- Capacity = 66 thousand barrels per day (2,772,000 gallons per day)



Petroleum Types and Transport – Rail Transport Bakken Crude

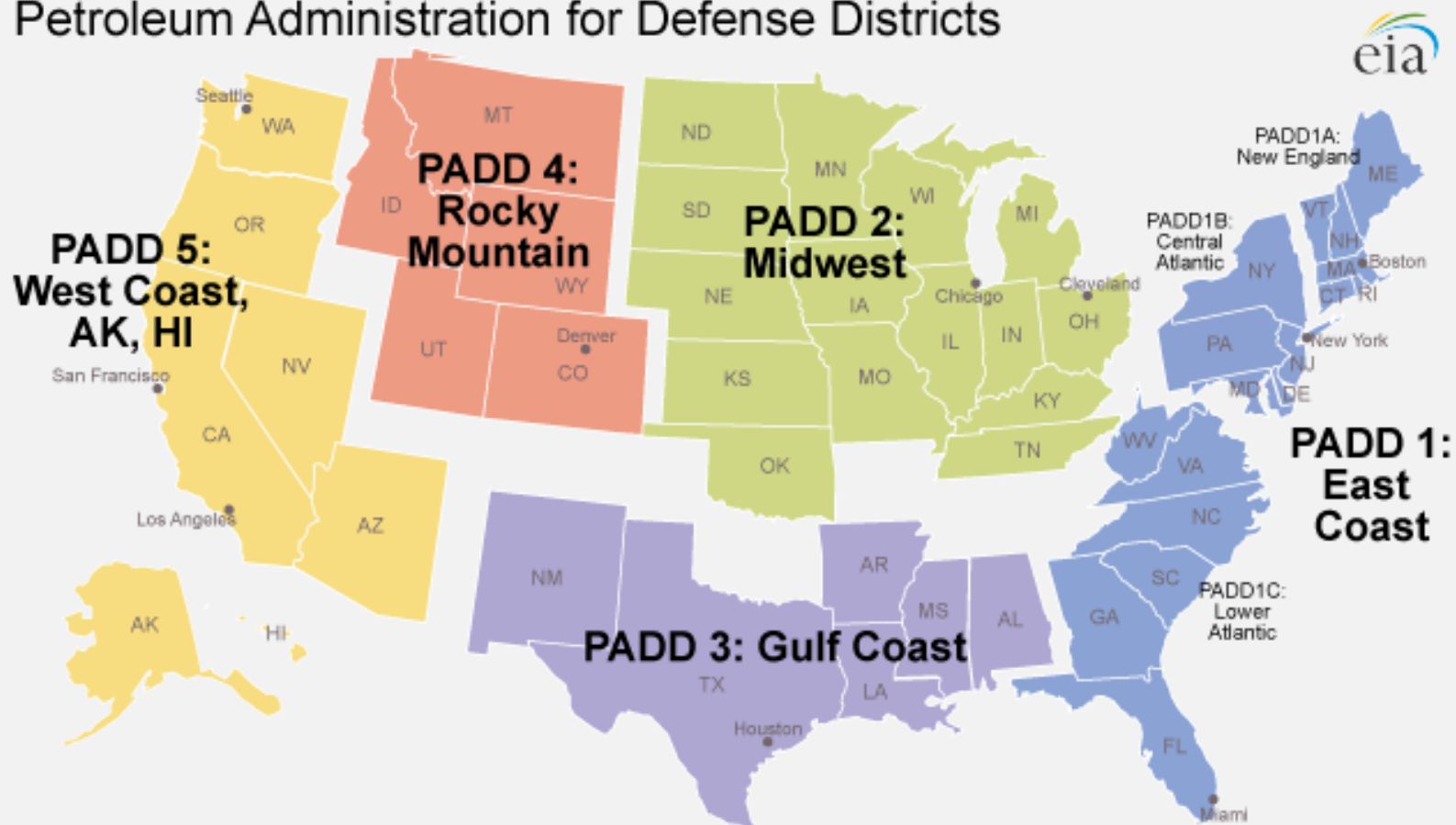


Petroleum Types and Transport – Rail Transport Bakken Crude



Petroleum Types and Transport – Rail Transport Bakken Crude

Petroleum Administration for Defense Districts



These were created during World War II to help organize the allocation of fuels derived from petroleum products, including gasoline and diesel. Today, these regions are still used for data collection and analysis.

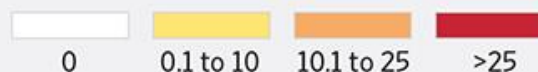
Petroleum Types and Transport – Rail Transport Bakken Crude

Cru

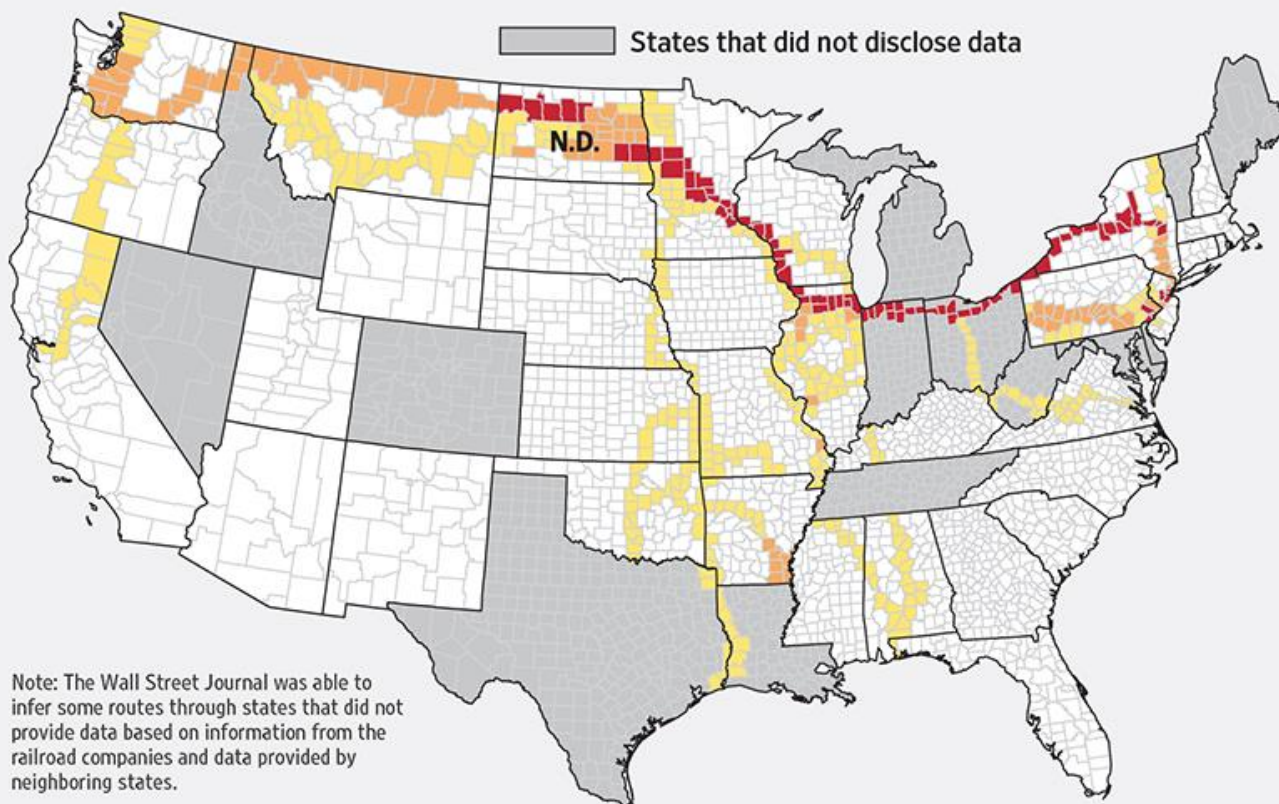
Crude By Rail Routes 2014

Railroads have become virtual pipelines carrying crude from North Dakota to the East, West and Gulf Coasts.

Weekly average number of crude-oil trains from the Bakken Shale in North Dakota that pass through each county



States that did not disclose data

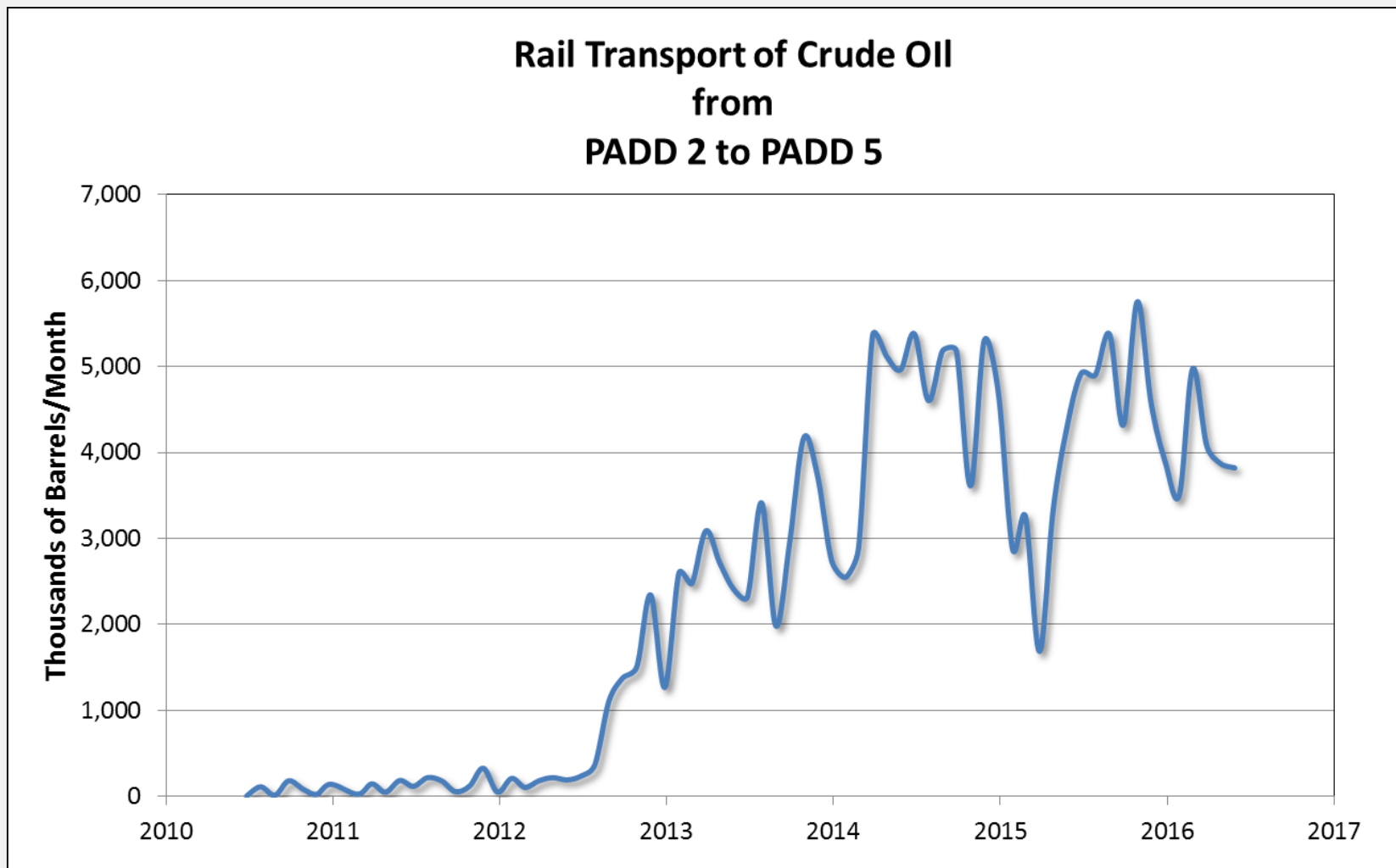


Note: The Wall Street Journal was able to infer some routes through states that did not provide data based on information from the railroad companies and data provided by neighboring states.

Source: State Emergency Response Commissions

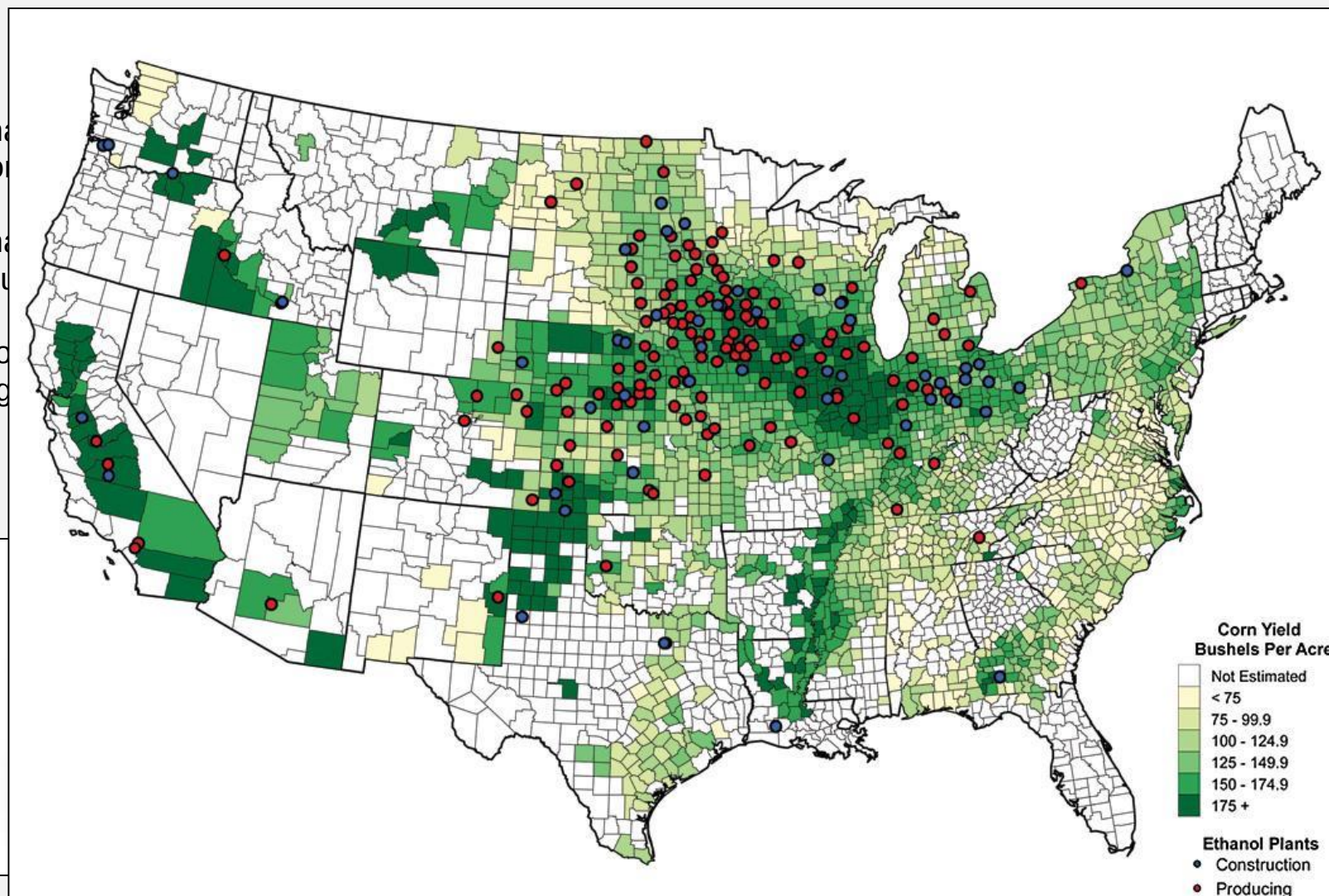
The Wall Street Journal

Petroleum Types and Transport – Rail Transport Bakken Crude



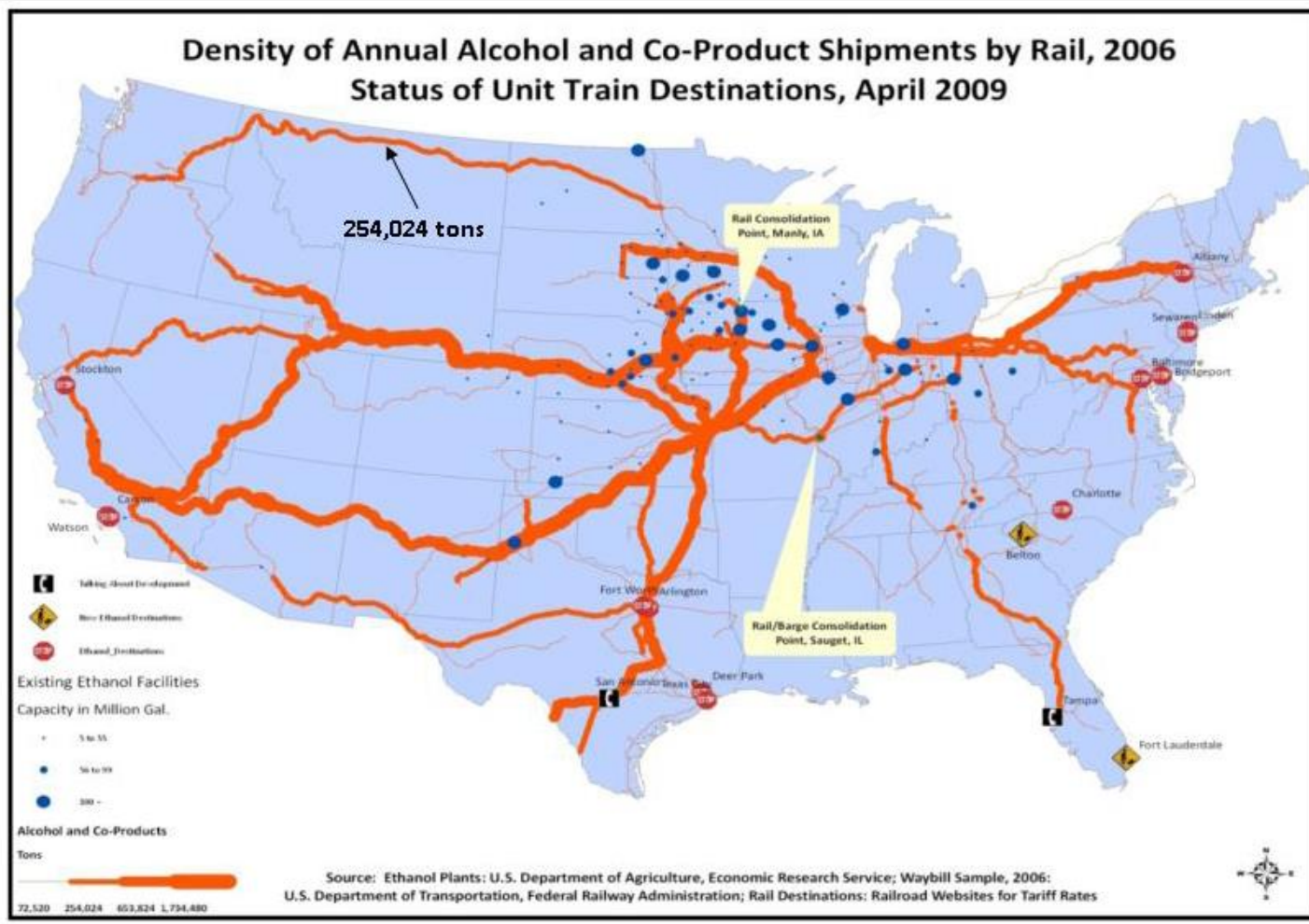
Petroleum Types and Transport – Rail Transport Ethanol

- Ethanol
- Ethanol
- Absolute

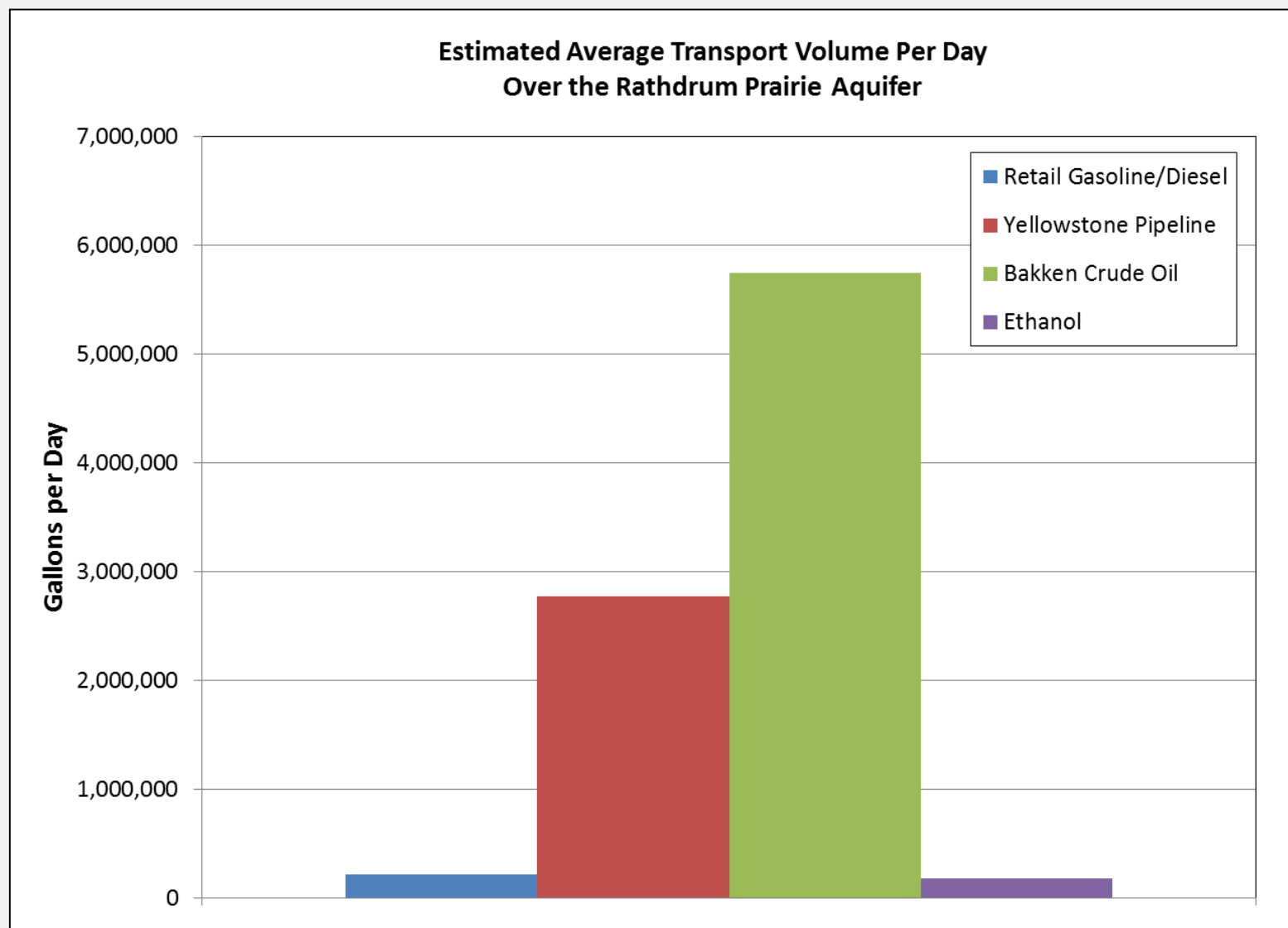


Petroleum Types and Transport – Rail Transport Ethanol

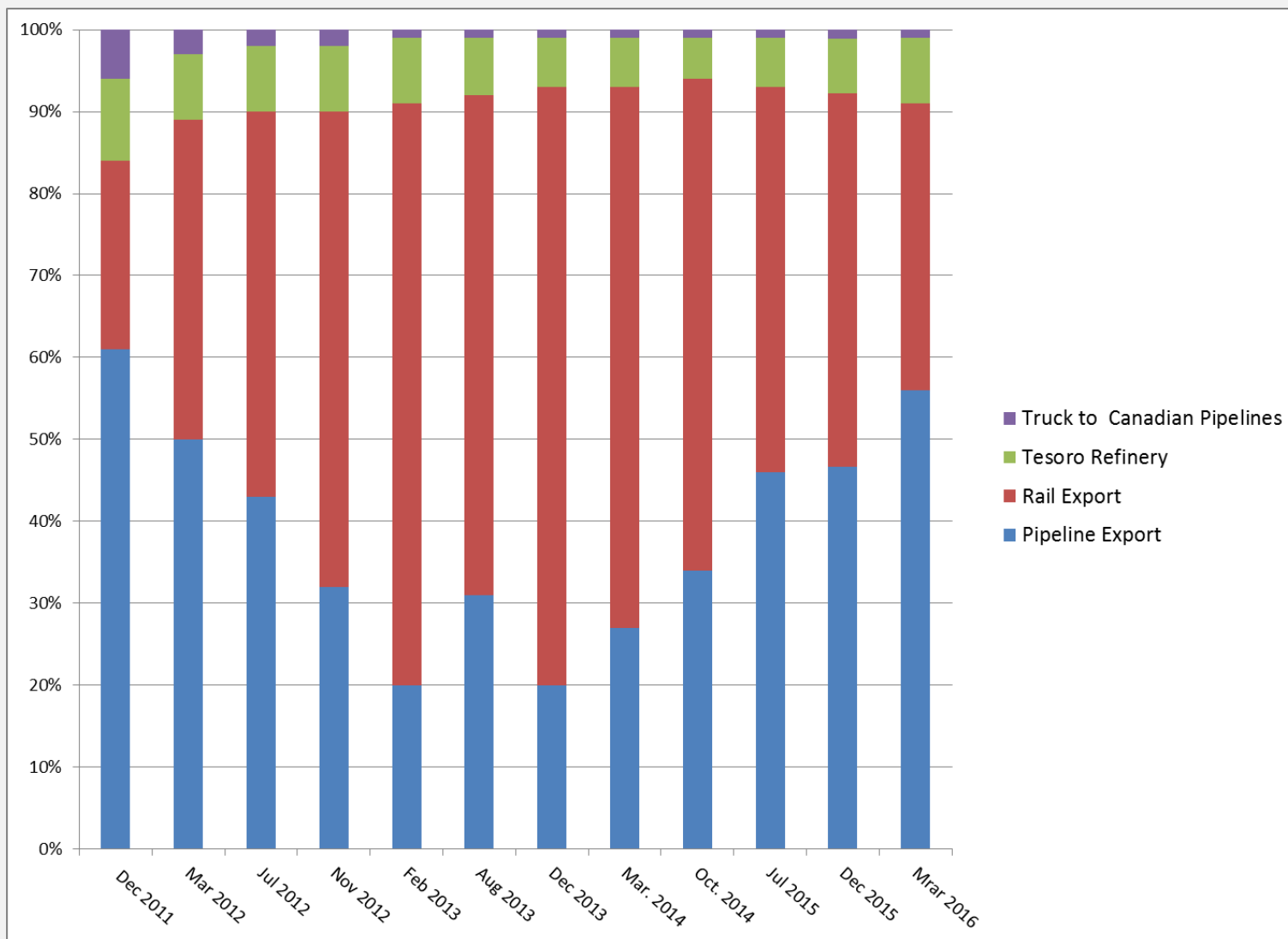
Ethanol Transport Volume over the RPA = 179,623 gallons per day



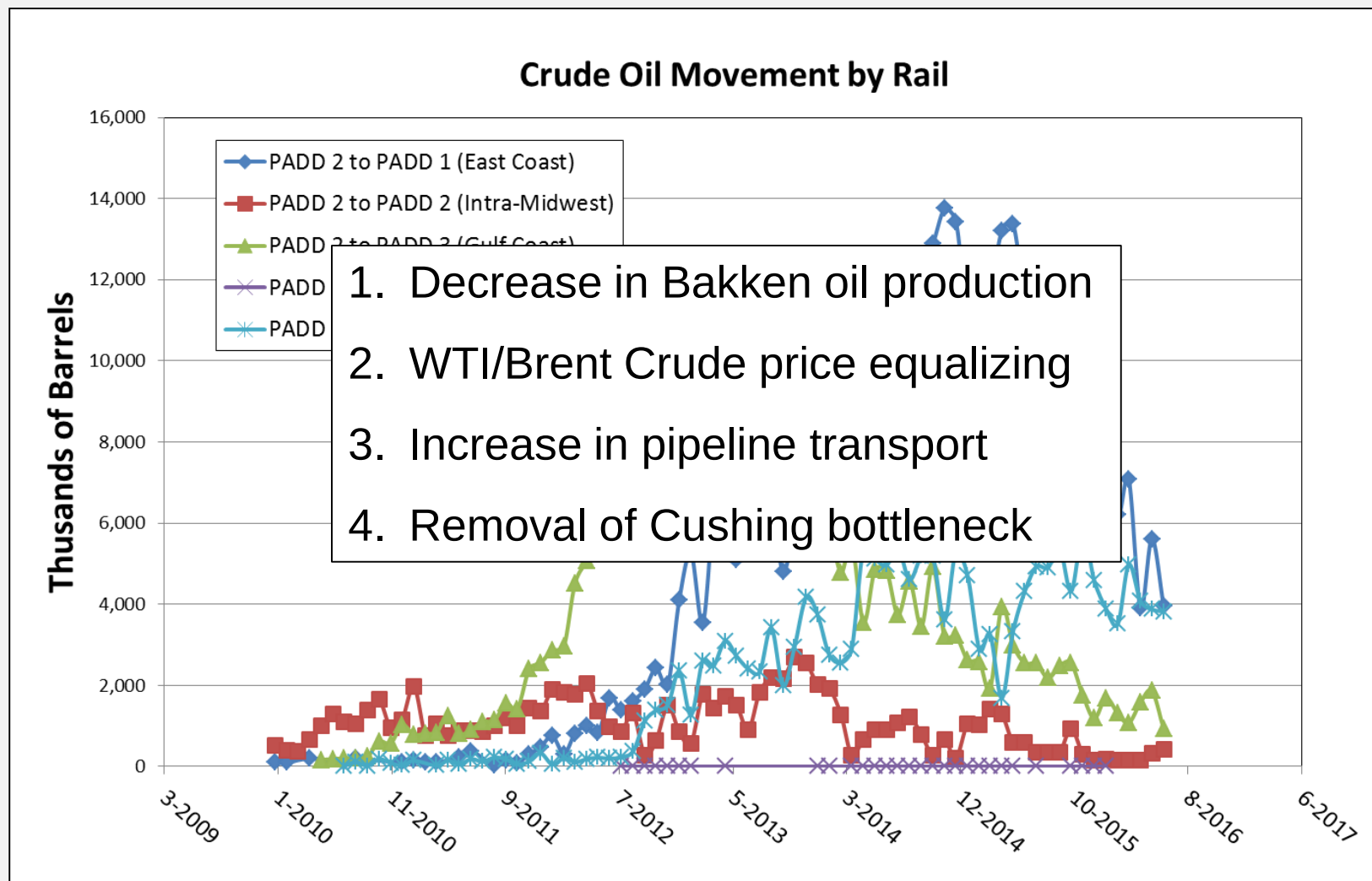
Volumes Transported Over the RPA



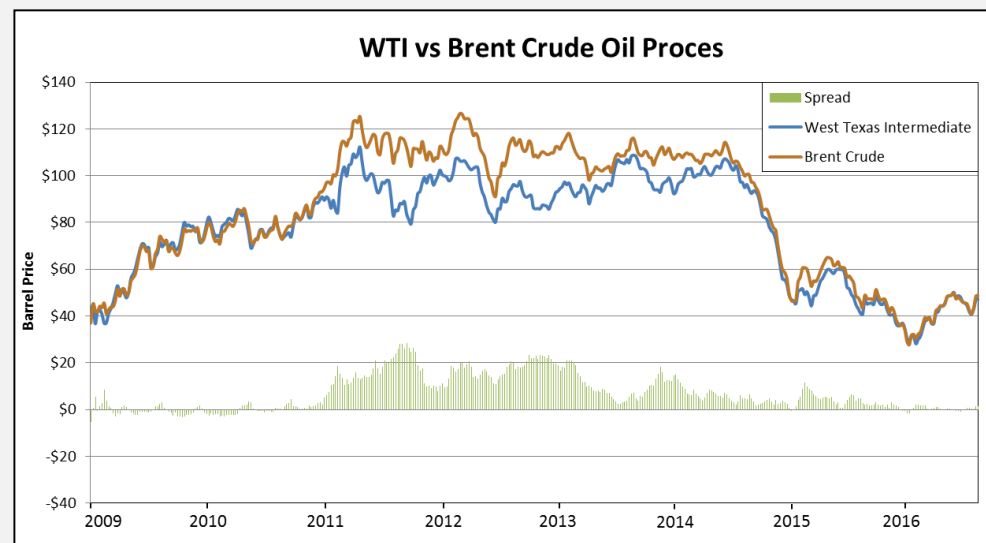
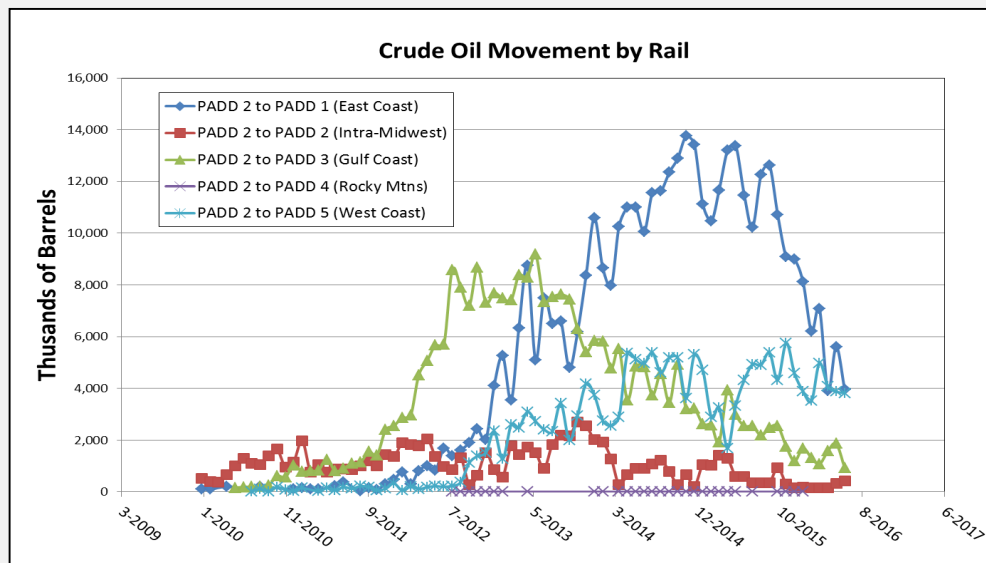
Dakota/US Transport – North Dakota Crude Oil Transport



Dakota/US Transport – East Coast



Dakota/US Transport – East Coast



Dakota/US Transport – Dakota Access Pipeline

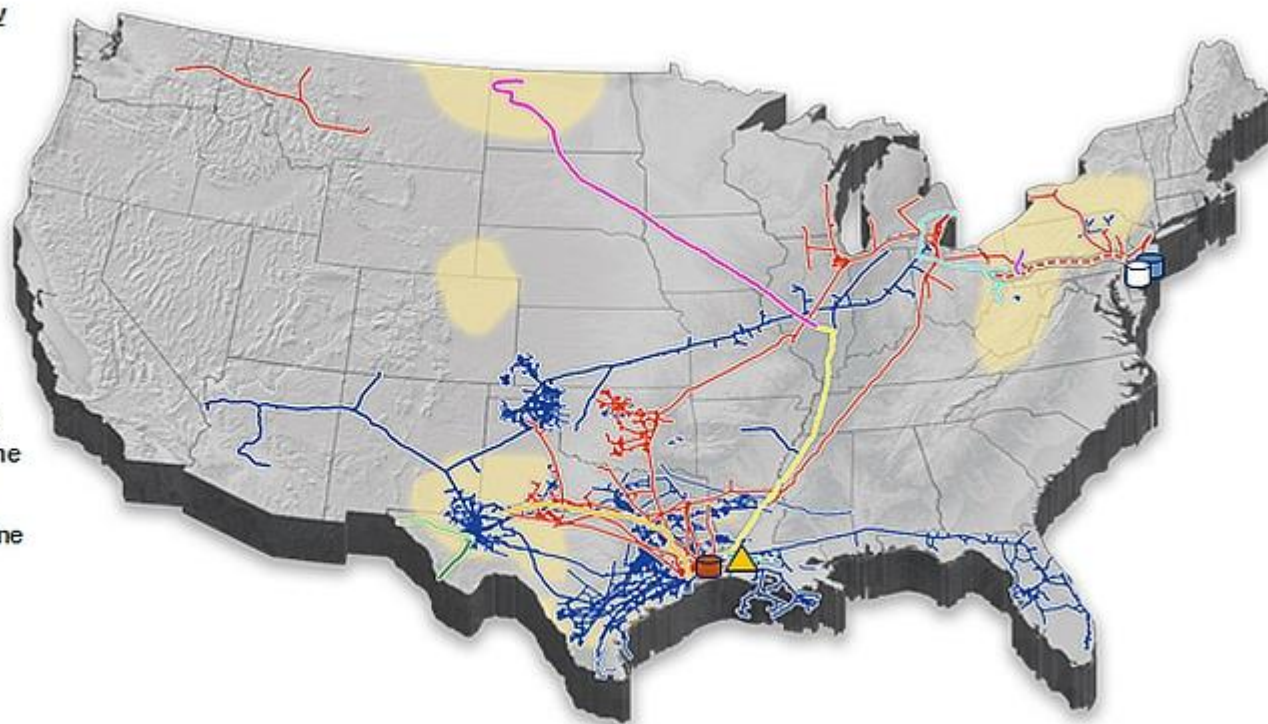


Energy Transfer Asset Overview

- ETP Assets
- SXL Assets

Development Projects

- Marcus Hook
- Eagle Point
- Nederland
- Lake Charles LNG
- Bayou Bridge Pipeline
- Comanche Trail Pipeline
- Crude Conversion Pipeline
- Dakota Access Pipeline
- Lone Star Express Pipeline
- Mariner East Phase 2
- Revolution Project
- Rover Pipeline
- Trans-Pecos Pipeline



- Will significantly reduce truck and rail transport
- Completion by end of 2016

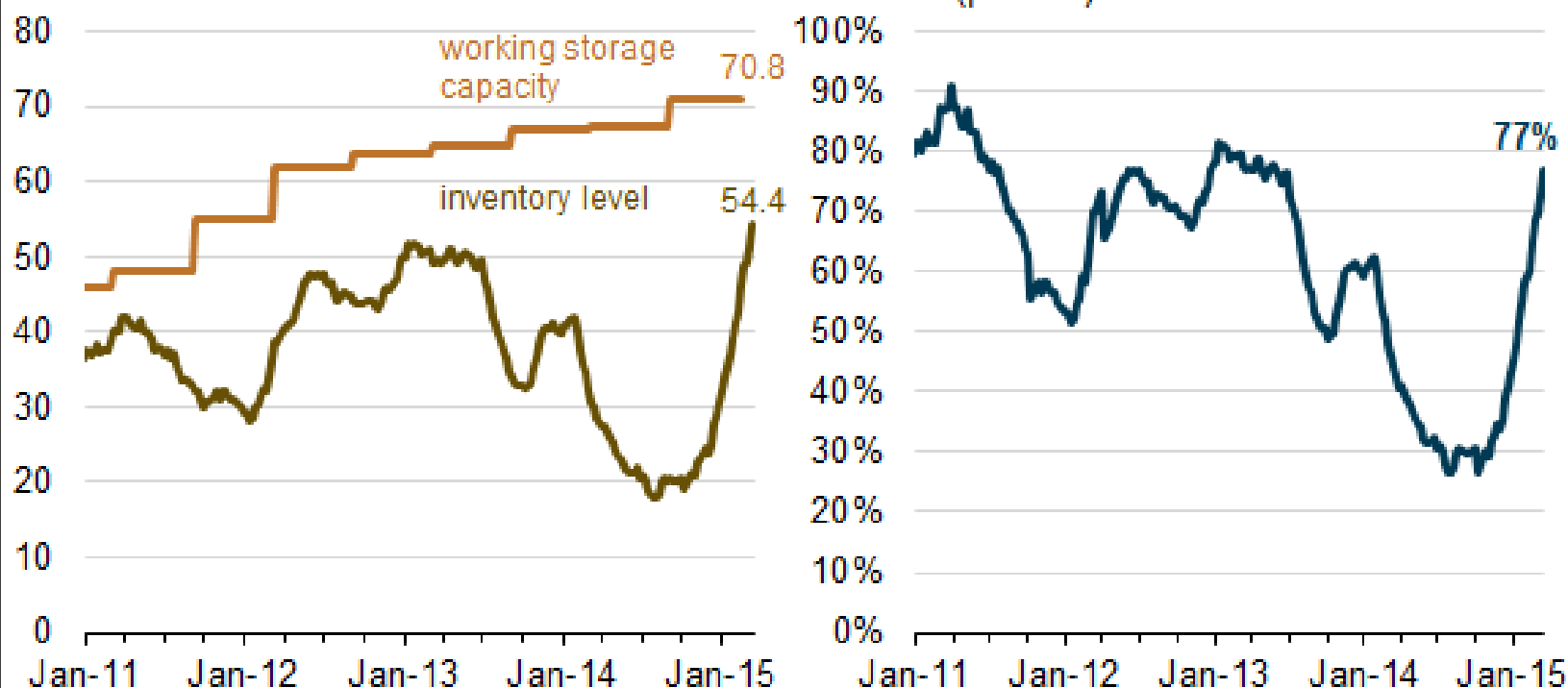


Dakota/US Transport – Cushing Oil Terminal

Cushing OK

Map of Major North American Crude Pipelines

Weekly crude oil inventory and storage capacities at Cushing, Oklahoma



Sources: Publicly available information



Department of
Environmental Quality



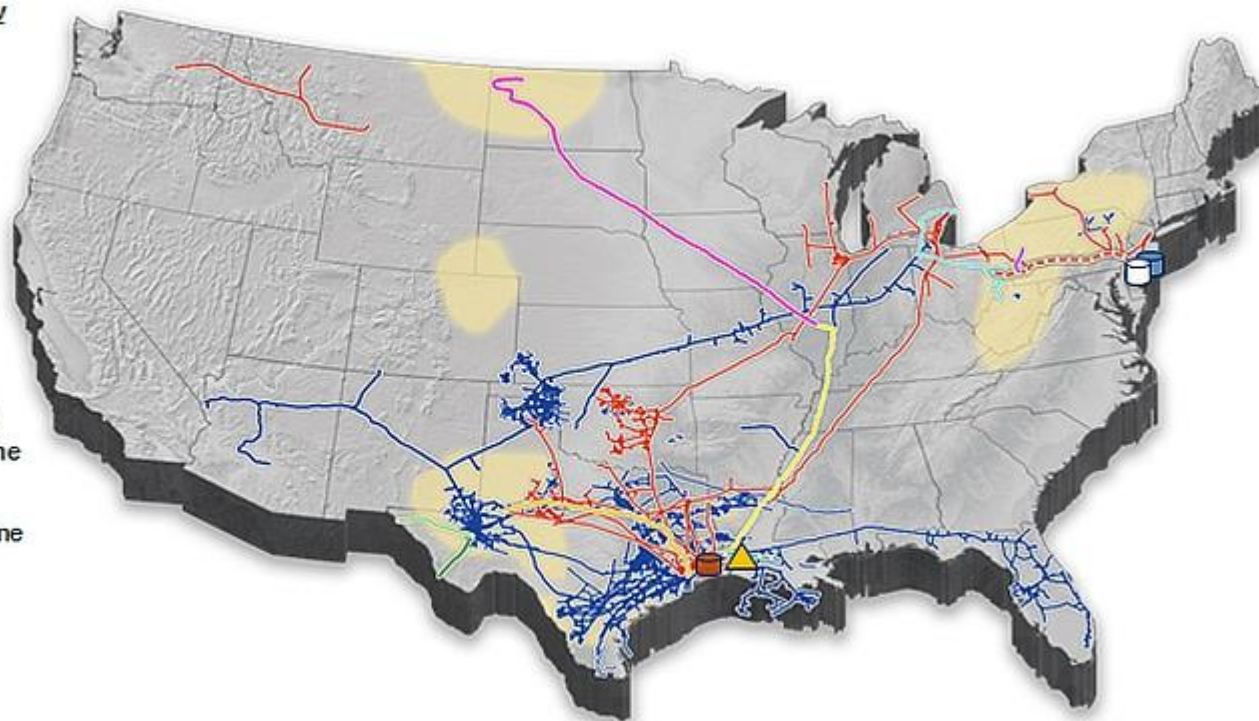
Dakota/US Transport – West Coast

Energy Transfer Asset Overview

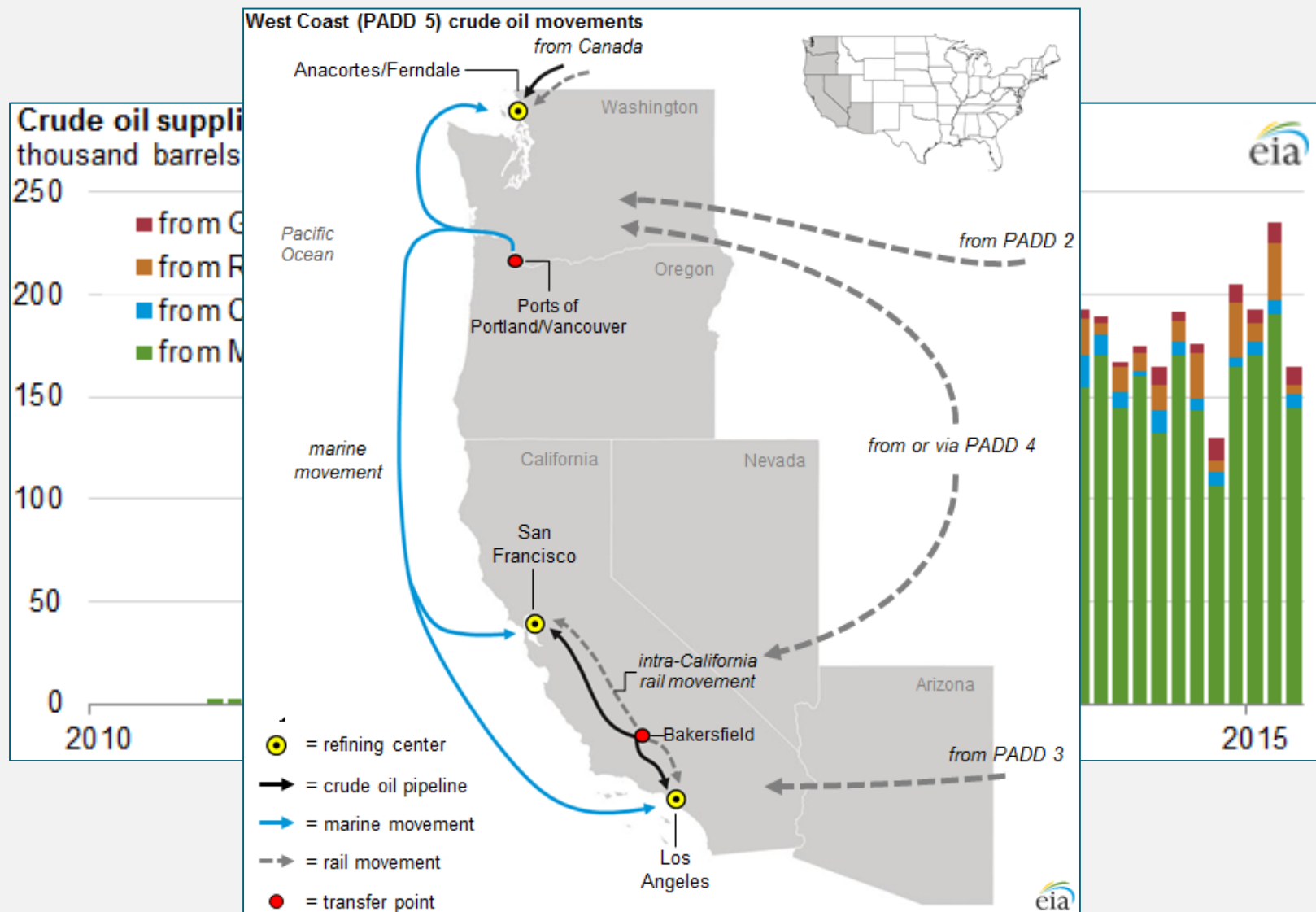
- ETP Assets
- SXL Assets

Development Projects

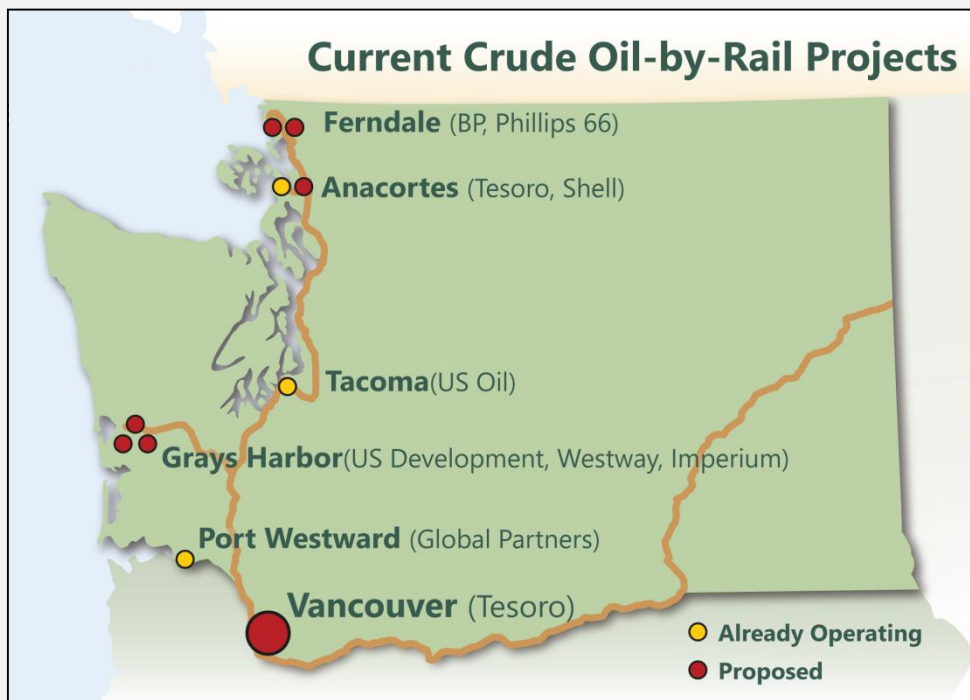
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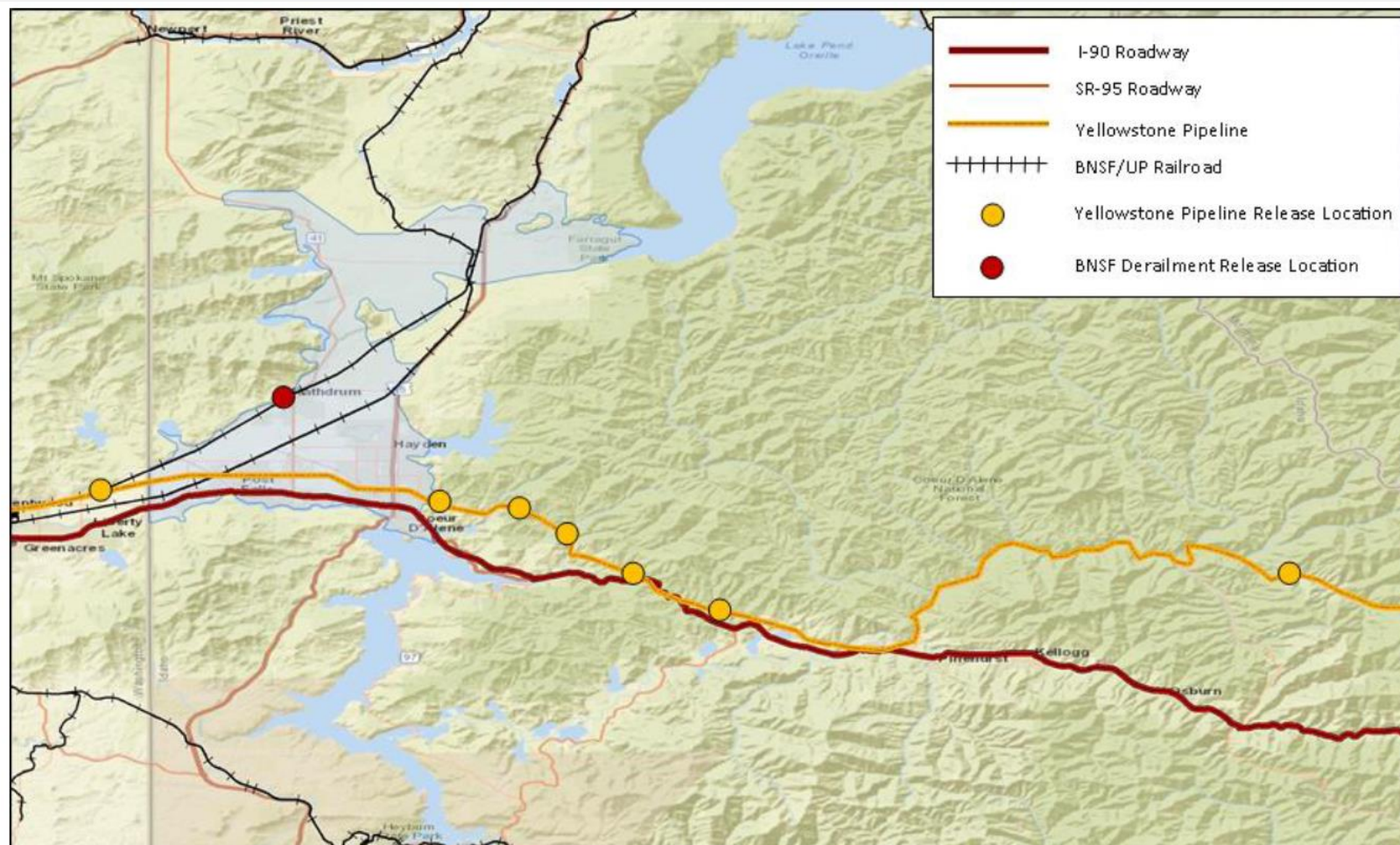
Dakota/US Transport – West Coast



Dakota/US Transport – West Coast



Historical Releases



Historical Releases – BNSF Hauser

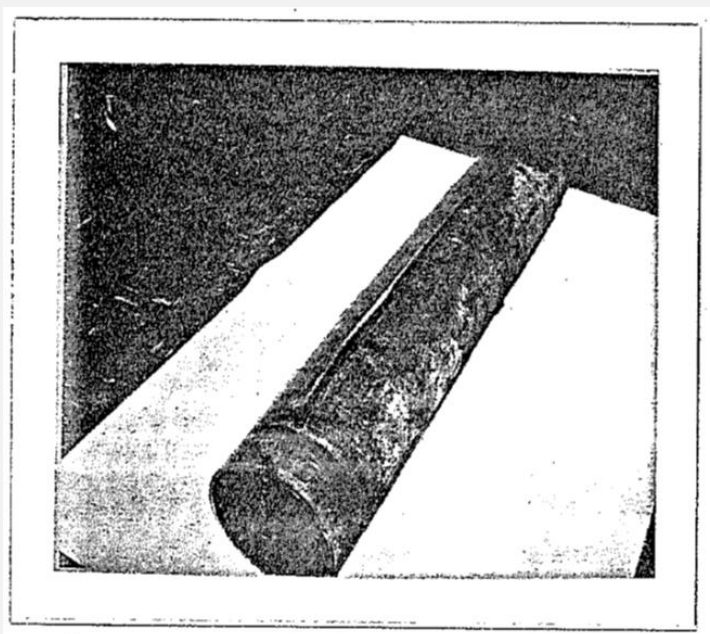


- Derailment Feb. 2001 approx. 2 miles Northeast of Hauser
- Cause- Damaged tread on car
- 28 railcars on two trains derailed, including seven railcars containing Fuel Oil #5.
- Approximately 3,000 gal of Fuel Oil #5 released
- 900 cubic yards of soil removed

Historical Releases – Yellowstone Pipeline

Yellowstone Pipeline Releases in ID and WA over the SVRP

Release Date	Location	Release Volume (gallons)	Substance Released	Cause
September 15, 1954	20 miles east of Coeur d'Alene	69,678	Gasoline	Dozer blade punctured pipeline
April 10, 1955	East of Coeur d'Alene	193,872	Diesel	Tractor crossing over pipeline
October 16, 1965	5 miles east of Coeur d'Alene	43,848	Diesel	Gunshot perforated pipeline
May 2, 1973	Near Murray , Idaho	169,302	Diesel	Pipe split - approximately 50 in. long
May 4, 1983	8 miles east of Coeur d'Alene	24,948	Gasoline	Pipe impacted while removal of gravel for bridge construction
July 23, 1987	Near I-90 Fourth of July Pass	27,048	Various	Grader widening forest service road cut into pipeline
October 23, 1996	Spokane Valley	Unknown	Unknown	Pinhole perforation found in pipeline during inspection



Historical Releases – United States

Train Derailments with remedial impacts and volumes

Location	Release Date	Material	Estimated Oil Release To Surrounding Area (gallons)	Estimated Oil Burned Volume (gallons)	Estimated Excavated Soil (yds ³)	Groundwater Contamination	Surface Water Contamination	Fire
Lac Megantic, QB	7/5/2013	Bakken Crude	1,505,780	4,494,220	366,226	No	Yes	Yes
Casselton, ND	12/30/2013	Bakken Crude	400,000	NA ¹	7,479	Yes	No	Yes
Galena, IL	3/5/2015	Bakken Crude	110,543	94,929	1,304	Yes	Yes	Yes
Heimdal, ND	5/6/2015	Bakken Crude	94,000	34,000	1,929 ²	No	No	Yes
Culbertson, MT	7/16/2015	Bakken Crude	27,210	0	3,925	Yes	No	No
Rathdrum, ID	2/27/2001	Fuel Oil #5	3,000	0	900	No	No	No

¹ Volume not calculated but a significant volume of crude oil was reported have been consumed in the fire.

² 2,439.39 tons with density of 1.5 g/cc



Petroleum Properties

Density – Crude oil measured in API units (gravity degree), Gasoline in grams per cubic centimeter.

Light crude oil $> 31^{\circ}$ (< 0.87 g/cc)

Heavy crude oil $< 31^{\circ}$ (> 0.87 g/cc)

Bakken Crude = 40° to 43° (0.81 to 0.83 g/cc)

Gasoline = 0.73 to 0.75 g/cc

Sulfur Content $< 0.5\%$ by weight = Sweet

$> 0.5\%$ by weight = Sour

Bakken Crude = 0.1% by weight

Gasoline = regulated by EPA at 30 ppm (0.0% by weight)

Dynamic Viscosity – Liquids resistance to shear stress or flow (centipoise)

Water = 1.0 cp

Motor Oil (SAE 40) = 250 cp

Bakken Crude = 2.7 cp

Gasoline = 0.37 to 0.45 cp

Interfacial Tension – Measure of adhesive force between oil and water (dynes/cm)

Oil/Water = 18.0 to 29.5 dynes/cm

Bakken Crude = 18.4 dynes/cm

Gasoline = 49 to 51 dynes/cm

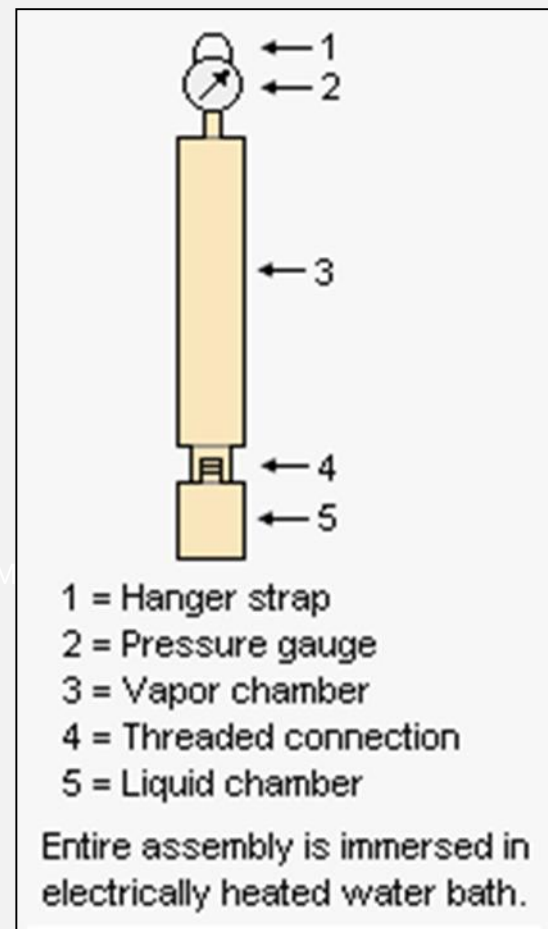
Petroleum Properties

Reid Vapor Pressure – Pressure exerted in a closed container by the vapor from the crude oil that has obtained equilibrium at 100° F.

Bakken Crude Oil contains methane, propane, butane and pentane.

RVP provides a bulk measurement of volatiles.

The greater the RVP the greater the volatile content



Petroleum Properties

- North Dakota Industrial Commission requires conditioning at the well site to remove volatiles for safer transport (Order No. 25417, effective April 1, 2015)
- ANSI/API RP 3000 (Classifying and Loading of Crude Oil into Rail Tank Cars) defines stable crude oil as having a vapor pressure equal to or less than 14.7 psi (one atmosphere).
- Will not boil at room temperature
- Equipment that test for vapor pressure has a margin of error of 1.0 psi so Industrial Commission chose **13.7 psi**.
- Cost approximately \$0.10 to \$0.20 per barrel, or \$120,000 to \$240,000 per day based on 1.2 million barrels per day production

Galena, IL Mar. 05, 2015

Casselton, ND Dec. 30, 2013

Bakken Crude Oil – Range 3.6 to 15.4 psi

Average 10.4 psi

80% of Bakken Crude < 11.8 psi

Lac Megantic, QB – RVP 9.0 to 9.5 psi

Mosier, OR – RVP 9.2 psi

Gasoline - EPA mandated RVP 7.8 to 9.0 psi

Petroleum Properties

Crude Name	Origin	API	RVP (psia)	Vol % of Light Ends (C2 – C5)
Arabian Super Light	Saudi Arabia	51	20.7	12.53 wt % ²⁵ (C1-C4 only)
Eagle Ford	Texas	48	7.95	8.3
Agbami	Nigeria	48	2.2	5.61 wt %
DJ Basin	Colorado	45	7.82	8.0
Sarahan Blend	Algeria	43	7.46	8.1
Bakken	North Dakota	42	7.83	7.2
WTI	Texas / New Mexico	41	5.90	6.1
Brent ²⁶	United Kingdom	37.5	9.33	5.28 wt %
API gravity of 37 or more defines light crude oil		37		
LLS	Louisiana	36	4.18	3.0
Alvheim blend	Norway	34.9	3.9	1.86 wt %
Arabian Heavy	Saudi Arabia	28.4	18.3	5.13 wt % (C1-C4)
Alberta Dilbit ²⁷	Alberta	21.1	7.18	7.30 wt %
Alba	United Kingdom	19.6	1.6	0.14 wt %

Casselton, ND



Fate & Transport Models

Purpose: Evaluate three idealized release scenarios using a subsurface with representative conditions

R.R. Tanker – Instantaneous & high volume release rate



Tanker Truck – Instantaneous & high volume release rate



Pipeline Release – Long term & low volume release rate

Cassellton

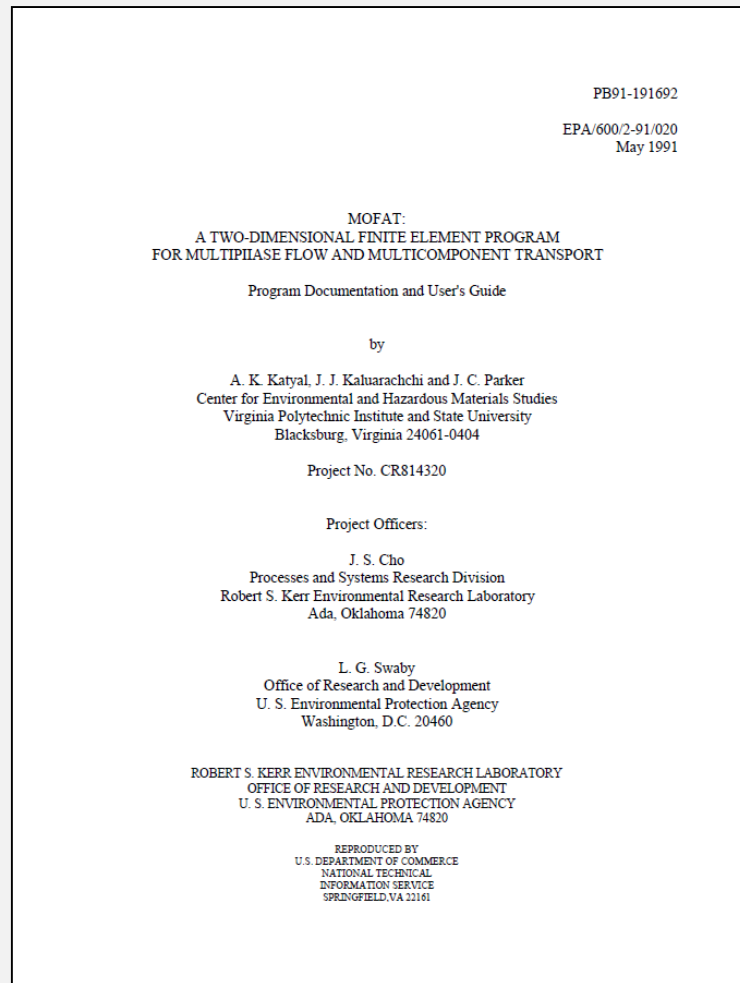


Fate & Transport Models

- Multispecies Oil Fate and Transport (MOFAT)
- Created by EPA 1991
- Written in Fortran
- Two –Dimensional Finite Element Program
- Cannot exceed 1,500 nodes
- Models LNAPL & DNAPL in the unsaturated zone
- Limited documentation and no technical support
- Must run in virtual XP machine
- Commonly used model for fate & transport of NAPL in unsaturated zone
- Can model complex scenarios

MOFAT for Windows

- Created by Draper Aden 1996
- Pre- and Post Processor, mesh editor
- No documentation or technical support
- Must run in virtual XP machine
- Output used in Surfer to construct 2D Contours



Fate & Transport Models

Hydrocarbon Spill Screening Model (HSSM)

- Created by EPA 1994
- Series of Analytical Solutions
- Models NAPL in the unsaturated and saturated zone (modeled benzene)
- One Dimensional in Unsat and Two-Dimensional in Saturated
- Upper bound to hydraulic conductivity
- Good GUI
- Good documentation and limited technical support
- Must run in virtual XP machine
- Commonly used model for fate & transport of NAPL in unsaturated & saturated zone
- Can model simple scenarios

THE HYDROCARBON SPILL SCREENING MODEL (HSSM) VOLUME 1: USER'S GUIDE

by

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Bob K. Lien
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and

Jacques B. Provost
Computer Sciences Corporation
Ada, Oklahoma 74820

HSSM-WIN - XZBT

File Edit Model Graph Window Help

Hydrologic Parameters

HYDROLOGIC PROPERTIES

Data file: C:\HSSM\XZBT.DAT

☒ Enable range checking

Water dynamic viscosity (cp) . . . 1.000

Water density (g/cm³) . . . 1.000

Water surf. tension (dyne/cm) . . . 65.00

Maximum k_{rw} during infiltration . . . 5000

Recharge

☒ Average recharge rate (m/d) value: 1.400E-02

☐ Saturation

Capillary pressure curve model

☐ Brooks and Corey

☒ van Genuchten

Brooks and Corey's lambda . . . 0

Air entry head (m) . . . 0

Residual water saturation . . . 1.000

POROUS MEDIUM PROPERTIES

Sat'd vert. hydraulic cond. (m/d) . . . 7.100

Ratio of horz/vert hyd. cond. . . . 2.500

Porosity . . . 4.300

Bulk density (g/cm³) . . . 1.510

Aquifer saturated thickness (m) . . . 15.00

Depth to water table (m) . . . 10.00

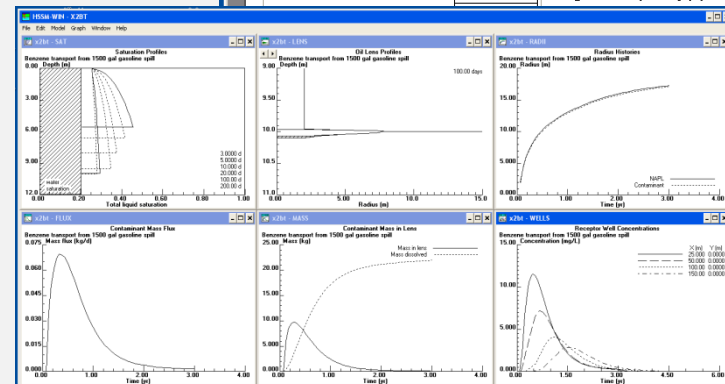
Capillary thickness parameter (m) . . . 1.000E-01

Groundwater gradient (m/m) . . . 1.000E-01

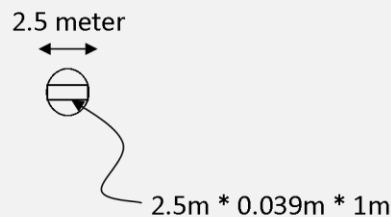
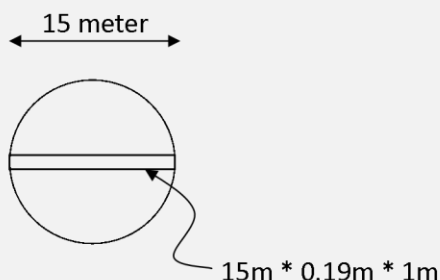
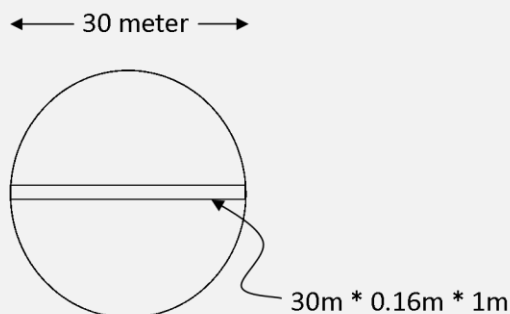
Longitudinal dispersivity (m) . . . 10.00

Transversal dispersivity (m) . . . 1.000

OK Cancel



Fate & Transport Models



Scenario #1 Fixed volume release of crude oil (MOFAT Only)

Calculated depth

30,000 gallons = 113.6 cubic meters

$$\text{Area} = \pi r^2 = 3.14 * (15\text{m})^2 = 706.9 \text{ m}^2$$

$$\text{Depth} = 113.6 \text{ m}^3 / 706.9 \text{ m}^2$$

$$\text{Depth} = 0.16 \text{ meters} = 6.3 \text{ in}$$

2D Model Infiltrated Volume

$$30\text{m} * 0.16 \text{ m} * 1\text{m} = 4.8 \text{ m}^3 = 1,268 \text{ gal.}$$

Scenario #2 Fixed volume release of gasoline (MOFAT Only)

Calculated Depth

9,000 gallons = 34.1 cubic meters

$$\text{Area} = \pi r^2 = 3.14 * (7.5\text{m})^2 = 176.7 \text{ m}^2$$

$$\text{Depth} = 34.1 \text{ m}^3 / 176.7 \text{ m}^2$$

$$\text{Depth} = 0.19 \text{ meters} = 7.5 \text{ in}$$

2D Model Infiltrated Volume

$$15\text{m} * 0.19\text{m} * 1\text{m} = 2.85 \text{ m}^3 = 753 \text{ gal}$$

Scenario #3 Constant rate release of gasoline (MOFAT & HSSM)

Calculated Depth

50 gallons = 0.189 cubic meters

$$\text{Area} = \pi r^2 = 3.14 * (1.25\text{m})^2 = 4.91 \text{ m}^2$$

$$\text{Depth} = 0.189 \text{ m}^3 / 4.91 \text{ m}^2$$

$$\text{Depth} = 0.039 \text{ meters} = 1.5 \text{ in}$$

2D Model Infiltrated Volume

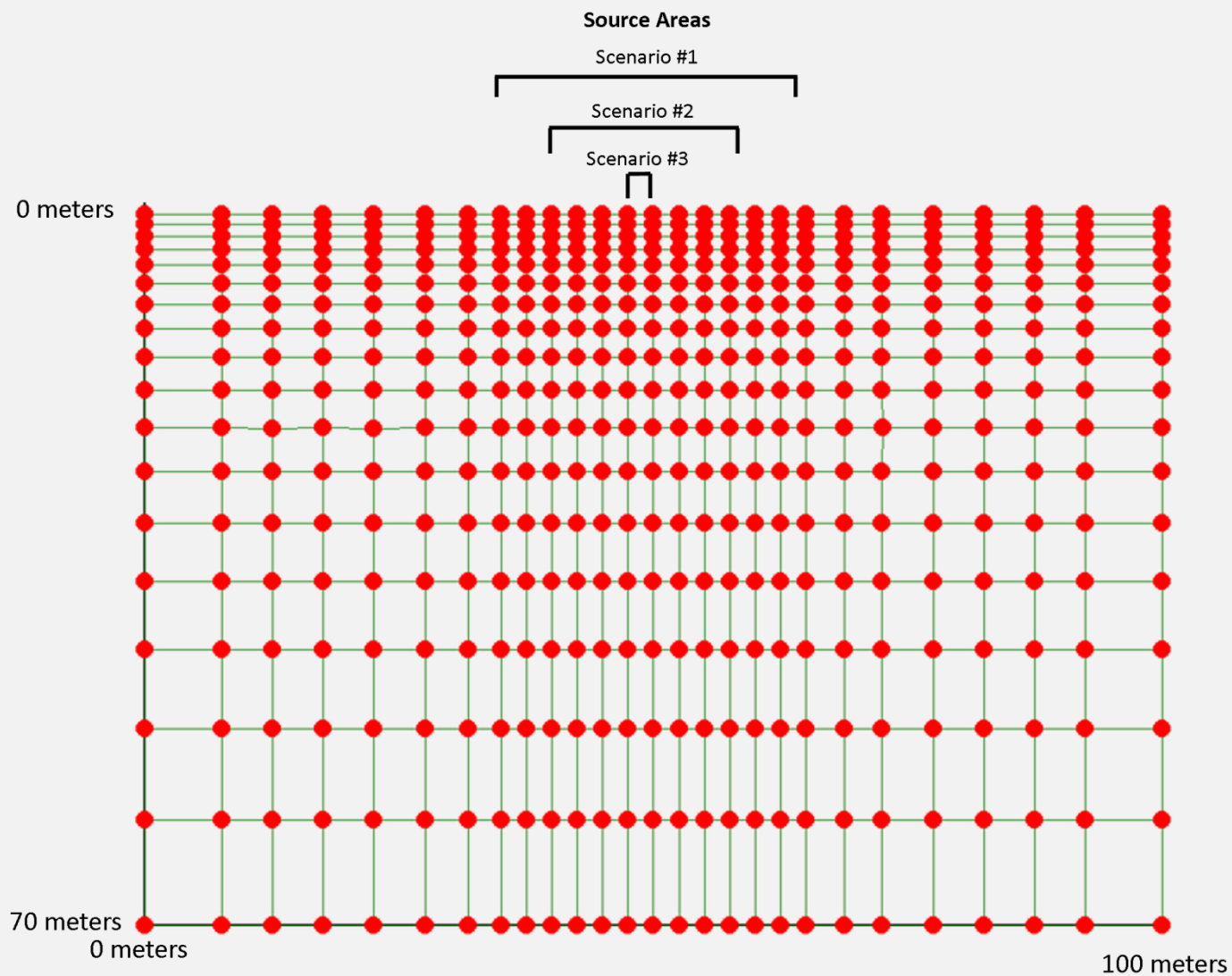
$$2.5\text{m} * 0.039\text{m} * 1\text{m} = 0.098\text{m}^3 = 26 \text{ gal}$$

Fate & Transport Models

Assumptions:

1. Single Subsurface Unit (No soil)
2. Subsurface is homogeneous and anisotropic (2:1)
3. Hydraulic Conductivity (model restricted)
MOFAT = 350 m/d horiz., 175 m/d vert.
HSSM = 500 m/d horiz., 250 md/ vert.
4. Increase gradient in HSSM model to achieve 6.0 m/d ($\approx$ 20 feet/day) saturated velocity
5. Porosity = 0.35
6. Residual Water Saturation = 0.1
7. No other external inputs (precipitation)
8. No evaporation or degradation

Fate & Transport Models – MOFAT Grid



Fate & Transport Models

Variable Hydraulic Conductivity

$$K(\Theta) = K_S \left[\frac{\Theta}{\Theta_S} \right] \quad (\text{Campbell Equation})$$

K_Θ = Unsaturated Hydraulic Conductivity

K_S = Saturated Hydraulic Conductivity

Θ = percent saturation

Θ_S = percent fully saturated

The greater the degree of saturation the greater the hydraulic conductivity

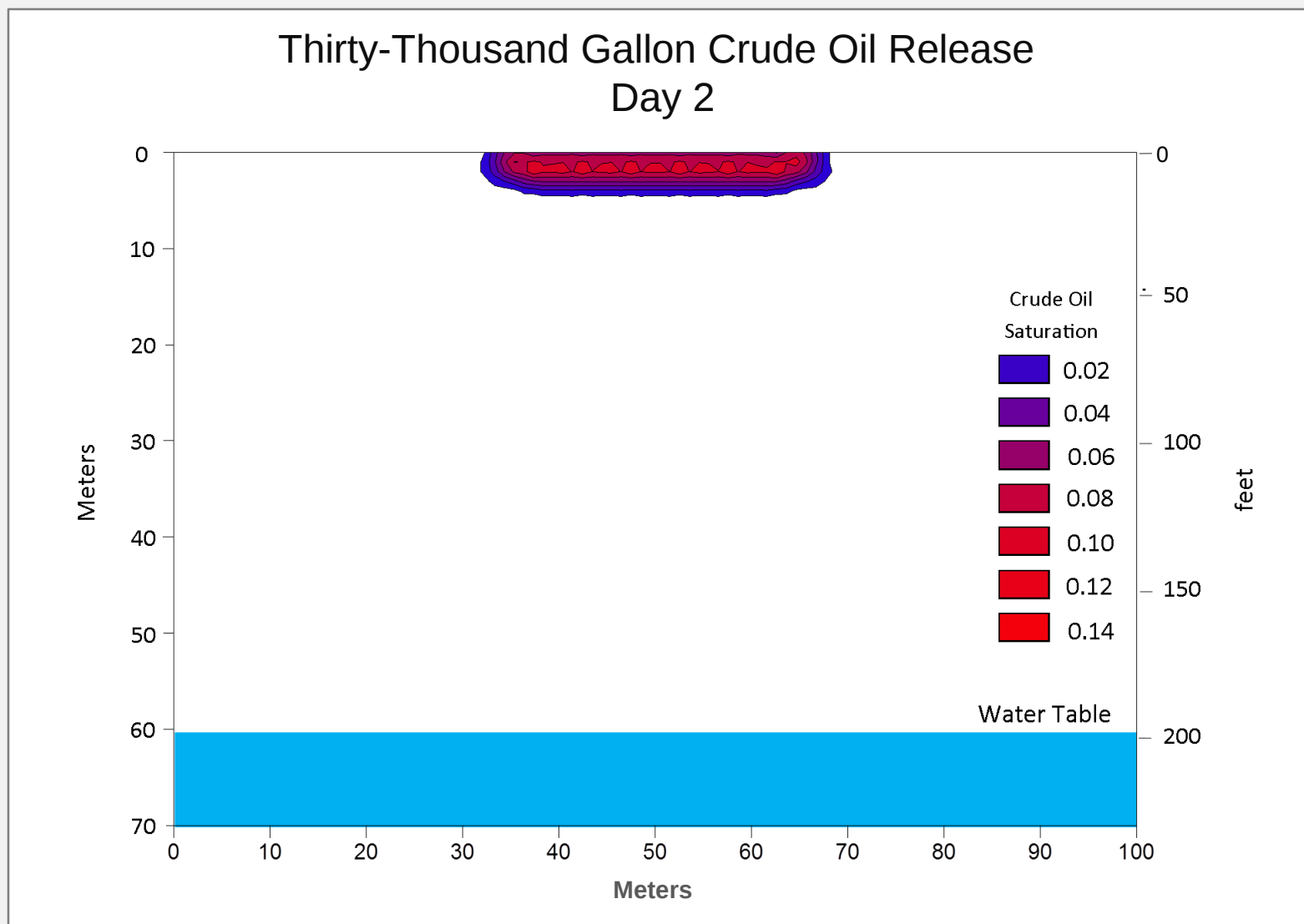
The lower the degree of saturation the lower the hydraulic conductivity

Residual NAPL Saturation

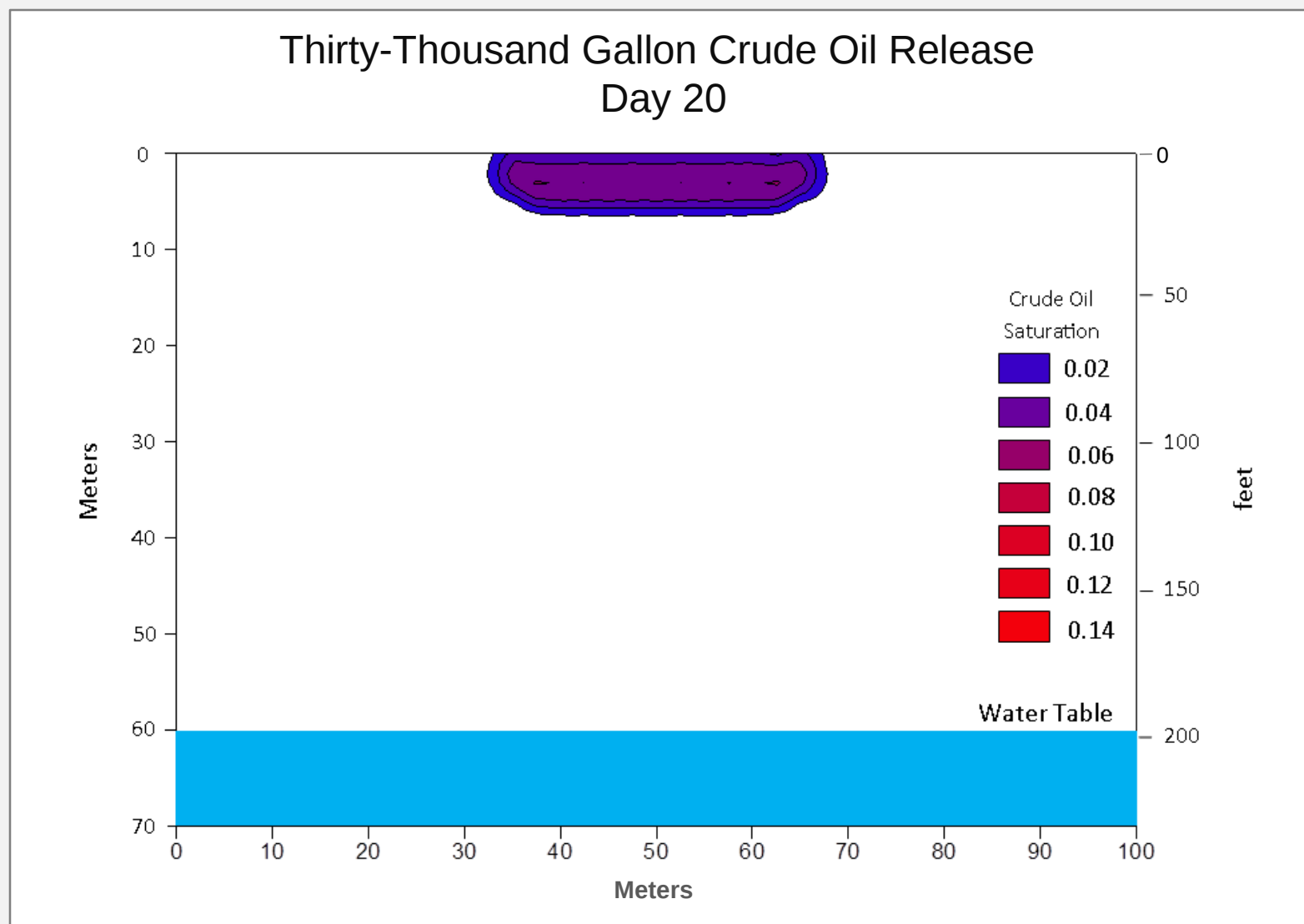
Once the NAPL saturation falls below the residual level the movement of NAPL will cease.

Values Range between 0.02 – 0.20

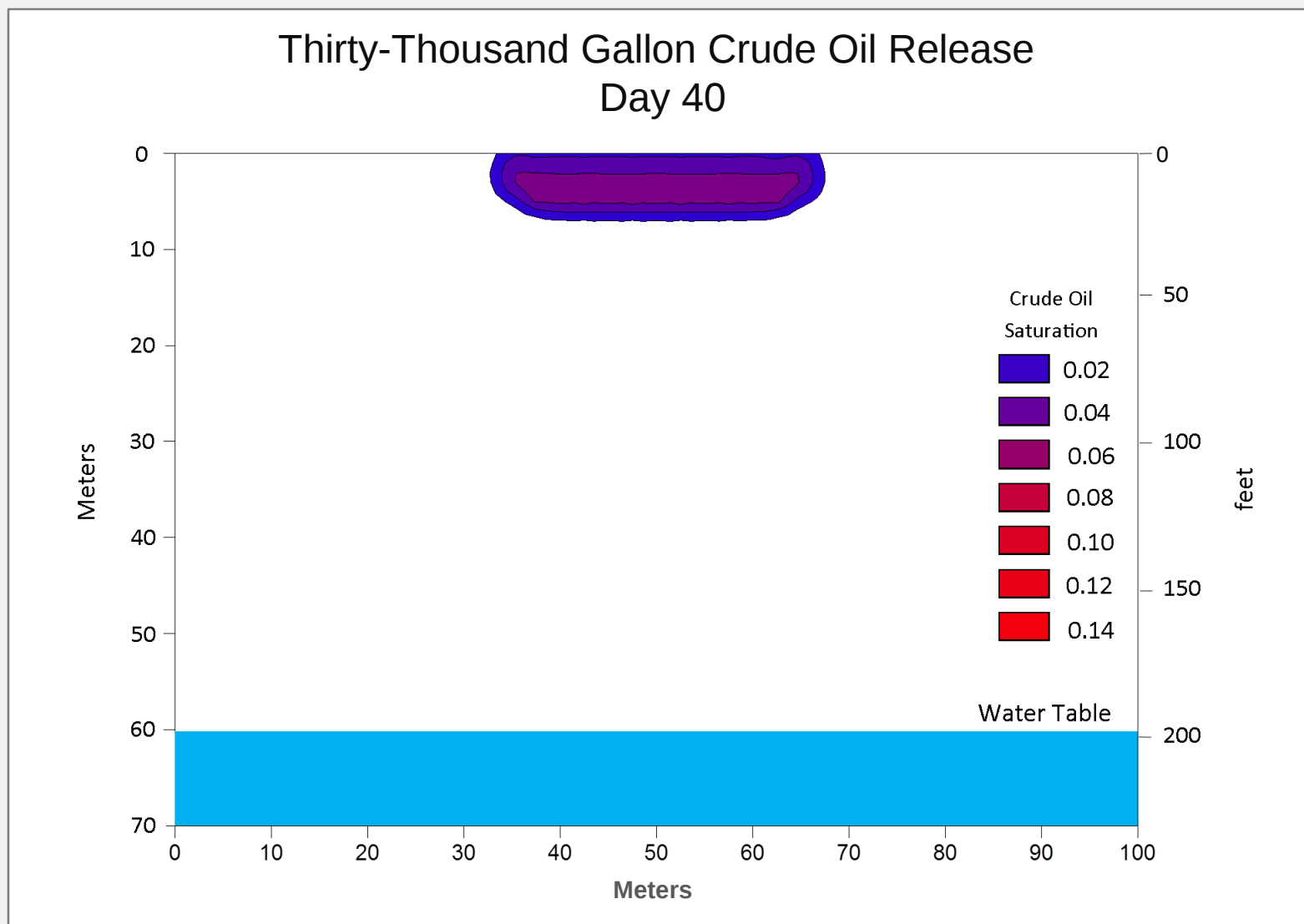
Fate & Transport Models



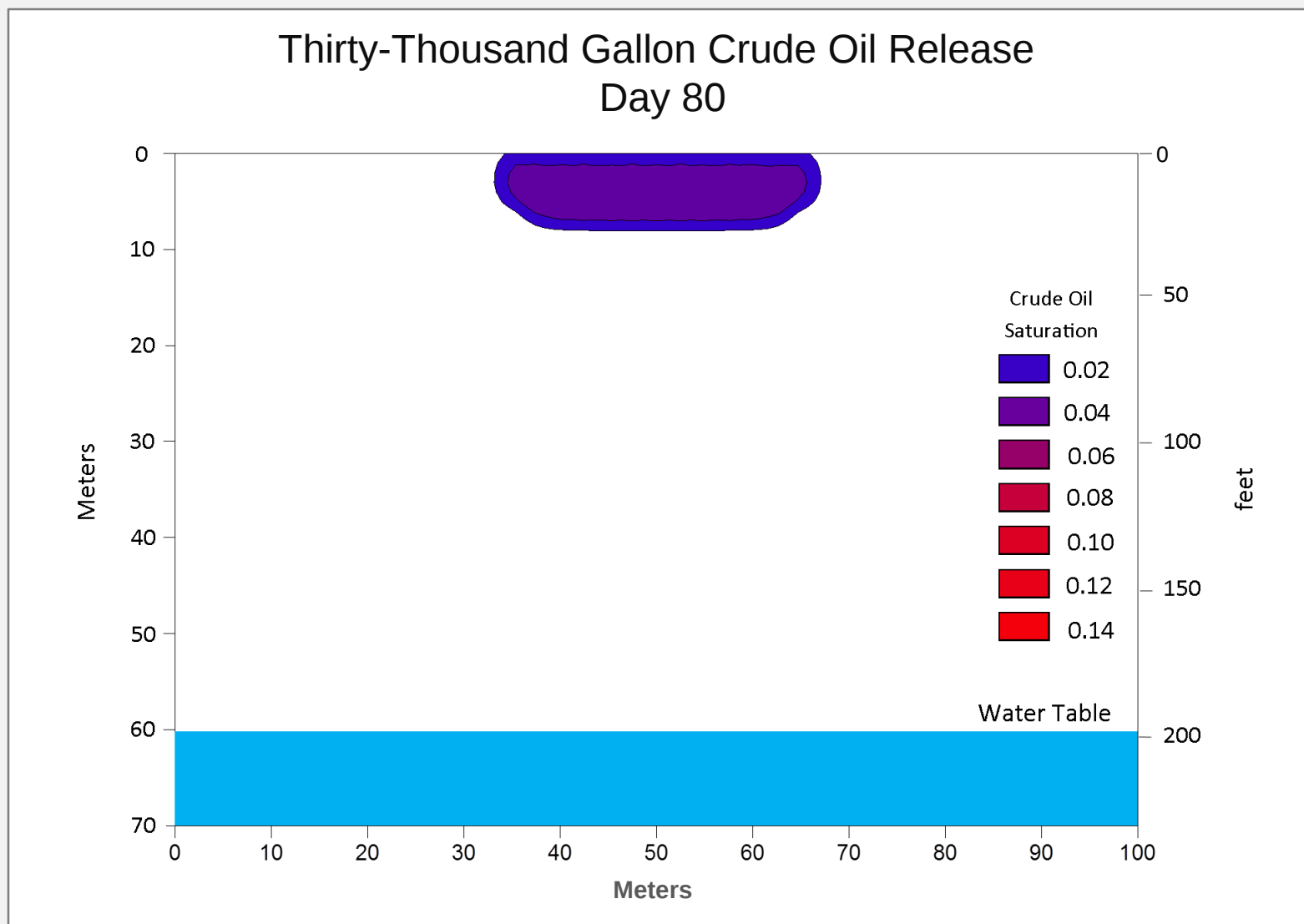
Fate & Transport Models



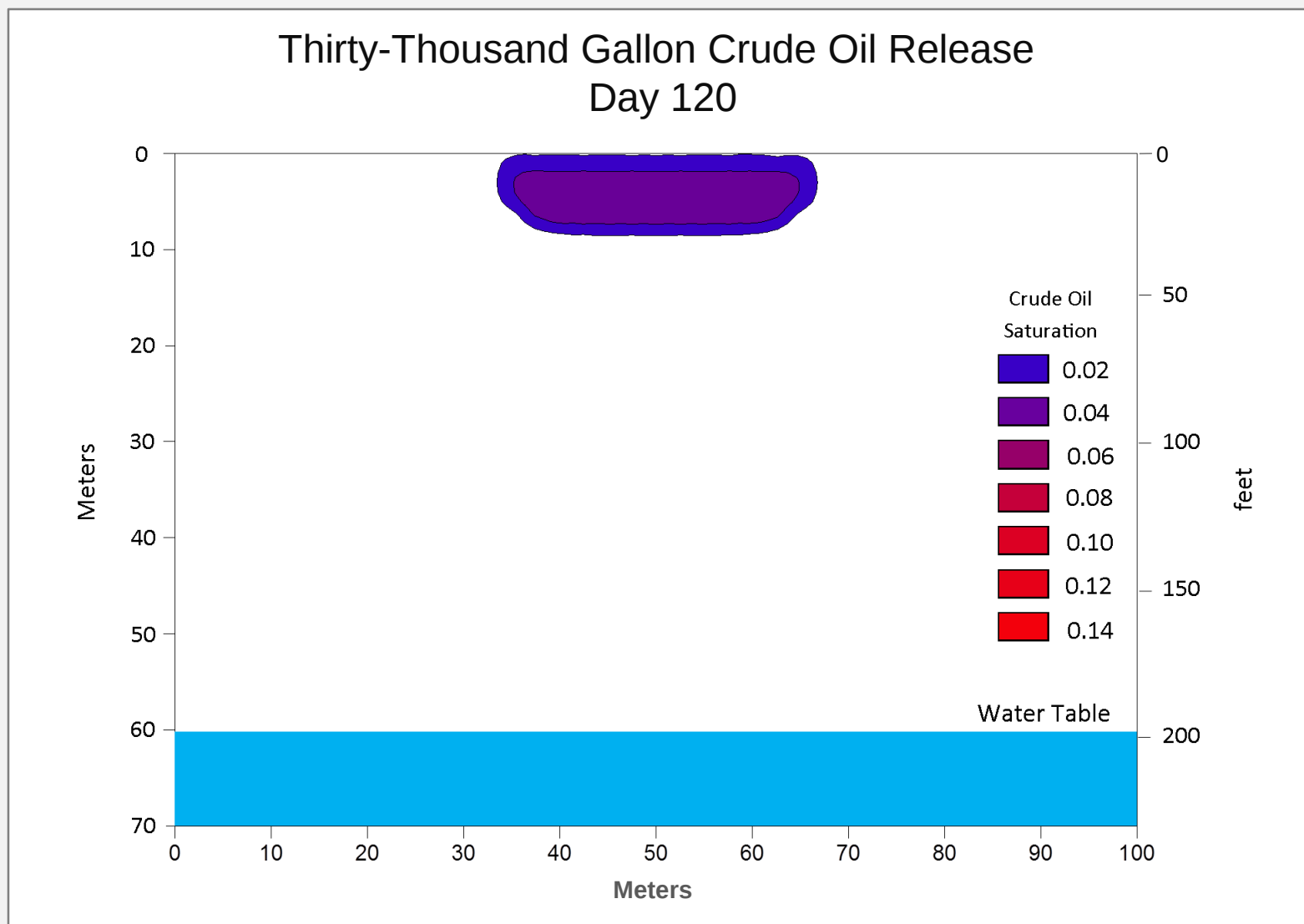
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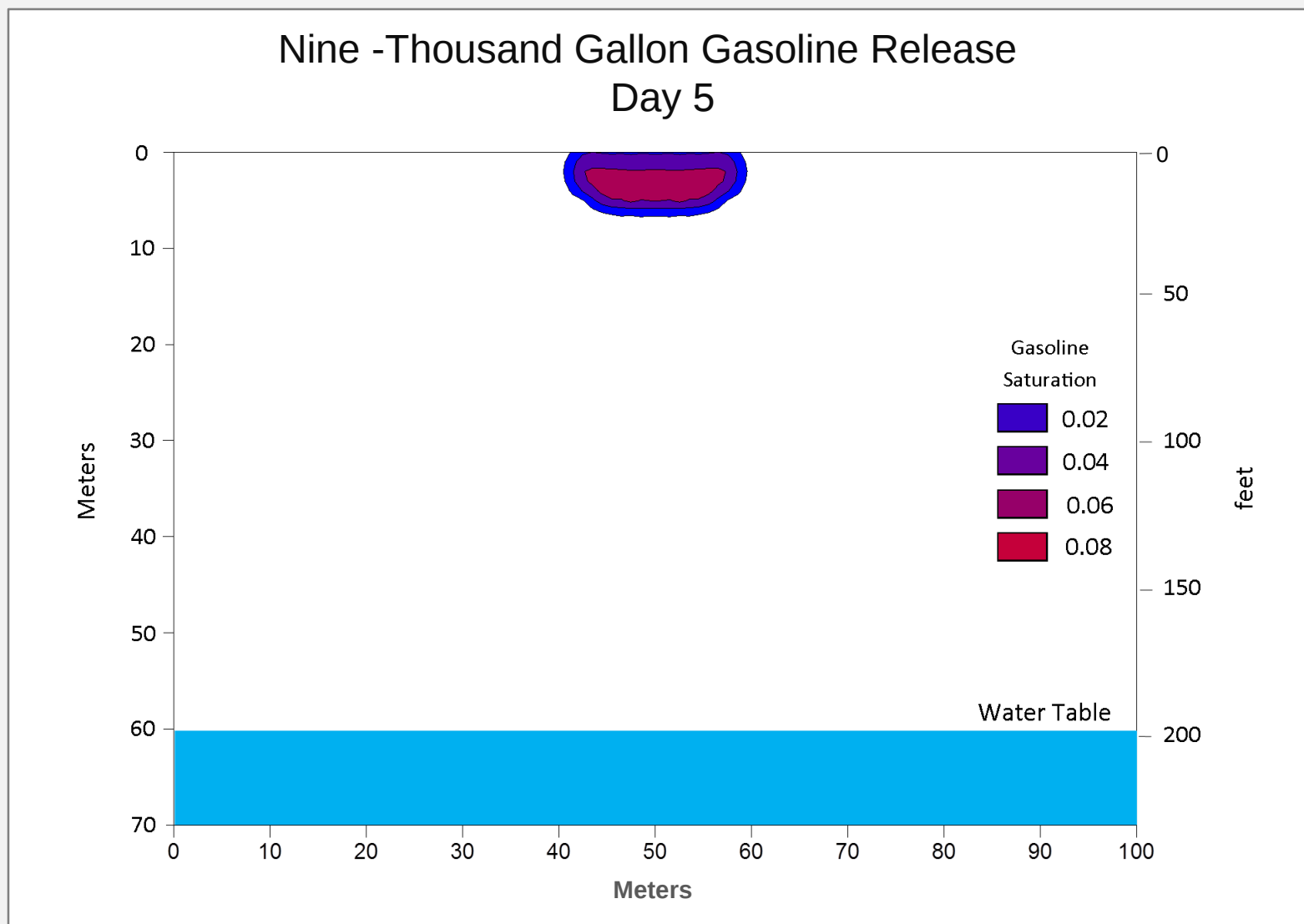
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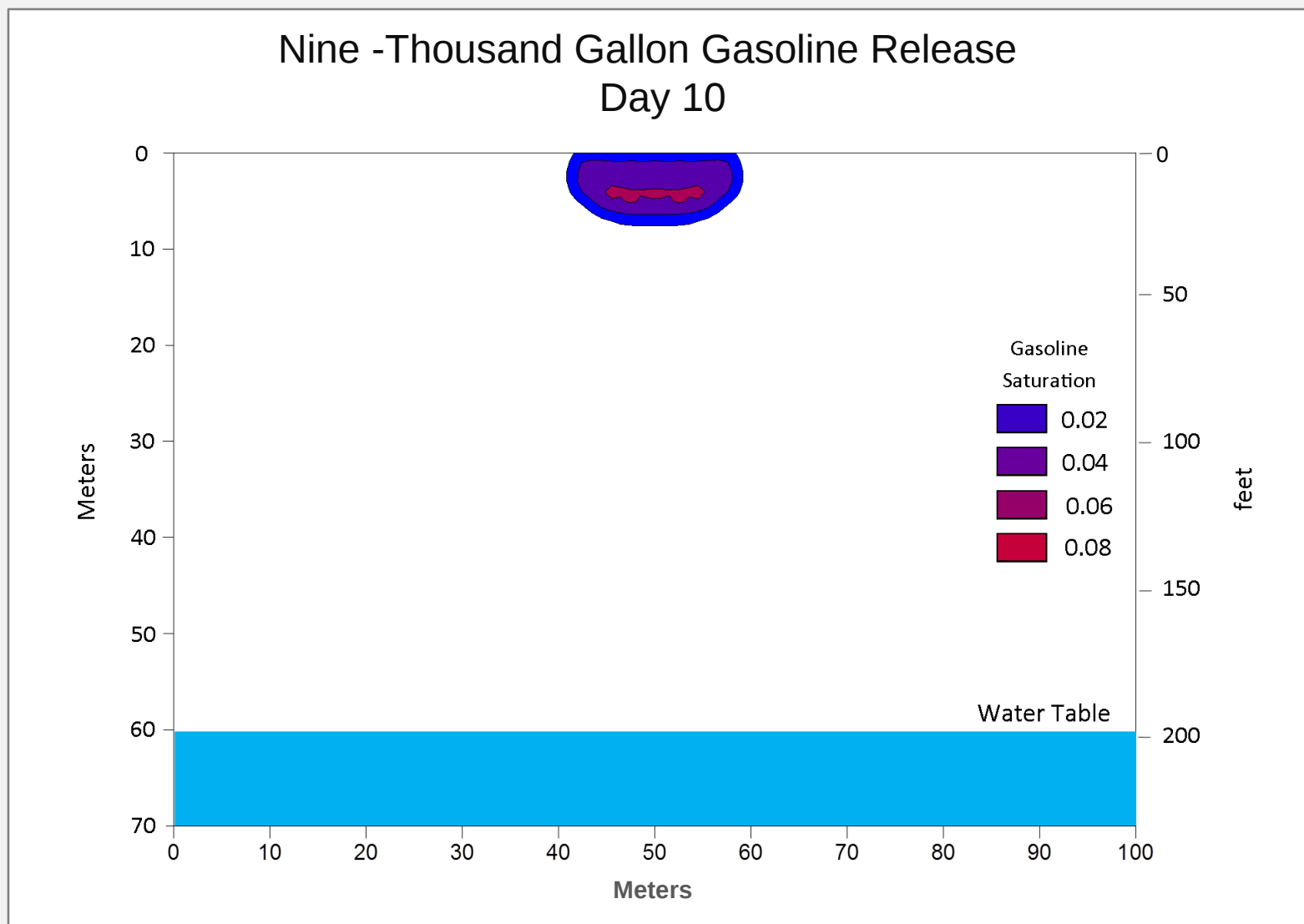
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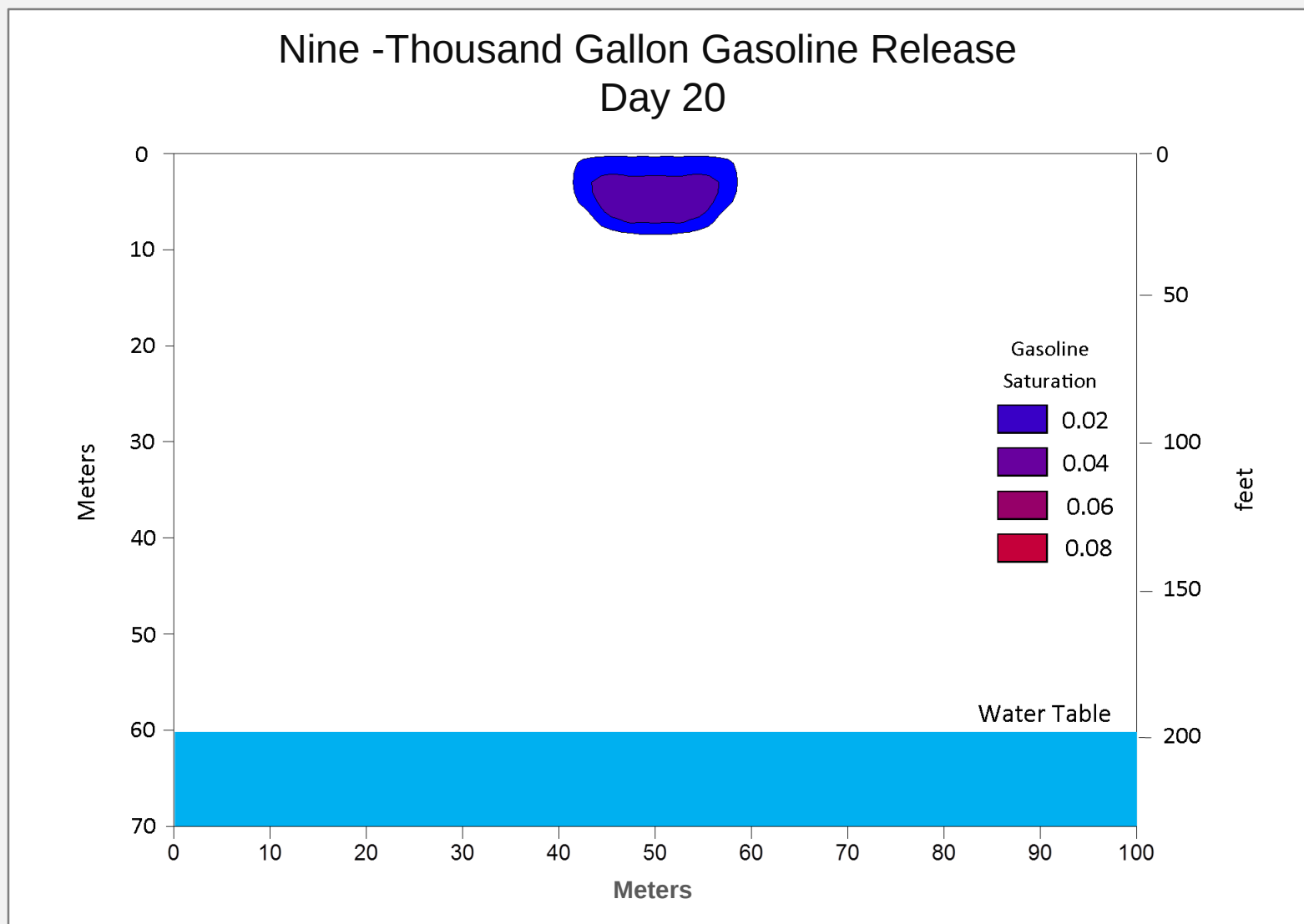
Fate & Transport Models



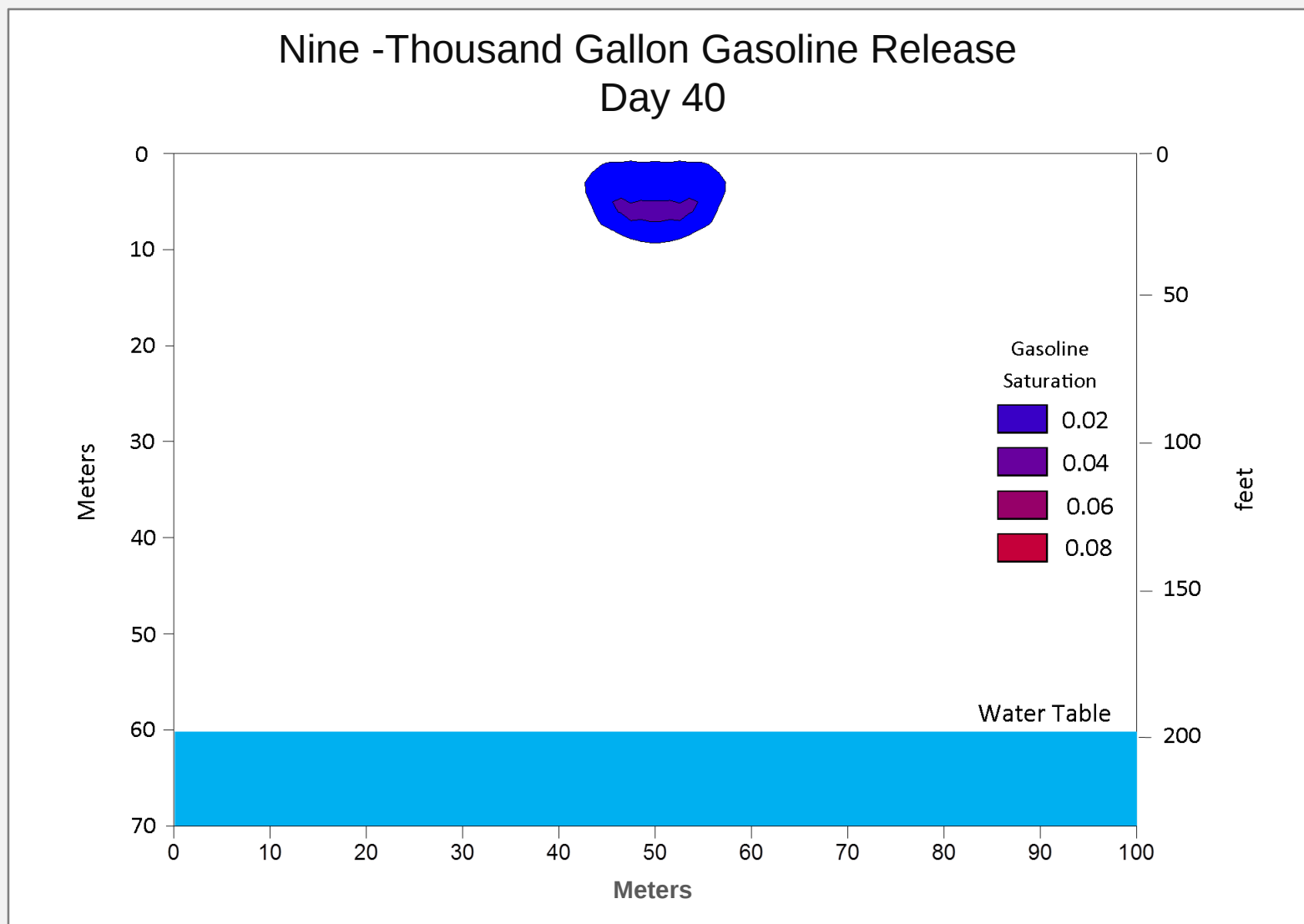
Fate & Transport Models



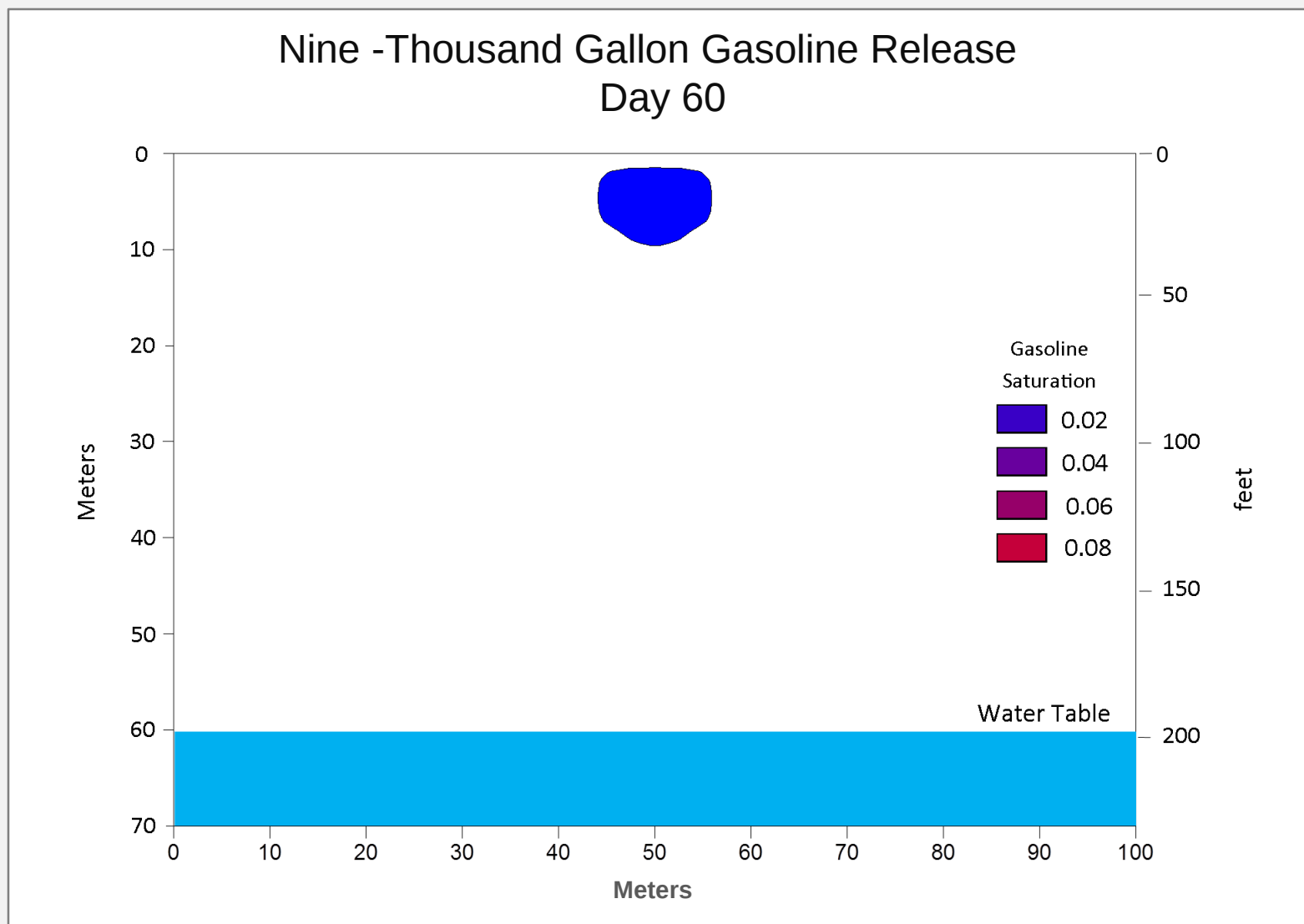
Fate & Transport Models



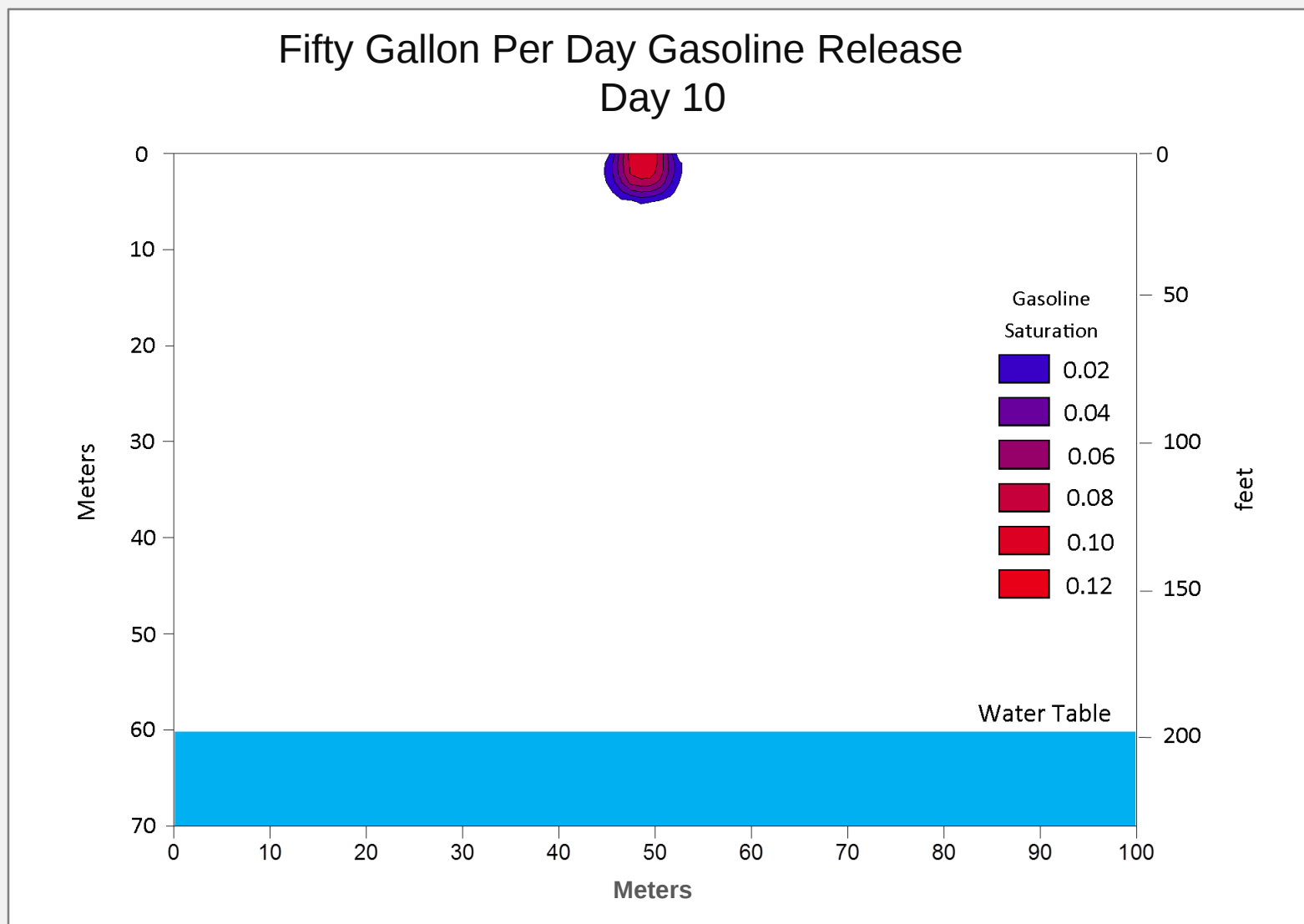
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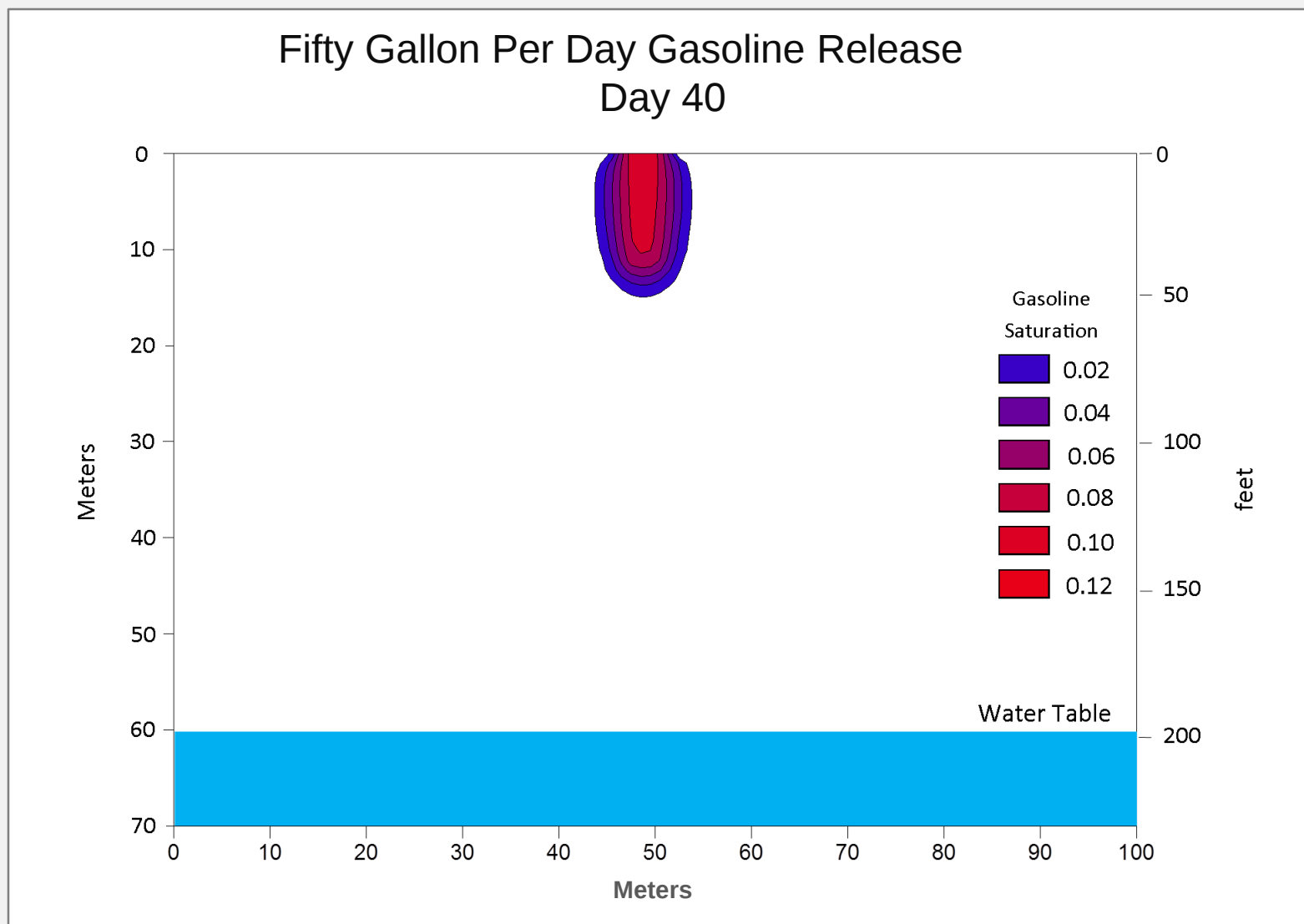
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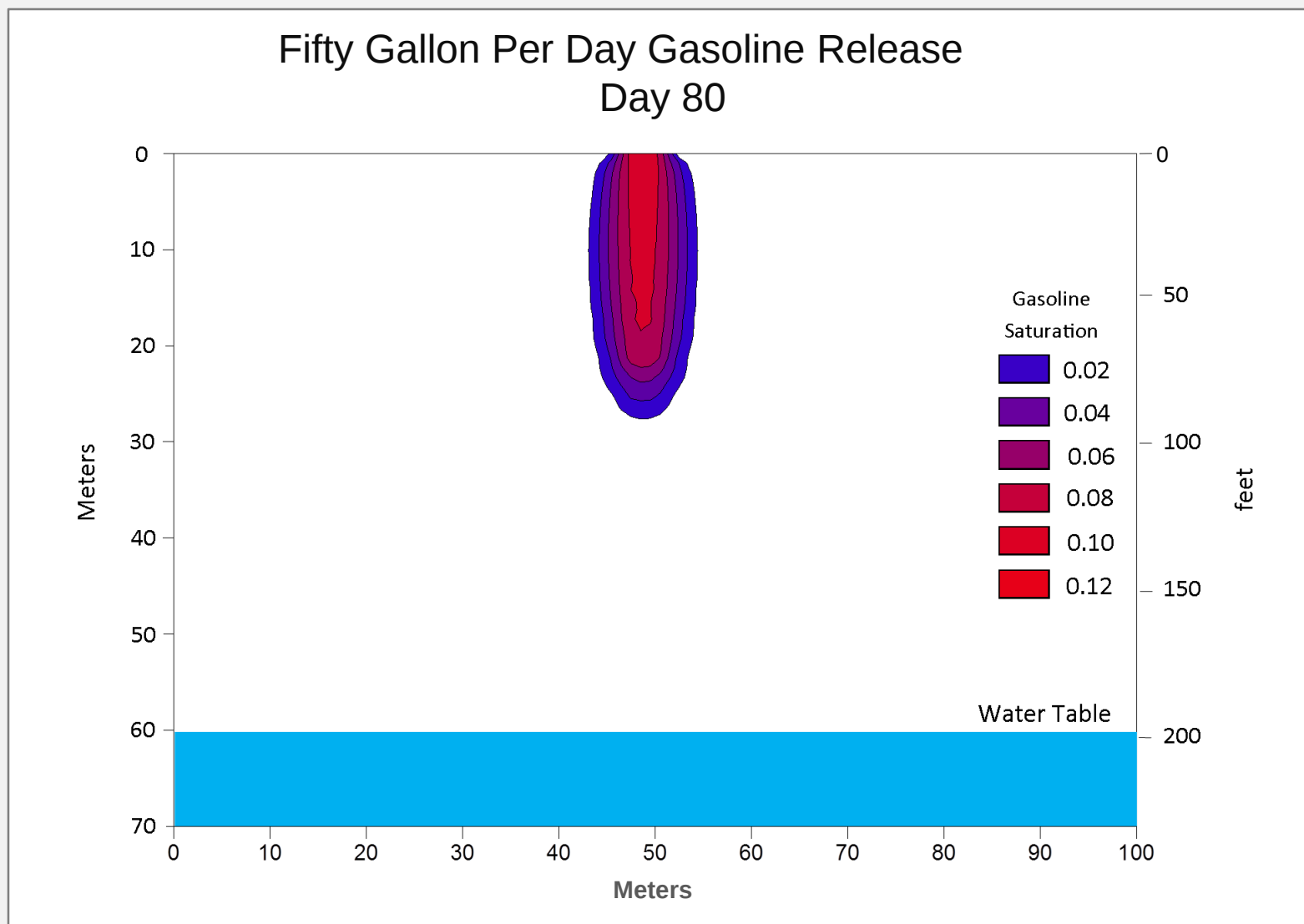
Fate & Transport Models



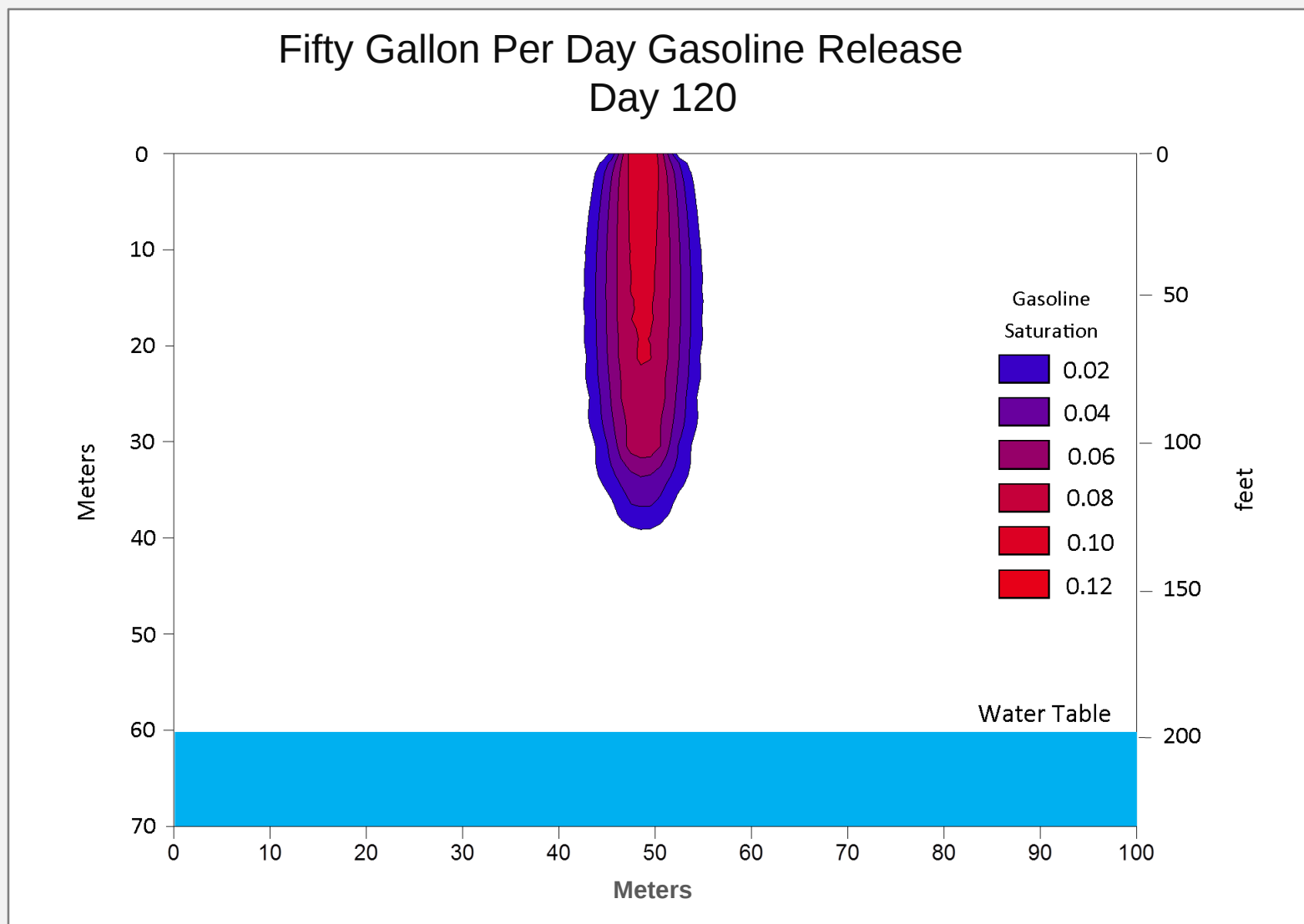
Fate & Transport Models



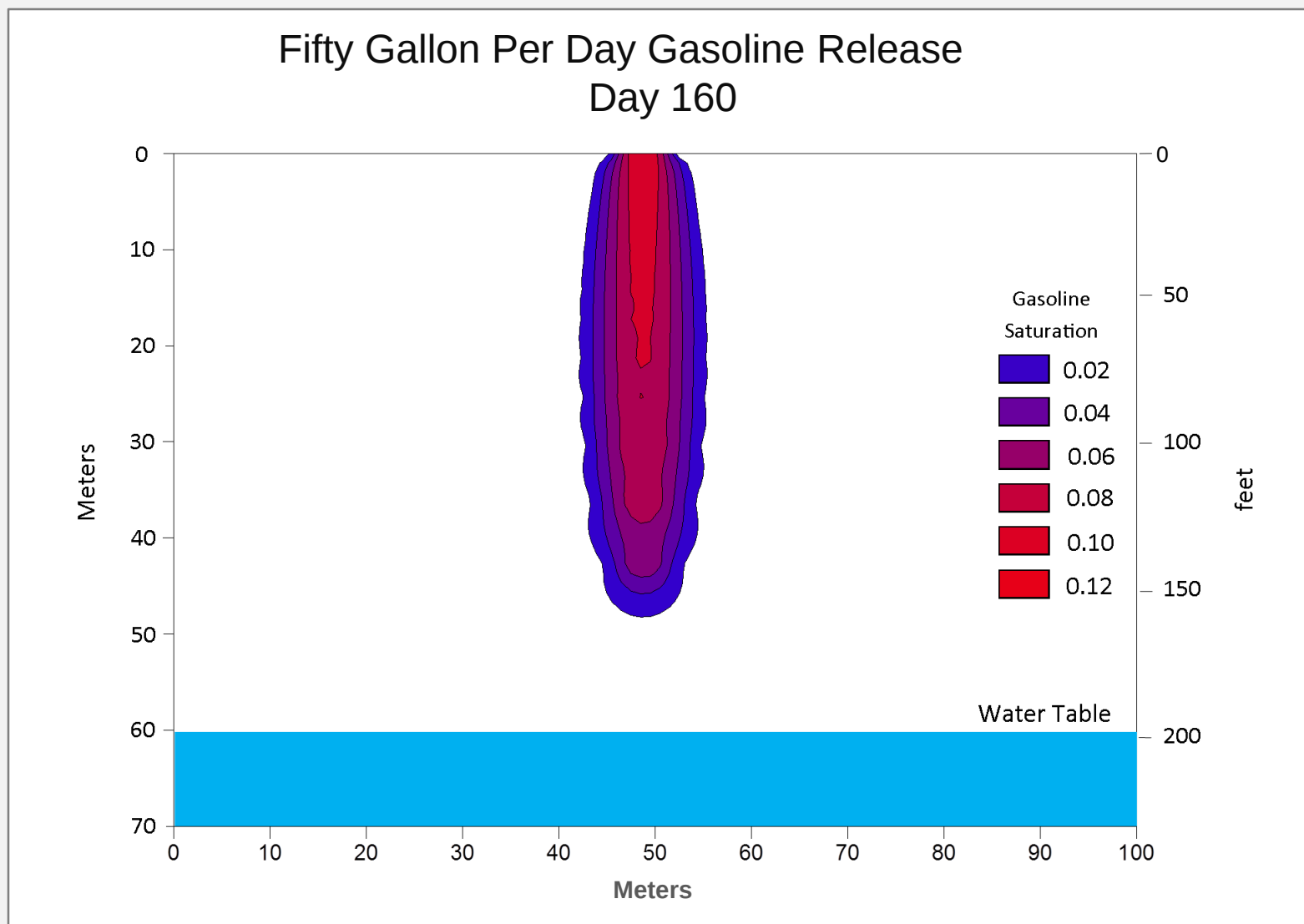
Fate & Transport Models



Fate & Transport Models

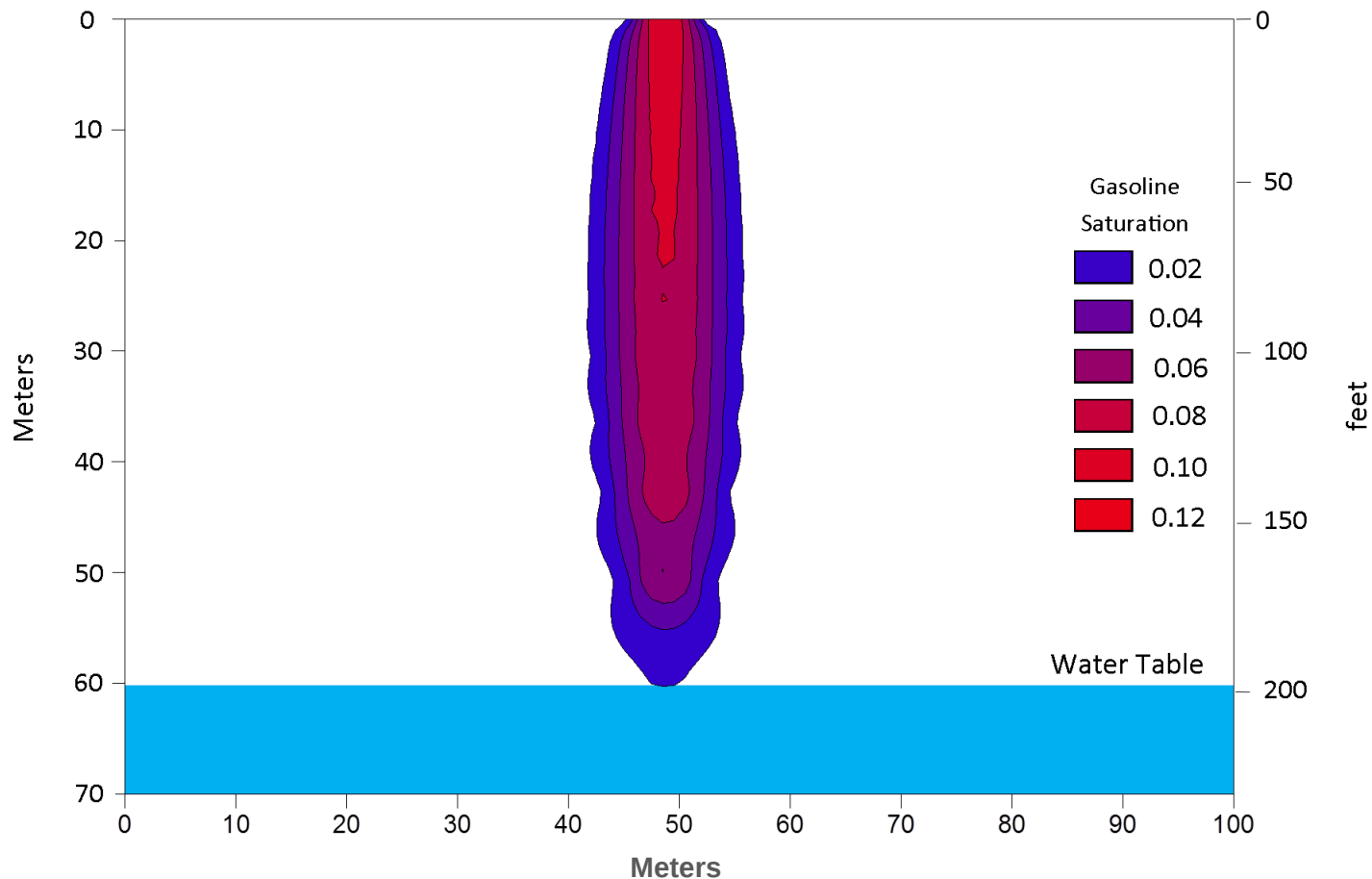


Fate & Transport Models



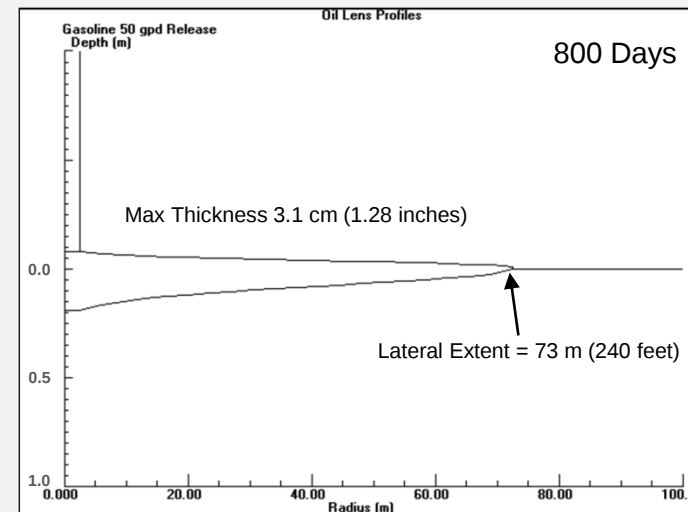
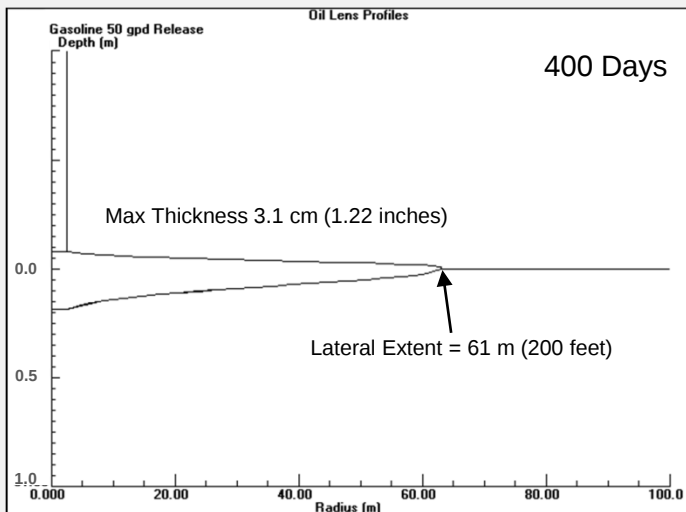
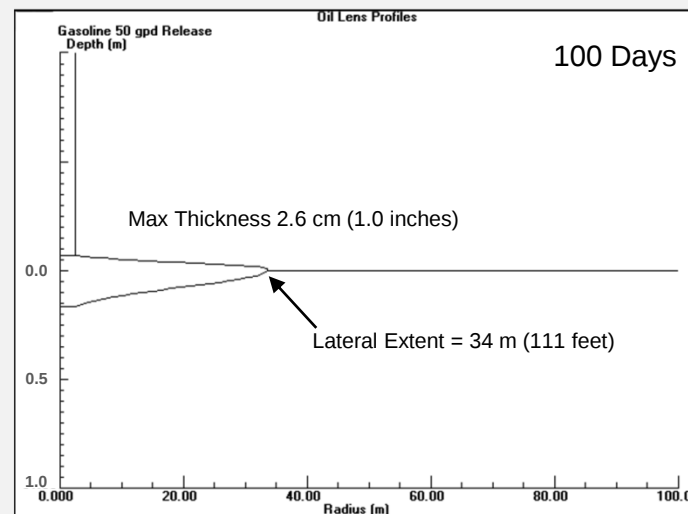
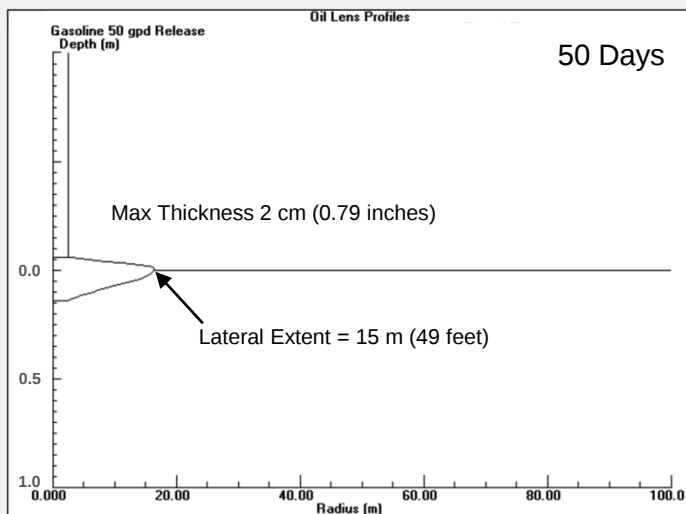
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Fifty Gallon Per Day Gasoline Release Day 200



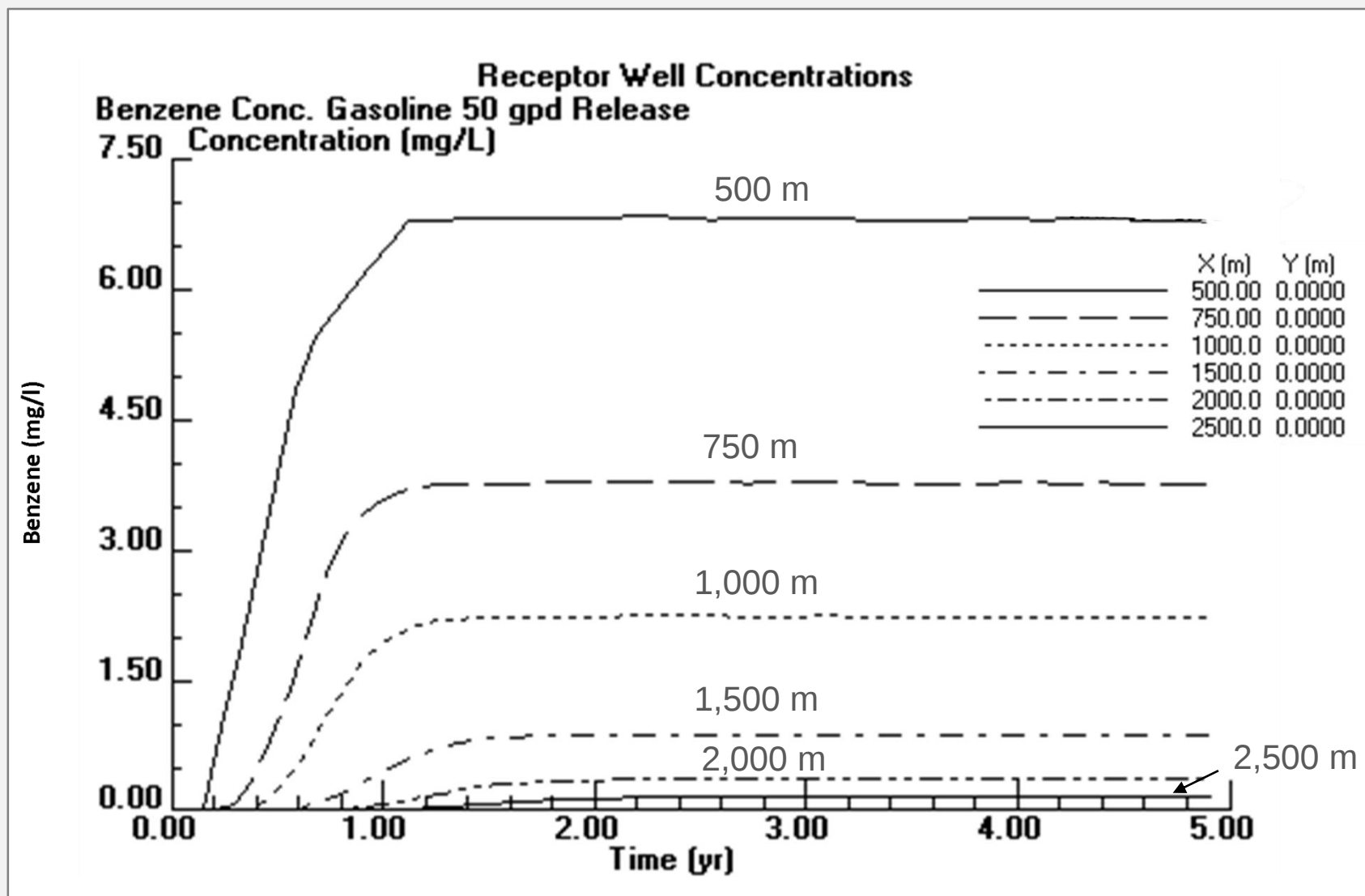
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Continuous 50 gpd over 2.5 meter dia. circle



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Drinking Water Standard = 0.005 mg/l



Conclusions

1. EIA data indicates that rail delivered crude oil to PADD 5 does not appear to be currently decreasing and due to the lack of pipeline infrastructure will remain significant transport mode
2. Crude oil by rail and the Yellowstone pipeline are significant transporters of petroleum products over the RPA.
2. Large instantaneous releases of petroleum are very visible and will infiltrate into the subsurface but the depth will be limited by volume
4. Small continuous releases may be more difficult to detect and have the potential to infiltrate through the unsaturated zone and contaminate both the soil and ground water.

Questions



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