A Static Modeling Approach to Understanding the PFOS Soil-to-Forage-to-Beef Exposure Pathway

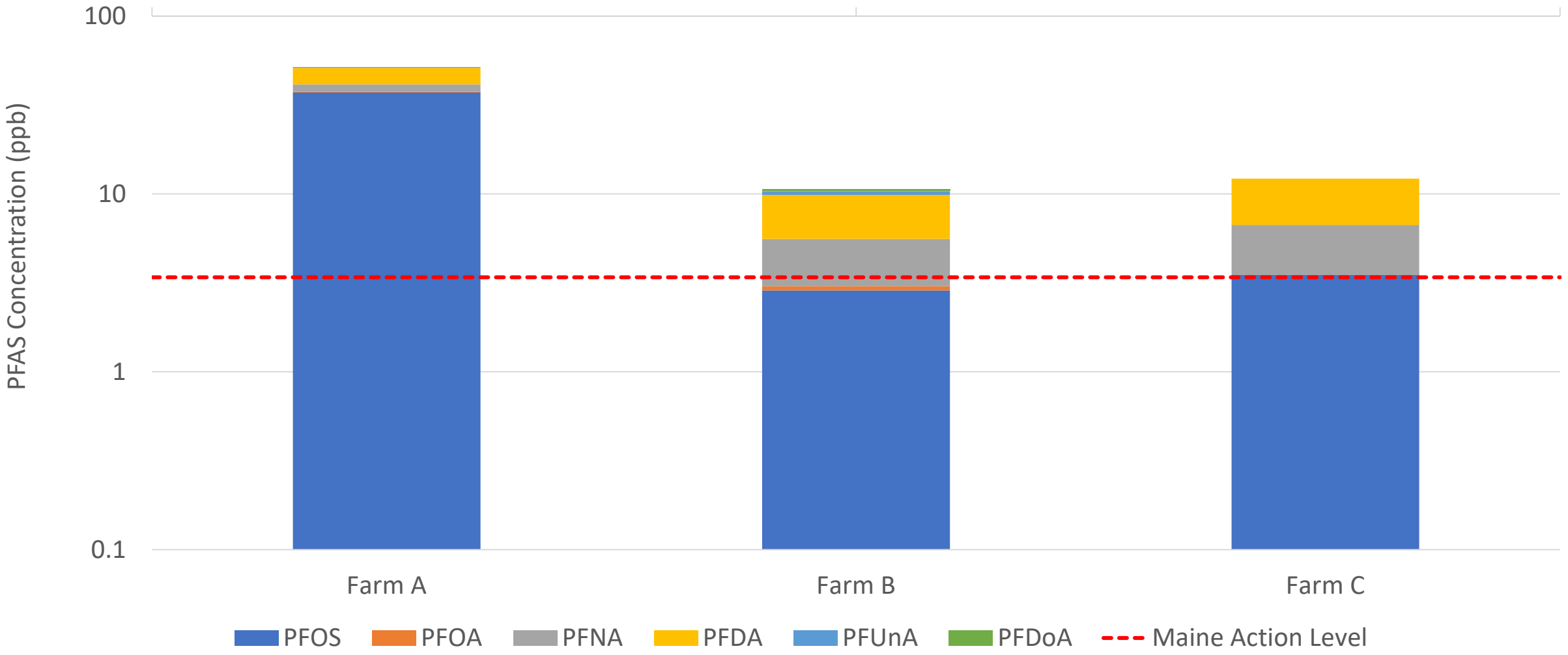
Barbara Astmann

Toxicologist

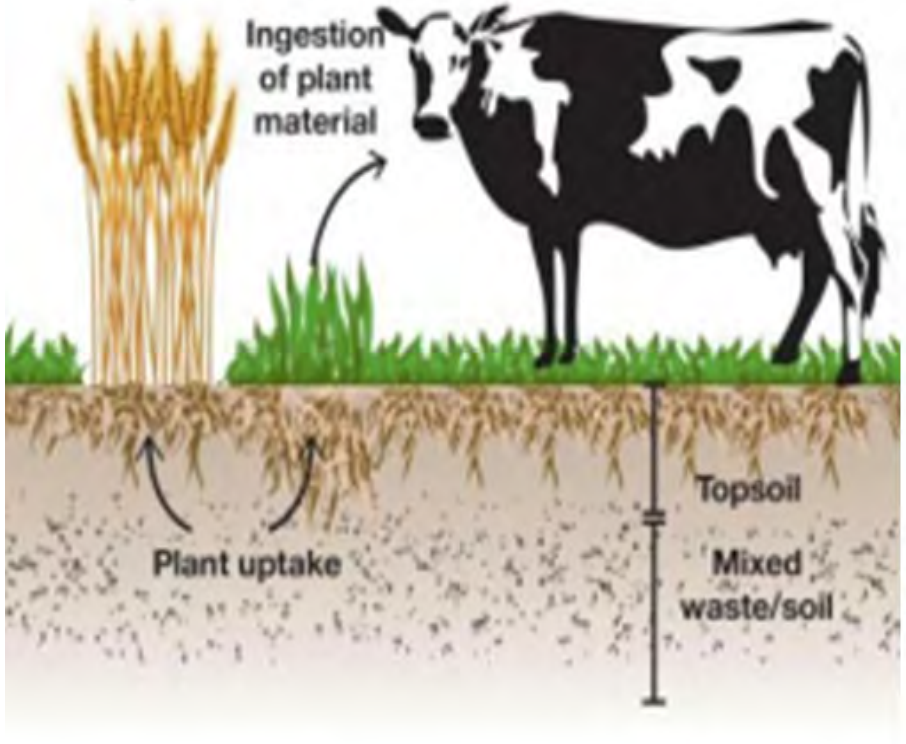
Maine Center for Disease Control and Prevention

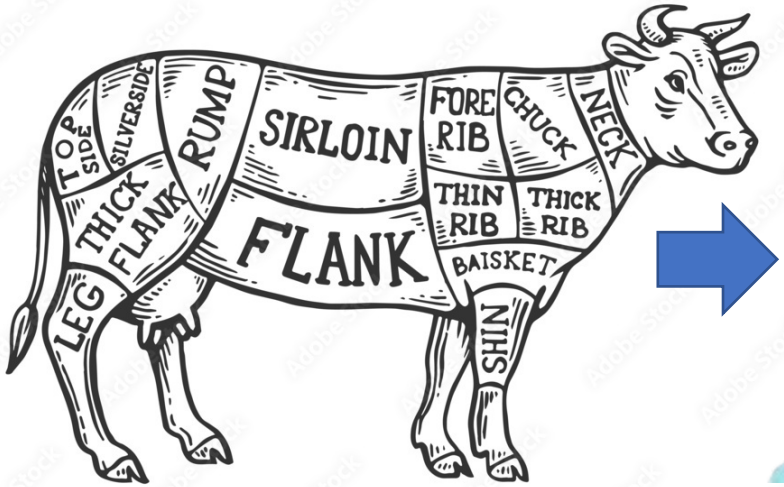
April 4, 2024

PFAS in Cow Muscle Tissue



How much is too much PFOS in soil to grow forage for livestock?







Soil → Hay/Corn → Cow → Beef → Child

How much is too much PFOS in Soil?
Modified EPA PRG Soil Screening Level Equations

Beef Action Level

$$SL_{soil} = \frac{C_{beef}}{TF_{beef} \times \left[\left(I_{feed} \times F_{onsite-f} \times F_{year-f} \times TF_{plant}\right) + \left(I_{soil} \times F_{onsite-g} \times F_{year-g}\right)\right]}$$

Intake to beef transfer factor

Feed ingestion rate

Fraction of time exposed to contaminated feed

Plant transfer factor

Soil ingestion rate

Fraction of time exposed to contaminated soil

Source: Modified equation from U.S. EPA Preliminary Remediation Goals for Radionuclides
https://epa-prgs.ornl.gov/radionuclides/users_guide.html

Model Inputs – Beef Action Levels

Maine Current Beef Action Level adopted 2020:

3.4 ng/g

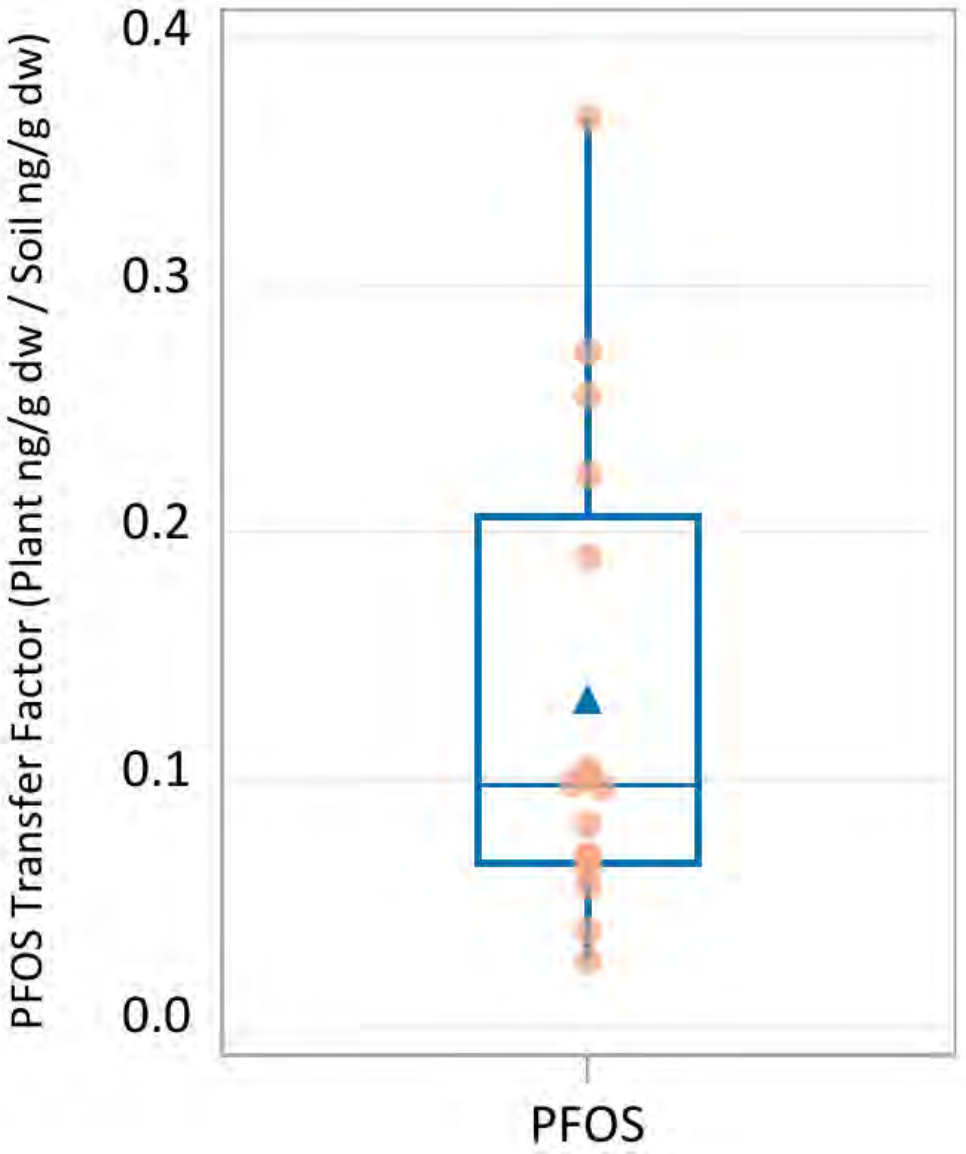
European Union Maximum Level for Beef adopted 2022:

0.3 ng/g

Sources:
PFOS Action Levels for Beef Derivation Memo August 4, 2020
https://www.maine.gov/dep/spills/topics/pfas/PFOS-Action-Levels-for-Beef-Derivation-Memo-08.04.20.pdf

COMMISSION REGULATION (EU) 2022/2388 of 7 December 2022 amending Regulation (EC) No 1881/2006 as regards maximum levels of perfluoroalkyl substances in certain foodstuffs
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R2388

Model Inputs – Plant Transfer Factor



- Mean PFOS TF = 0.13 (SD 0.1)
- Field means PFOS TF range = 0.026 – 0.37

Model Inputs – Intake to Beef Muscle Transfer Factor

$$PFOS\ intake\ to\ muscle\ TF\left(\frac{day}{kg}\right) = \frac{PFOS\ concentration\ in\ muscle\left(\frac{ng}{kg}\right)}{PFOS\ daily\ intake\left(\frac{ng}{day}\right)}$$

Derivation of PFOS TF for intake to muscle using data from Drew et al. 2021

0.18 day/kg

436.2 µg/L

0.076 µg PFOS / kg beef / µg PFOS / L serum

$$PFOS\ intake\ to\ muscle\ TF = \frac{Estimated\ steady\ state\ serum\ concentration \times Muscle{:}Serum\ partition\ coefficient}{PFOS\ concentration\ in\ water \times Average\ daily\ water\ intake\ rate}$$

3 µg/L

59.8 L/day (based on average cattle body weight of 427 kg and climate prior to sampling)

Sources:
Drew et al. 2021a https://doi.org/10.1080/19440049.2021.1942562
Drew et al. 2021b https://doi.org/10.1080/19440049.2021.1991004
National Research Council Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. https://doi.org/10.17226/9791
Australian Government Bureau of Meteorology. Climate statistics for Australian locations. http://www.bom.gov.au/climate/averages/tables/cw_086071.shtml

Example: Soil Screening Level – Grass-based Forage
Grass-fed Beef Farm

1.2 ng/g or 13.3 ng/g

$$SL_{soil} = \frac{C_{beef}}{TF_{beef} \times \left[\left(I_{feed} \times F_{onsite-f} \times F_{year-f} \times TF_{plant}\right) + \left(I_{soil} \times F_{onsite-g} \times F_{year-g}\right)\right]}$$

0.3 ng/g (EU) or 3.4 ng/g (ME)

0.18 day/kg

9.5 kg/day **1** **1** **0.13**

1.24 kg/day

0.38 kg/day **1** **0.5**

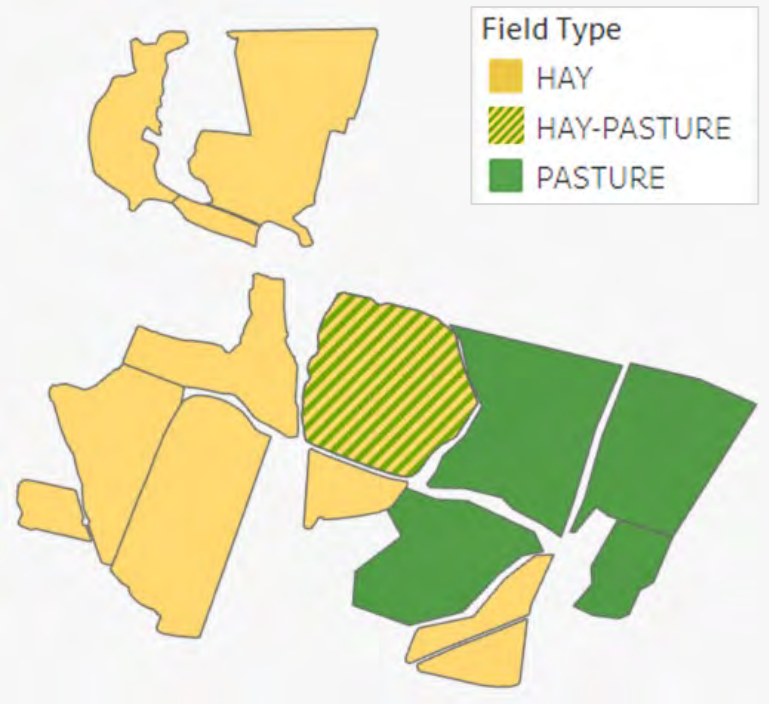
0.19 kg/day

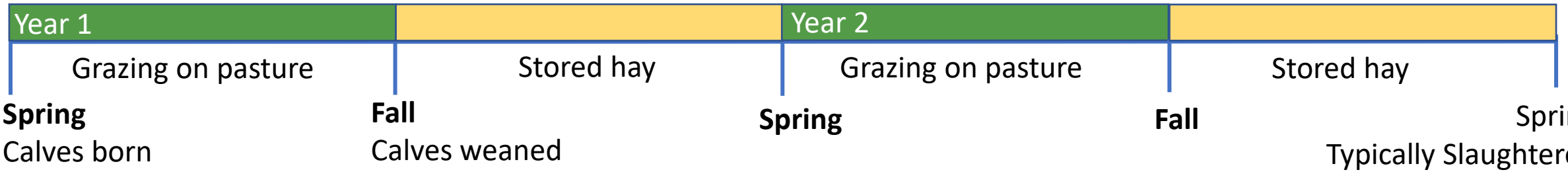
Source: Modified equation from U.S. EPA Preliminary Remediation Goals for Radionuclides
https://epa-prgs.ornl.gov/radionuclides/users_guide.html

Model checking using a small grass-based beef farm

"All models are wrong. Some models are useful" George E. P. Box

Farm Field Use

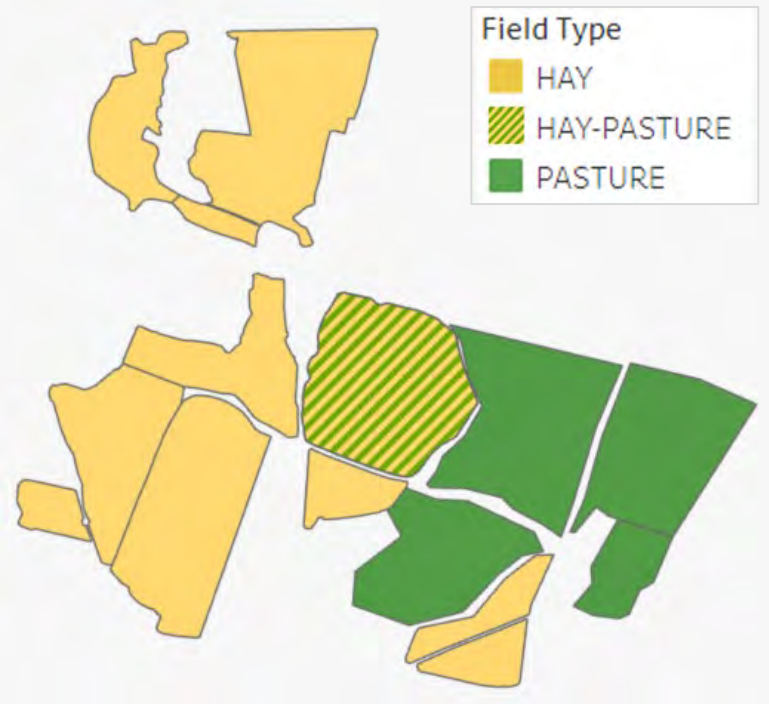




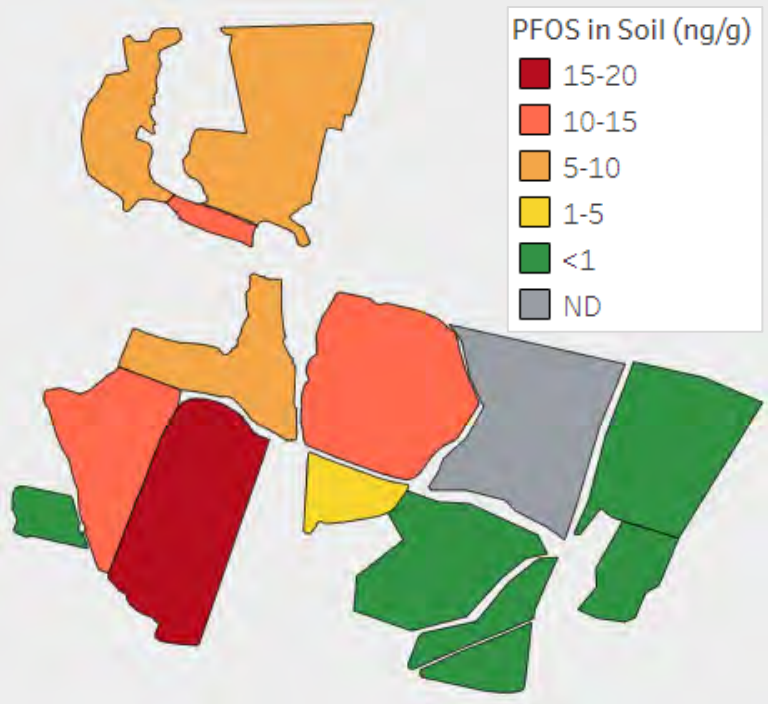
Model checking using a small grass-based beef farm

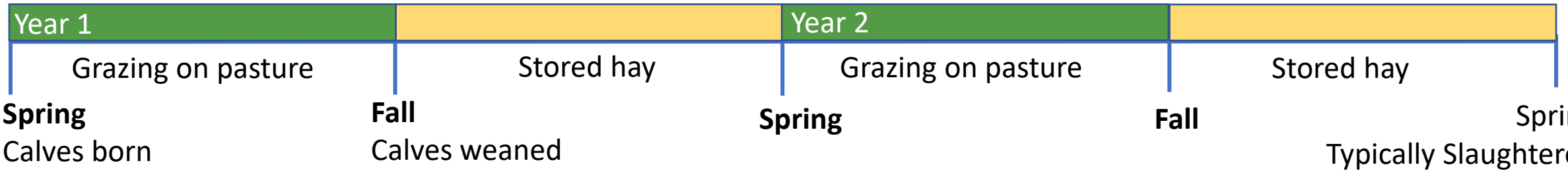
"All models are wrong. Some Models are useful" George E. P. Box

Farm Field Use



Soil PFOS

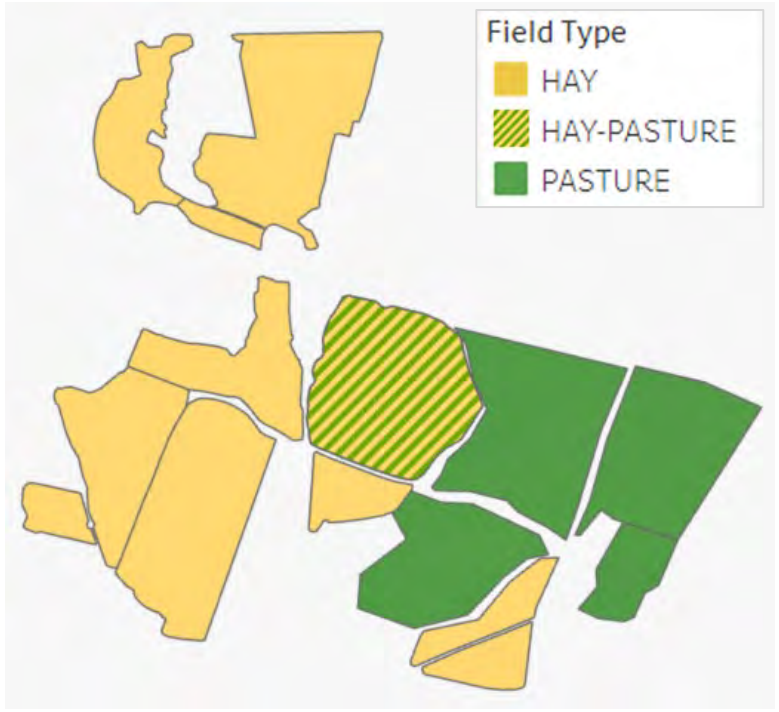




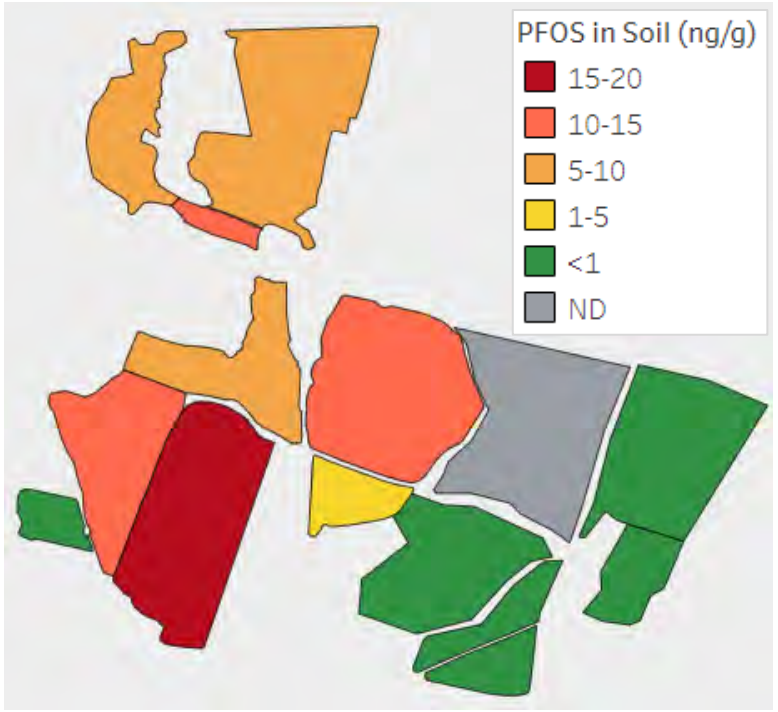
Model checking using a small grass-based beef farm

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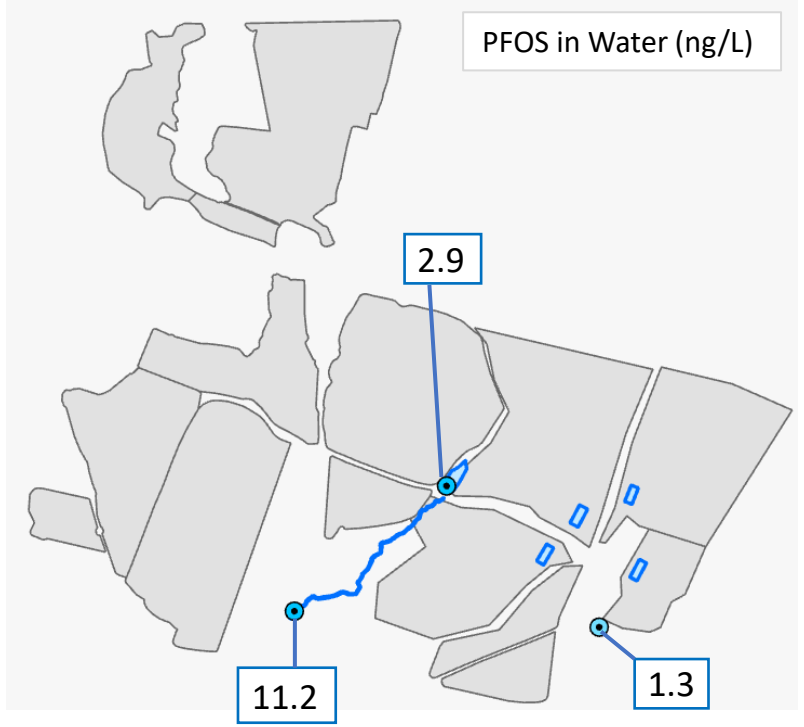
Farm Field Use

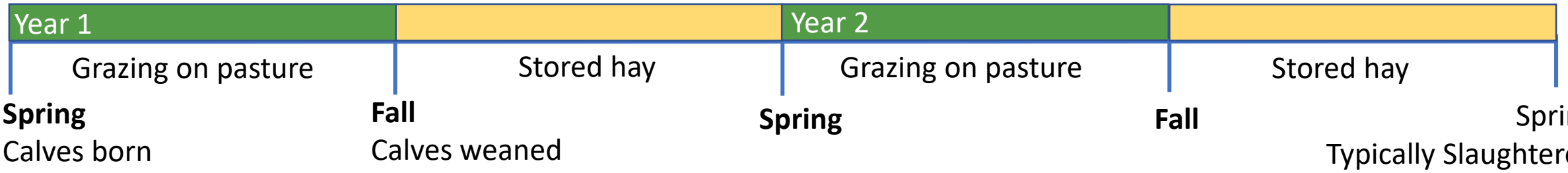


Soil PFOS



Water PFOS





Model Checking





$$C_{beef} = C_{soil} \times \left[TF_{beef} \times \left(I_{feed} \times F_{field-f} \times F_{time-f} \times TF_{plant}\right)\right]$$

$$C_{soil} = \sum_{i=1}^{11} \left(C_{soil-field,i} \times W_{field,i}\right)$$

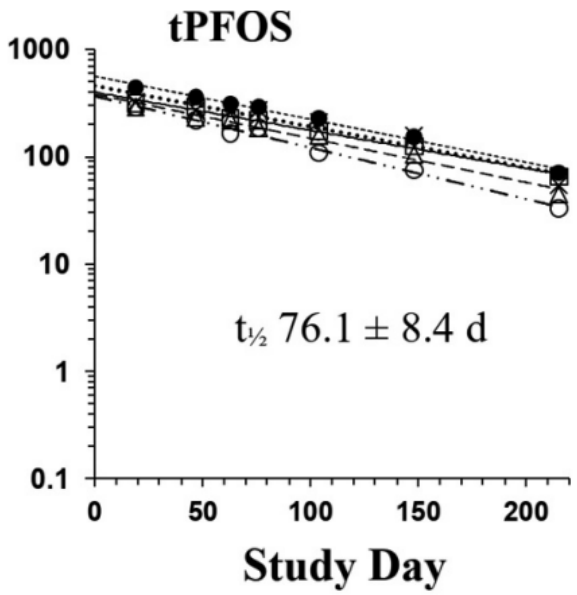
$$\frac{C_{beef}}{C_{serum}} = 0.076$$

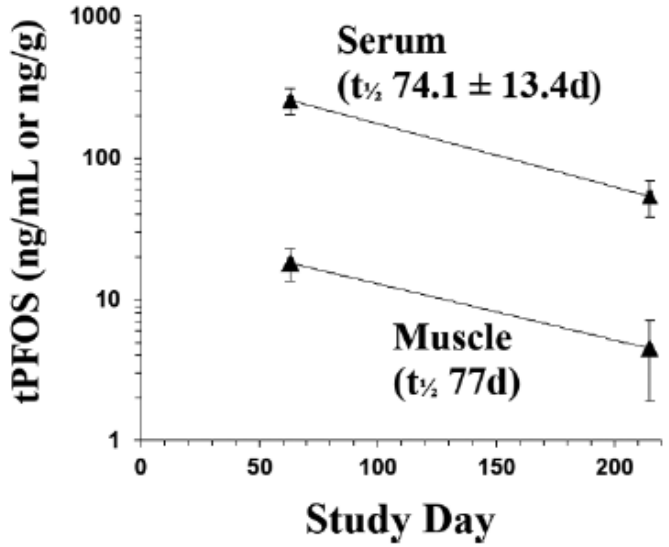
Source: Drew et al. 2021b https://doi.org/10.1080/19440049.2021.1991004

Modeling PFOS Depuration in Beef

$$C_{serum,t} = C_{serum,0} \times exp^{-kt}$$

where $k = \frac{\ln(2)}{t_{1/2}}$ and $t_{1/2} = 74.1$ days





Drew et al. 2021b https://doi.org/10.1080/19440049.2021.1991004

Model Checking Scenarios



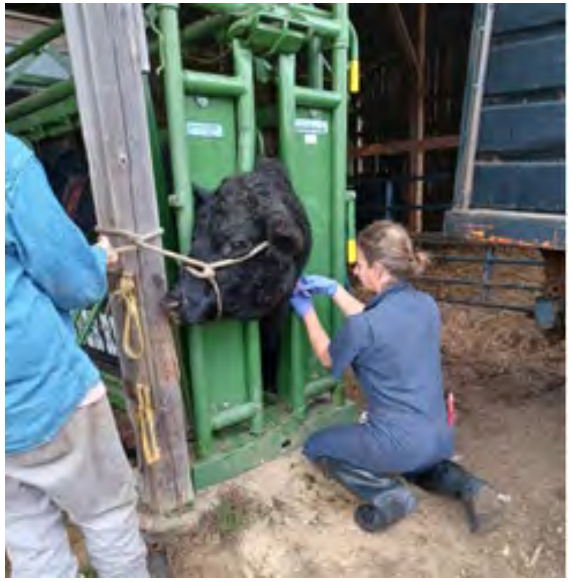
2021 Frozen Beef Samples

1 15-year-old
1 2-year-old



2022 Muscle and Serum Samples

5 2-year-olds



2023 Serum Samples

6 1-year-olds

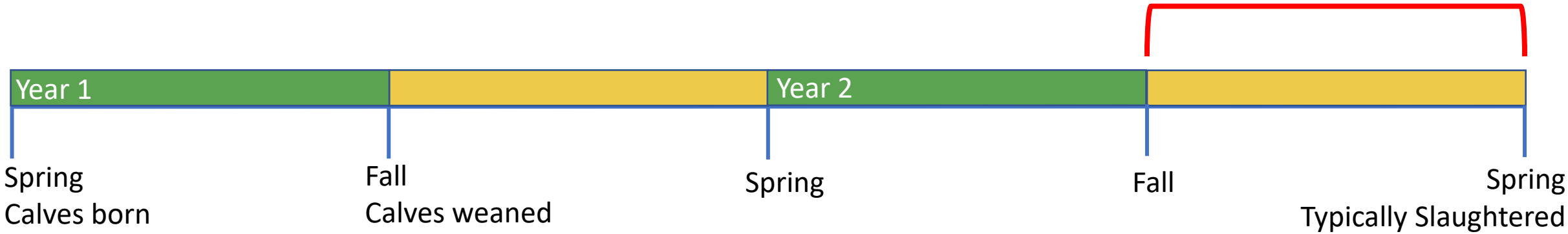
Model Checking

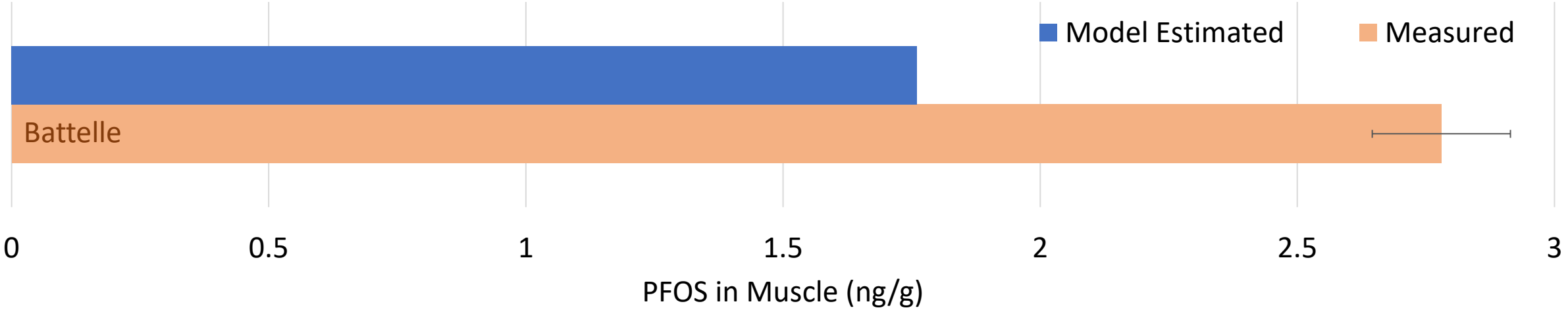
1. 2021 Frozen Beef Samples



2 animals (one 15 y.o., one 2 y.o)

6 months contaminated hay until slaughter

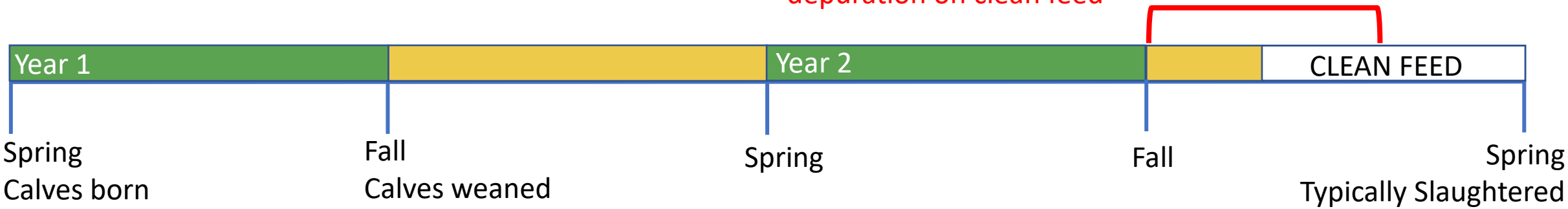


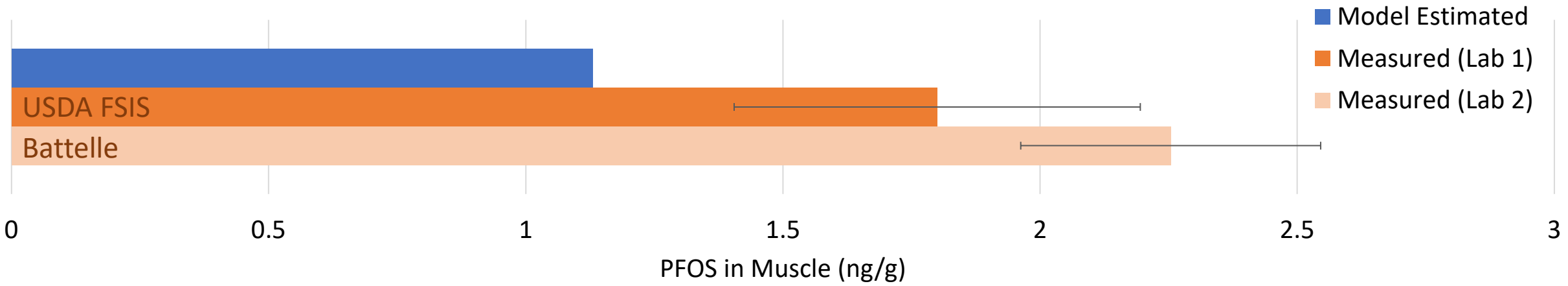


Model Checking
2. 2022 Muscle and Serum Samples



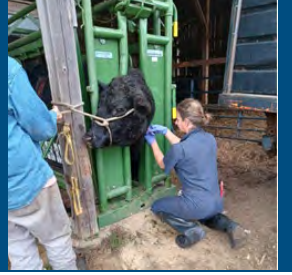
- 5 animals (1.5 to 2 years old)
- 2 months contaminated hay followed by 2 months depuration on clean feed



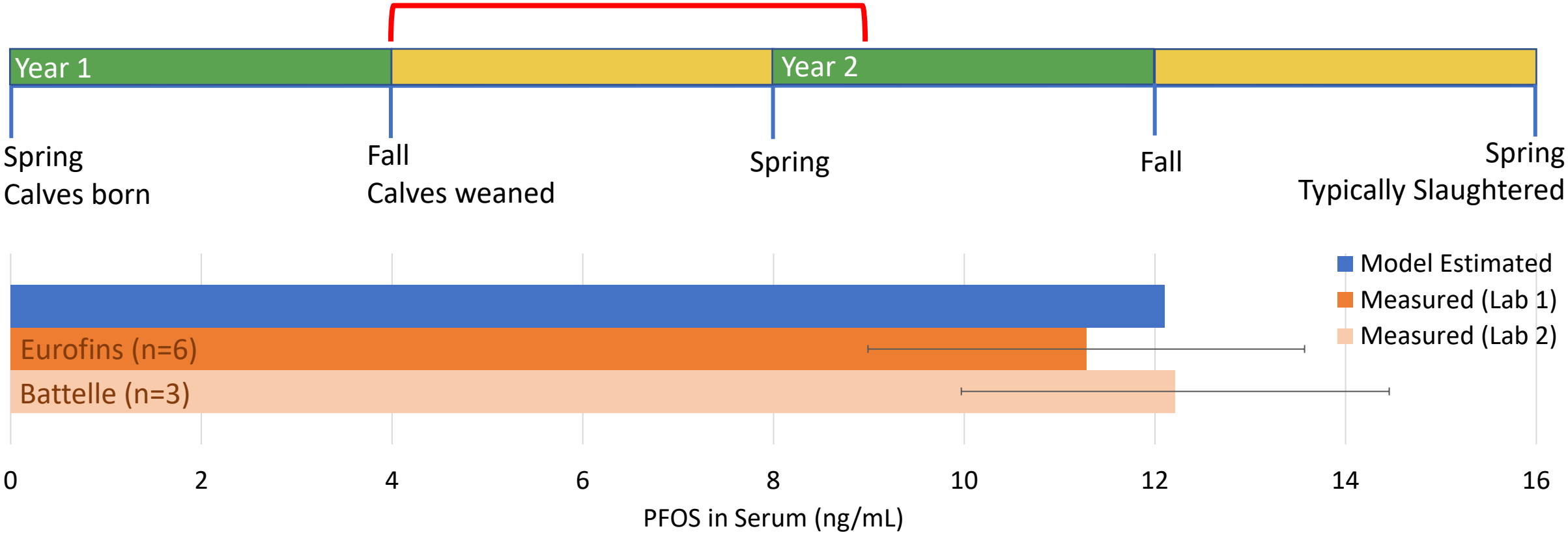


Source:
Drew et al. 2021b https://doi.org/10.1080/19440049.2021.1991004

Model Checking
3. 2023 Serum Samples



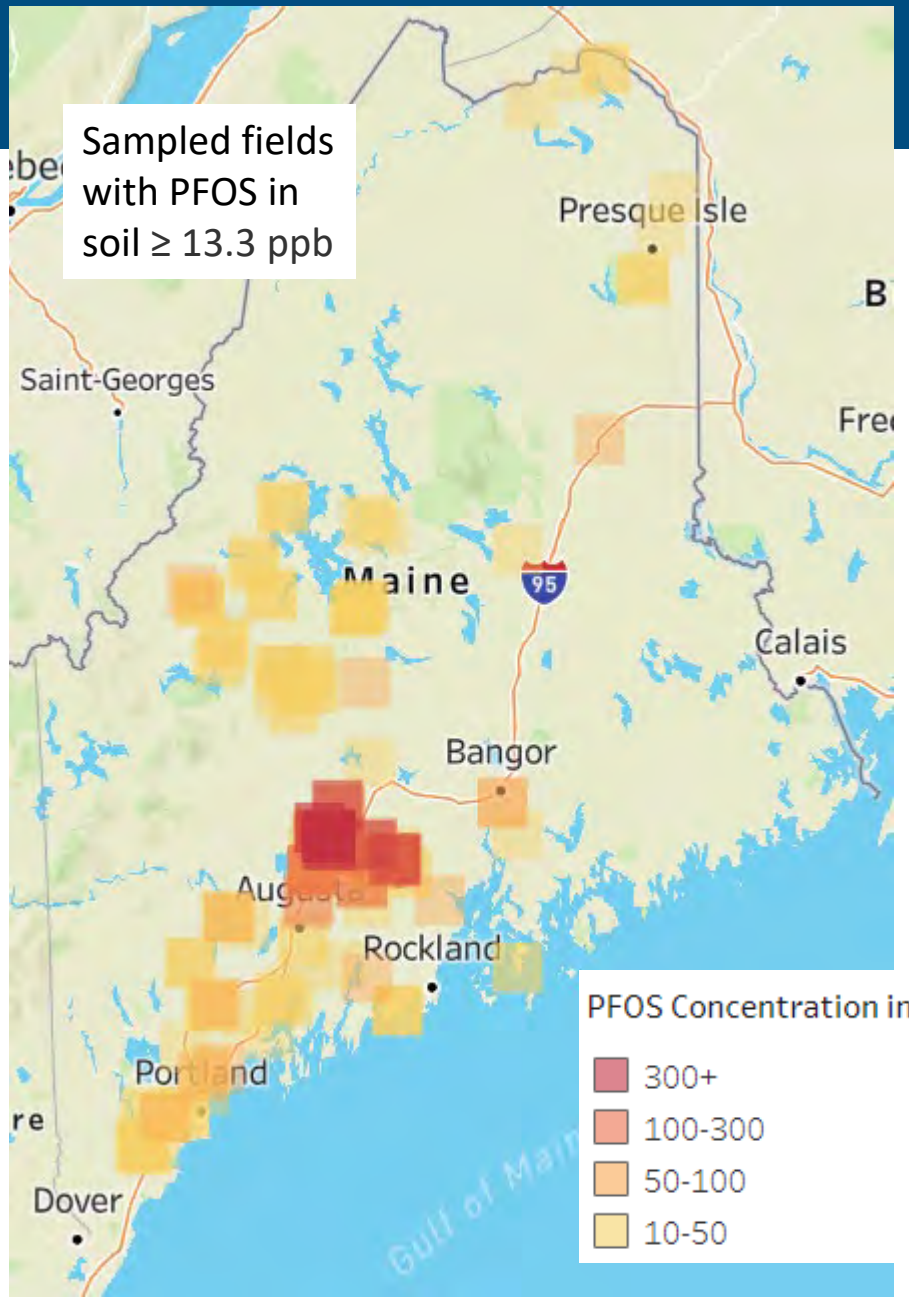
- 6 animals (approx. 1 year old)
- 6 months contaminated hay followed by 49 days on pasture



Source:
Drew et al. 2021b https://doi.org/10.1080/19440049.2021.1991004

Summary

- Static model shows good agreement with measured beef muscle and serum results (< 50%)
- PFOS soil screening level for grass-fed beef cattle ranges from 1.2 to 13.3 ng/g depending on beef action level
- Testing of farm fields in Maine with a history of biosolids application have found approximately 30% with average soil levels above both action levels



Collaborators

Andrew Smith, SM, ScD and Thomas Simones, Ph.D.
Maine Center for Disease Control and Prevention

Antti Mikkonen, Ph.D.
Environmental Protection Authority Victoria

Meghan Flanagan, DVM and others
Department of Agriculture, Conservation, and Forestry

United States Department of Agriculture
Food Safety and Inspection Services (FSIS)

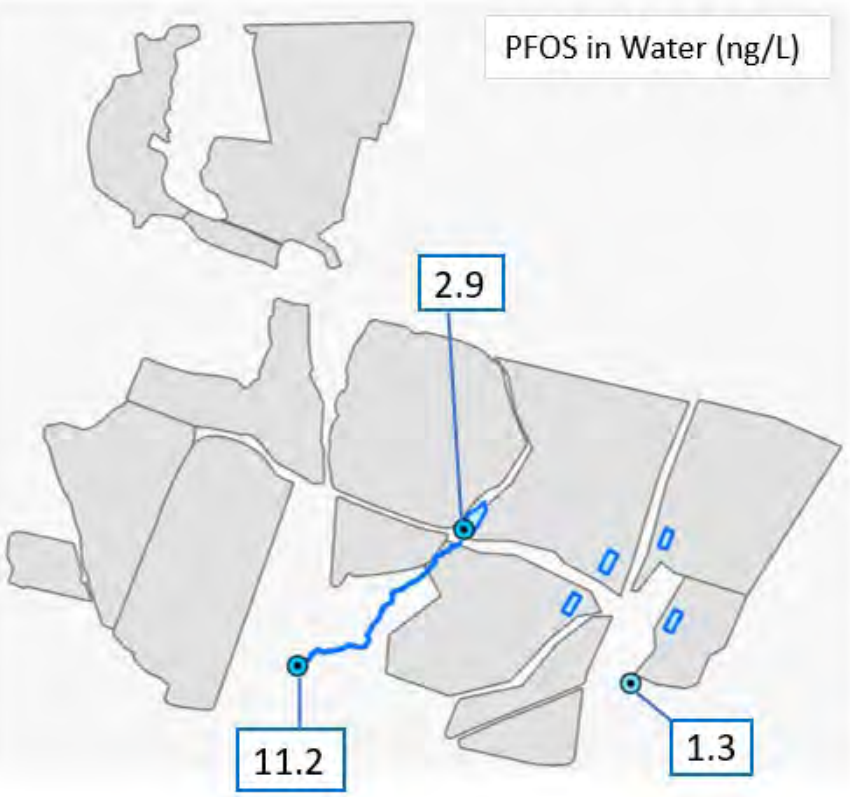
Maine Farms

Questions?

Andrew Smith, SM, ScD
State Toxicologist
Maine Center for Disease Control and Prevention
andy.e.smith@maine.gov

Barbara Astmann, MS
Toxicologist
Maine Center for Disease Control and Prevention
barbara.a.astmann@maine.gov

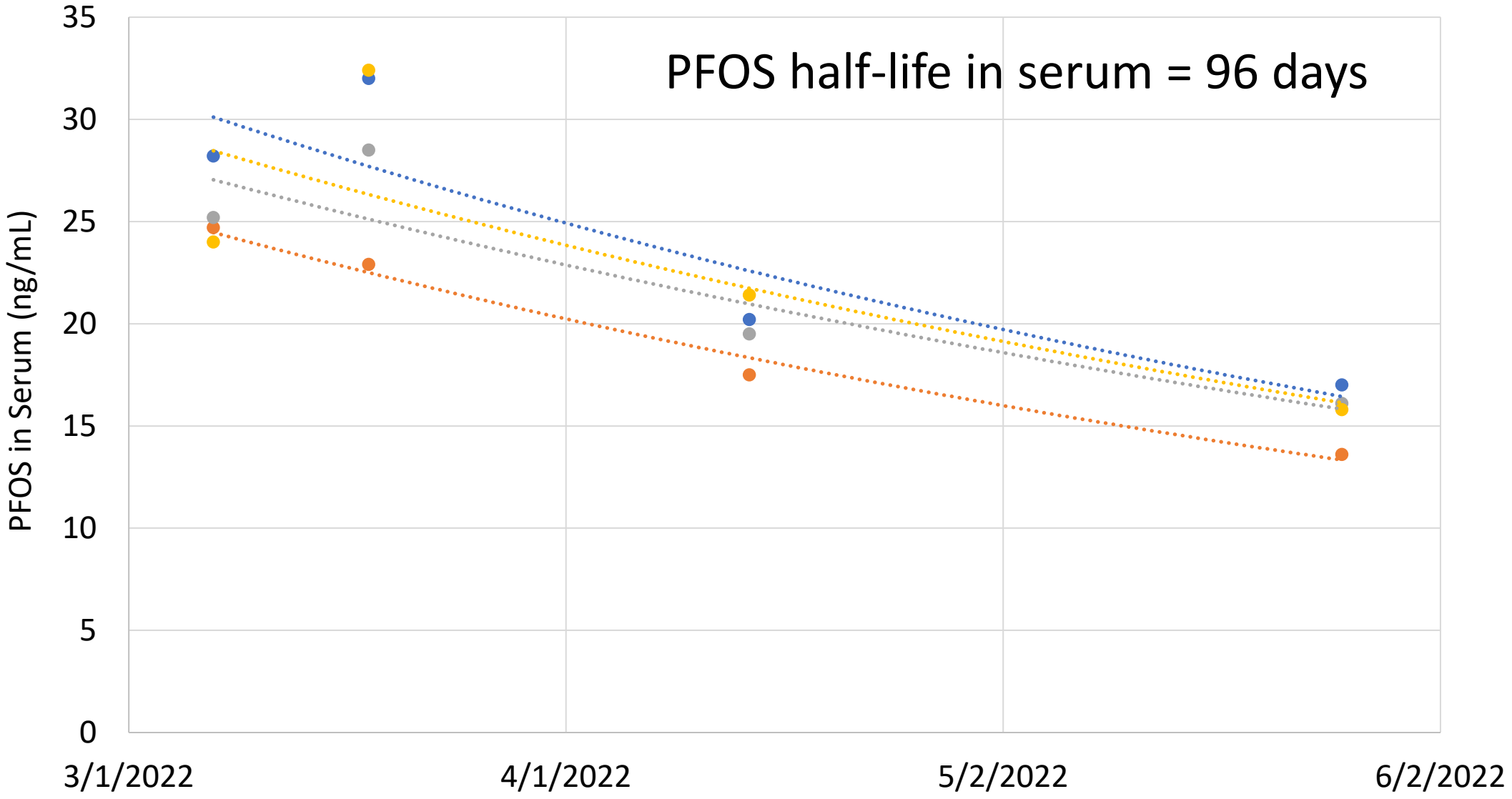
Water to Beef Pathway



$$SL_{water}\left(\frac{ng}{L}\right) = \frac{C_{beef}\left(\frac{ng}{g}\right)}{TF_{beef}\left(\frac{day}{kg}\right) \times I_{water\ beef}\left(\frac{L}{day}\right) \times F_{water} \times CF_{kg-g}}$$

- Untreated farm well water has varied from 1 to 17.5 ppt
- If highest measured untreated well water was sole source of drinking water, at a high-end estimate of water intake (87 L/d):
  - Estimated PFOS in muscle would be 0.3 ng/g (3.6 ng/mL in serum)
  - Only 11-17% of measured PFOS in muscle (15% in serum)

Source: National Research Council Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. https://doi.org/10.17226/9791


PFOS half-life in serum = 96 days
PFOS in Serum (ng/mL)
35
30
25
20
15
10
5
0
3/1/2022
4/1/2022
5/2/2022
6/2/2022