EPA Tools & Resources Training Webinar:

PFAS Removal in Drinking Water Treatment Systems

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Progress for a Stronger Future

Overview

- Background of EPA PFAS (per- and polyfluoroalkyl substances) Treatment Research

- EPA Models
  - Treatability database
  - Performance models
  - Cost models

- Demonstration of Performance Models
  - How to download
  - Example runs

EPA's PFAS Drinking Water Research

Problem: Utilities lack treatment technology cost data for PFAS removal

Actions:

- Gather performance and cost data from available sources (DOD, utilities, industry, etc.)
- Conduct EPA research on performance of treatment technologies including home treatment systems
- Update EPA's Treatability Database, Treatment Models and Unit Cost Models
- Connect EPA's Treatability Database to EPA's Unit Cost Models for ease of operation
- Model performance and cost, and then extrapolate to other scenarios
- Address treatment impact on corrosion
- Evaluate reactivation of granular activated carbon

Impact: *Enable utilities to make informed decisions about cost-effective treatment strategies for removing PFAS from drinking water*

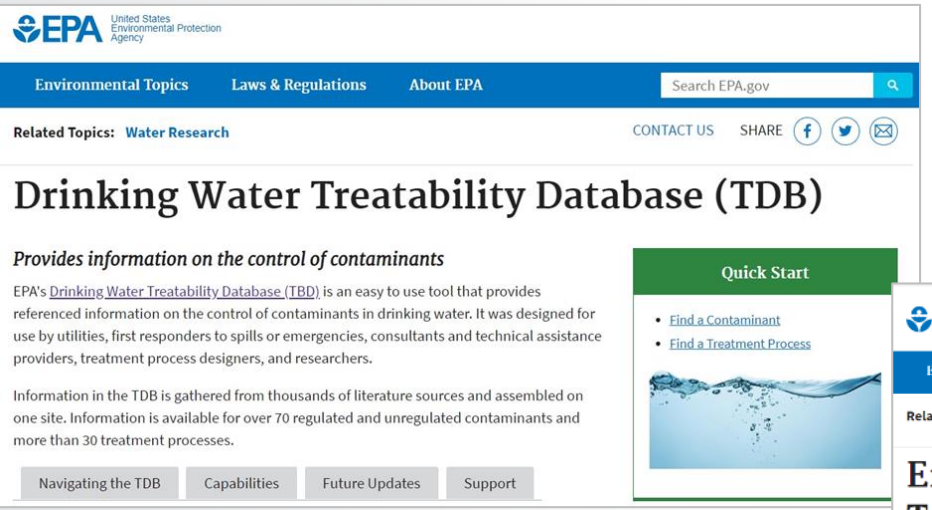
Model Scenarios

- Variable source waters
- Variable PFAS concentrations in source water
- Alternate treatment goals
- Changing production rates
- Different reactivation/disposal options
- Document secondary benefits

Suite of Tools

To provide tools to accurately predict the performance and cost of treating PFAS in drinking waters

Treatability Database



Performance Models

Cost Models

Treatment Information

Publicly Available Drinking Water Treatability Database

Recently updated!

Interactive literature review database that contains 123 regulated and unregulated contaminants and covers 35 treatment processes commonly employed or known to be effective (thousands of sources assembled on one site)

Contains treatment information to be used in performance or cost models

Currently available:

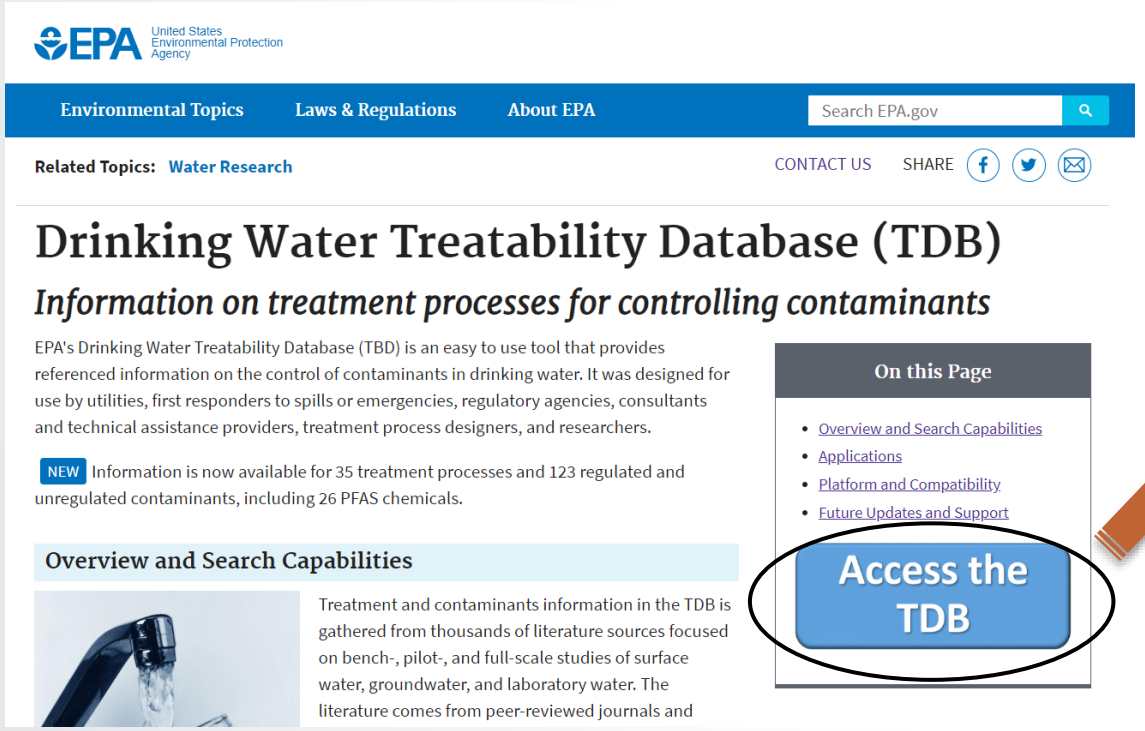
PFOA, PFOS, PFTriA, PFDoA, PFUnA, PFDA, PFNA, PFHpA, PFHxA, PFPeA, PFBA, PFDS, PFHpS, PFHxS, PFBA, PFBS, PFOSA, FtS 8:2, FtS 6:2, N-EtFOSAA, N-MeFOSAA and GenX

epa.gov/water-research/drinking-water-treatability-database-tdb

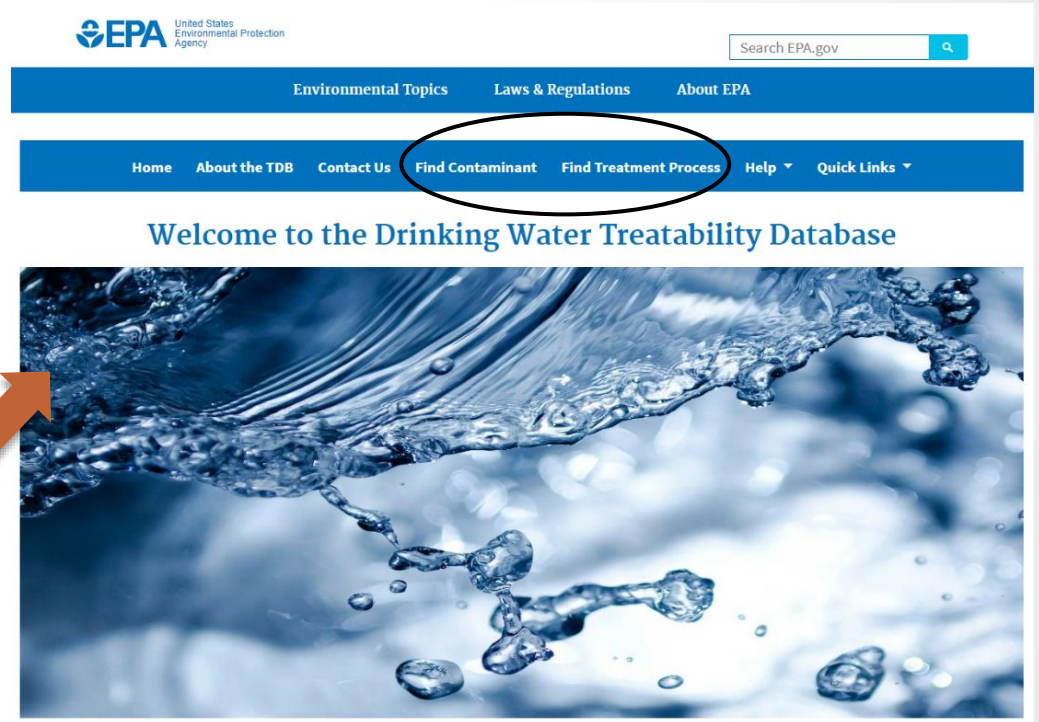
Search: EPA TDB

Treatability Database

Agency Landing Page



Database Homepage



epa.gov/water-research/drinking-water-treatability-database-tdb

Search: EPA TDB

PFAS Treatment

Per- and Polyfluoroalkyl Substances

Informational Links

Contaminant Navigation

Overview | Treatment Processes | Properties | Fate and Transport | References

Overview

CAS Number:

Synonyms:
Heptafluoropropyl 1,2,2,2-tetrafluoroethyl ether (E1),2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate (FRD-902),2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid (FRD-903),Ammonium perfluoro-2-methyl-3-oxahexanoate (GenX),Heptadecafluorononanoic acid,Heptafluorobutyric acid,Nonadecafluorocapric acid,Nonadecafluorodecanoic acid,Pefluorobutane sulfonate,Perfluorobutyric acid,Perfluorocapric acid,Perfluorohexanesulfonic acid potassium salt,Potassium tridecafluoro-1-hexanesulfonate,Tridecafluorohexane-1-sulfonic acid potassium salt

Contaminant Type: Chemical

Description:
Per- and polyfluoroalkyl substances (PFASs) are fluorinated aliphatic substances with unique properties, such as being both hydrophobic, lipophobic, and extremely stable due to the strength of the C-F bond [2539]. Their properties have led to their extensive use as surface active agents in products like stain repellants and fire-fighting foams [2527, 2539]. The two most frequently studied PFASs, perfluorooctane sulphonate (PFOS) and perfluorooctanoic acid (PFOA), have their own, separate entries in this treatability database. Both PFOS and PFOA are compounds with eight carbon atoms. This group entry covers

Per- and Polyfluoroalkyl Substances

Informational Links

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Treatment Processes

The following processes were found to be effective for the removal of PFASs: granular activated carbon (GAC) (up to > 98 percent), membrane separation (up to > 99 percent), and ion exchange (up to > 99 percent). These results cover the removal of specific PFASs including PFTriA, PFDoA, PFUnA, PFDA, PFNA, PFHpA, PFHxA, PFPeA, PFPeS, PFDS, PFHpS, PFHxS, PFBA, PFBS, PFPrS, PFOSA, PFMOAA, PFO3OA, PFO2HxA, FtS 8:2, FtS 6:2, N-EtFOSAA, N-MeFOSAA, and GenX. For results on the removal of PFOS and PFOA, see the separate treatability database entries for those specific contaminants.

Studies were identified evaluating the following treatment technologies for the removal of PFASs:

Adsorptive Media
A bench-scale study conducted batch tests of adsorption using magnetic nanoparticles with different polymer coatings. In ultrapure water, the best performing of these achieved high removals of long chain and sulfonated PFASs (e.g., >90 percent ...

See more

Aeration and Air Stripping
At a full-scale site, packed tower aeration was not effective for removing PFASs [2441].

PFAS Treatment: Activated Carbon

Matrix of conditions and results from treatment references that can be downloaded into a spreadsheet

Ref #	Author	Year	Log or Percent Removal	Removal Type	Contaminant Influent	Contaminant Effluent	Contaminant Units	Contaminant	Scale	Design Flow	Water	Location Studied	GAC Type	Manufacturer	Product Name
2441	Dickenson,	2016	-10.5 to 13.7#	Percent	4.4 to 5.1#	5.7 to 6.3#	ng/L	PFHpA	F	5	SW	New Jersey	B	Calgon	F300
2441	Dickenson,	2016	-11 to 5#	Percent	3.6 to 5.8#	4.0 to 5.5#	ng/L	PFHxS	F	5	SW	New Jersey	B	Calgon	F300
2441	Dickenson,	2016	-13 to 6#	Percent	1.8 to 2.4#	1.7 to 2.7#	ng/L	PFNA	F	5	SW	New Jersey	B	Calgon	F300
2441	Dickenson,	2016	-19 to 10#	Percent	6.8 to 7.3#	6.1 to 8.7#	ng/L	PFHxA	F	5	SW	New Jersey	B	Calgon	F300
2441	Dickenson,	2016	-26#	Percent	<5.0#	6.3#	ng/L	PFBA	F	5	SW	New Jersey	B	Calgon	F300
2441	Dickenson,	2016	-34 to 8#	Percent	0.59 to 0.97#	0.54 to 1.3#	ng/L	PFDA	F	5	SW	New Jersey	B	Calgon	F300
2441	Dickenson,	2016	-66 to 70#	Percent	1.23 to 1.81#	0.537 to 2.48#	ng/L	PFBA	F	0.5472 to	GW	Minnesota	B	Calgon	F600
2441	Dickenson,	2016	0 to 19#	Percent	<0.05 to 0.085	<0.05 to 0.069#	ng/L	PFPeA	F	0.5472 to	GW	Minnesota	B	Calgon	F600
2441	Dickenson,	2016	0 to 76#	Percent	<0.05 to 0.210	<0.05#	ng/L	PFHxS	F	0.5472 to	GW	Minnesota	B	Calgon	F600
2441	Dickenson,	2016	33#	Percent	15#	10#	ng/L	PFBA	F	5#	SW	Colorado	B	Norit	GAC 300
2441	Dickenson,	2016	46 to 60#	Percent	0.127 to 0.192	<0.05 to 0.1023	ng/L	PFHxA	F	0.5472 to	GW	Minnesota	B	Calgon	F600
2441	Dickenson,	2016	5 to 6#	Percent	2.1 to 3.6#	2.0 to 3.4#	ng/L	PFBS	F	5	SW	New Jersey	B	Calgon	F300
2441	Dickenson,	2016	7.2 to 12.7#	Percent	4.8 to 5.5#	6.4 to 6.9#	ng/L	PFPeA	F	5	SW	New Jersey	B	Calgon	F300
2441	Dickenson,	2016	74#	Percent	17#	4.4#	ng/L	PFPeA	F	5#	SW	Colorado	B	Norit	GAC 300
2441	Dickenson,	2016	91#	Percent	11#	0.97#	ng/L	PFNA	F	5#	SW	Colorado	B	Norit	GAC 300
2441	Dickenson,	2016	>89#	Percent	4.5#	<0.50#	ng/L	PFHpA	F	5#	SW	Colorado	B	Norit	GAC 300
2441	Dickenson,	2016	>96#	Percent	5.8#	<0.25#	ng/L	PFHxS	F	5#	SW	Colorado	B	Norit	GAC 300
2441	Dickenson,	2016	>96#	Percent	6.4#	<0.25#	ng/L	PFBS	F	5#	SW	Colorado	B	Norit	GAC 300
2505	Cummings,	2015	>72 to >93#	Percent	18 to 72	<5	ng/L	PFNA	F		SW	Logan System Birch	B	Calgon	F-400

Drinking Water Treatment for PFOS

Ineffective Treatments

Conventional Treatment
Low Pressure Membranes
Biological Treatment (including slow sand filtration)
Disinfection
Oxidation
Advanced oxidation

PAC Dose to Achieve	
50% Removal	16 mg/l
90% Removal	>50 mg/L

Dudley et al., 2015

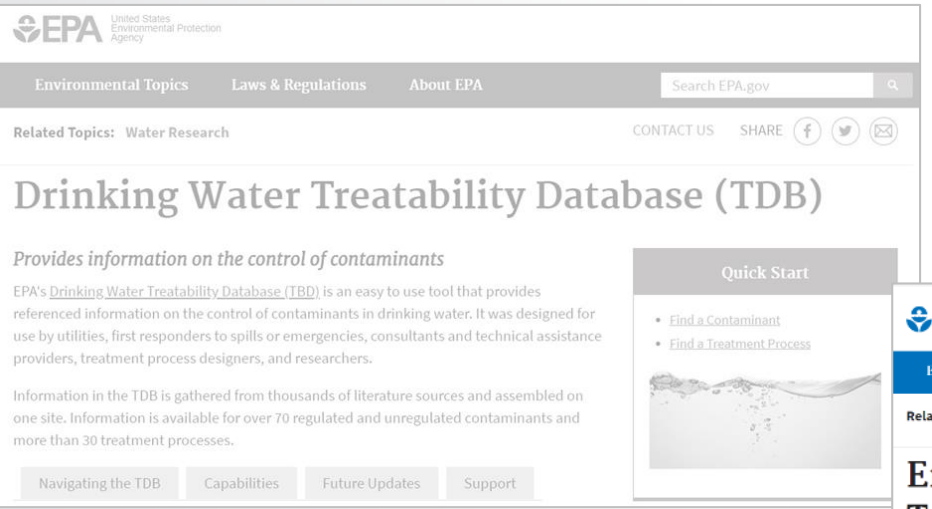
Effective Treatments

	Percent Removal	
Anion Exchange Resin (IEX)	90 to 99	- Effective
High Pressure Membranes	93 to 99	- Effective
Powdered Activated Carbon (PAC)	10 to 97	- Effective for only select applications
Granular Activated Carbon (GAC)		
Extended Run Time	0 to 26	- Ineffective
Designed for PFAS Removal	> 89 to > 98	- Effective

Suite of Tools

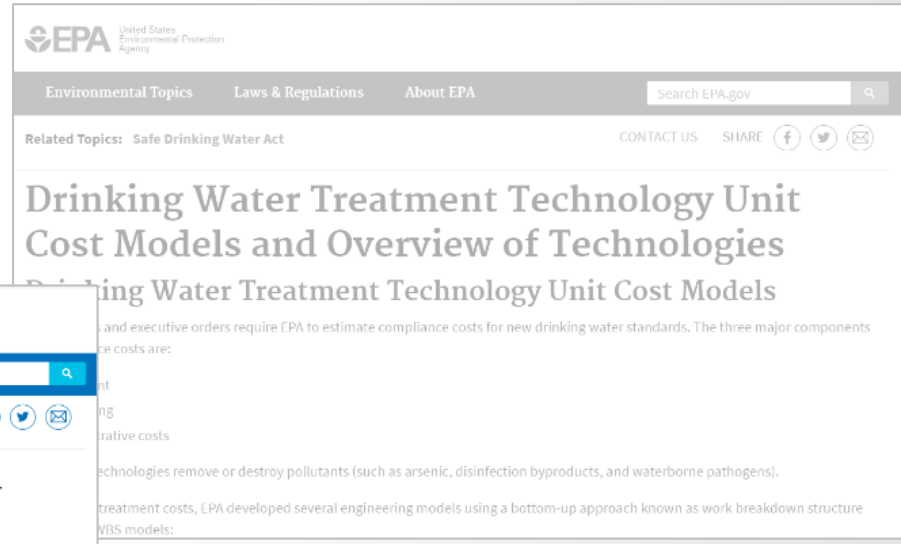
To provide tools to accurately predict the performance and cost of treating PFAS in drinking waters

Treatability Database



Performance Models

Cost Models



Available Modeling Tools

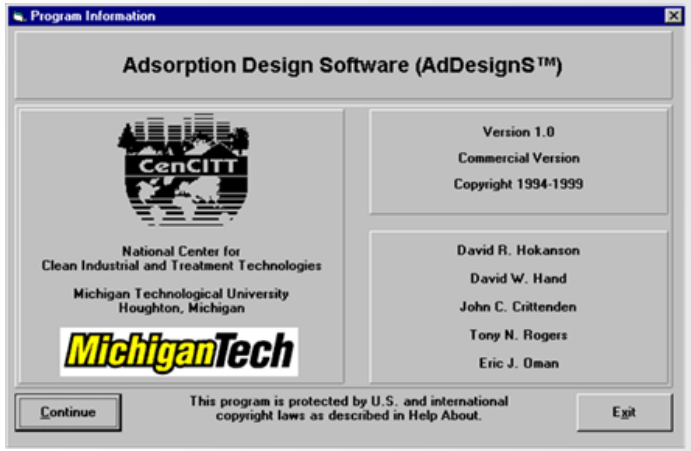
https://www.epa.gov/water-research/environmental-technologies-design-option-tool-etdot

Search: EPA ETDOT

Available Modeling Tools

Models available at the GitHub site:

- Adsorption Design Software for Windows (AdDesignS) *Version 1.0*
- Advanced Oxidation Process Software (AdOx) *Version 1.0.2*
- Aeration System Analysis Program (ASAP) *Version 1.0*
- Biofilter Design Software *Version 1.0.27*
- Continuous Flow Pore Surface Diffusion Model for Modeling Powdered Activated Carbon Adsorption *Version 1.0*
- Dye Study Program (DyeStudy) *Version 1.0.0*
- Predictive Software for the Fate of Volatile Organics in Municipal Wastewater Treatment Plants (FaVOr) *Version 1.0.11*
- Ion Exchange Design Software (IonExDesign) *Version 1.0.0*
- Software to Estimate Physical Properties (StEPP) *Version 1.0*



The engines are written in FORTRAN with a Visual Basic front end

epa.gov/water-research/environmental-technologies-design-option-tool-etdot

Expected Interest/Users

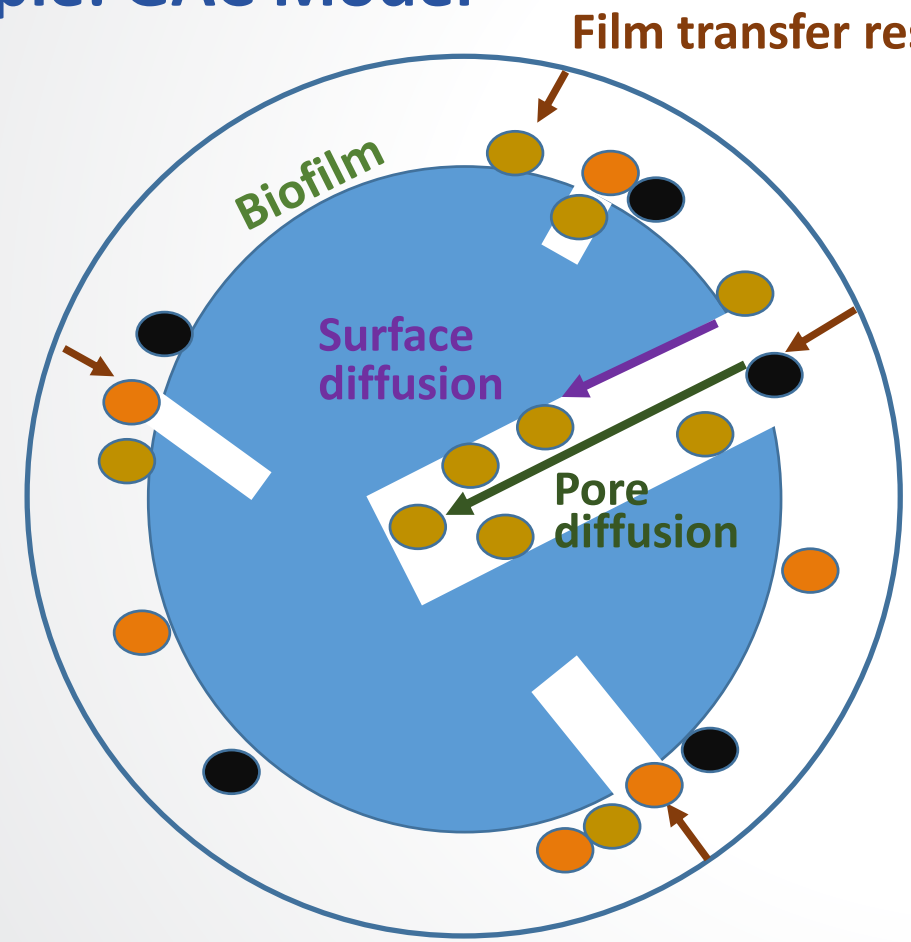
ETDOT Modeling Tool

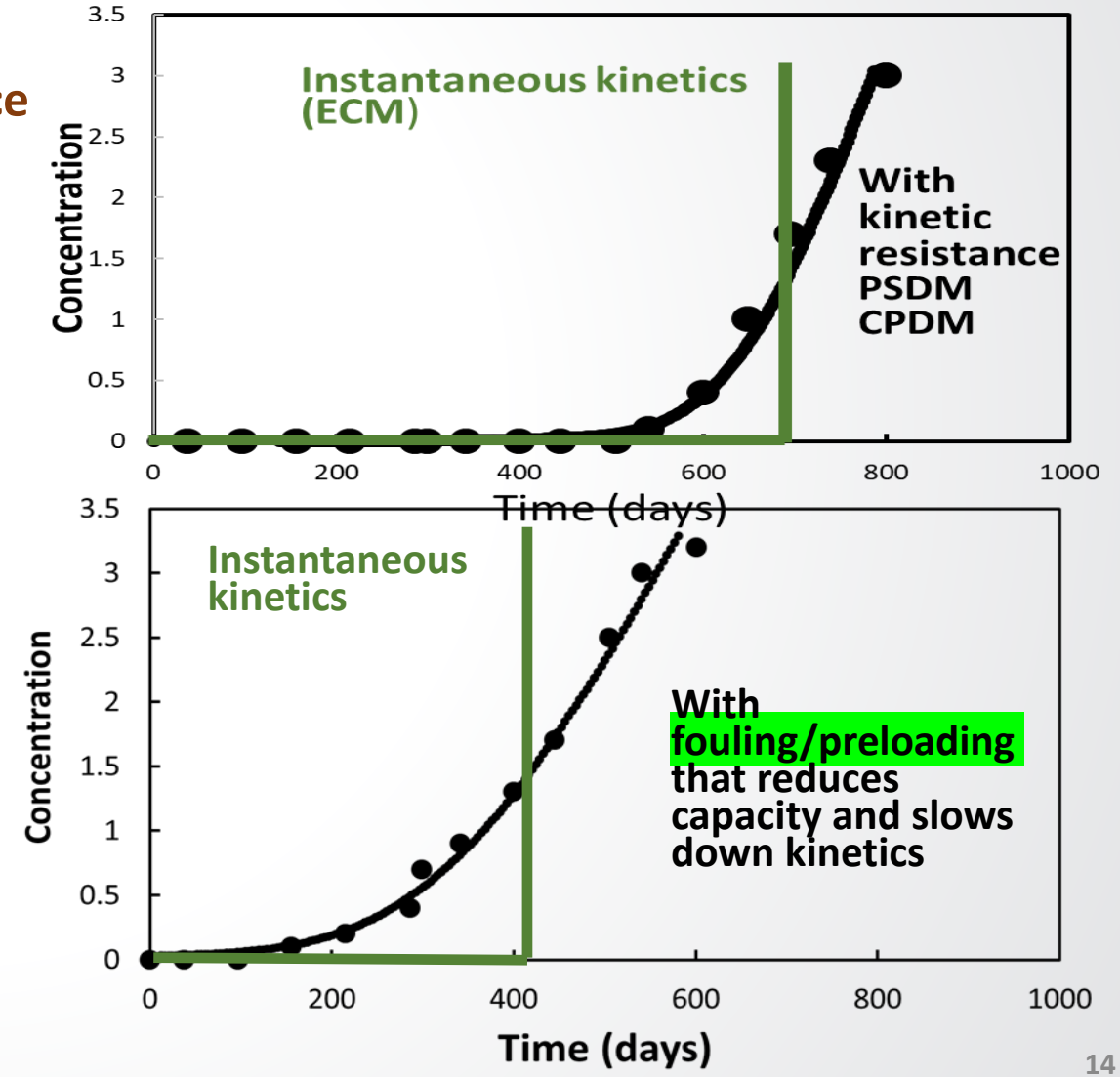
It is expected that these established and new models will be useful to the following:

- State primacy personnel interested in evaluating data sets
- Water utilities with experience in running models
- Consulting engineers
- University academicians

Incorporation of Complex Mechanisms

Example: GAC Model





The models range from simple to complex

EPA's Drinking Water Cost Models

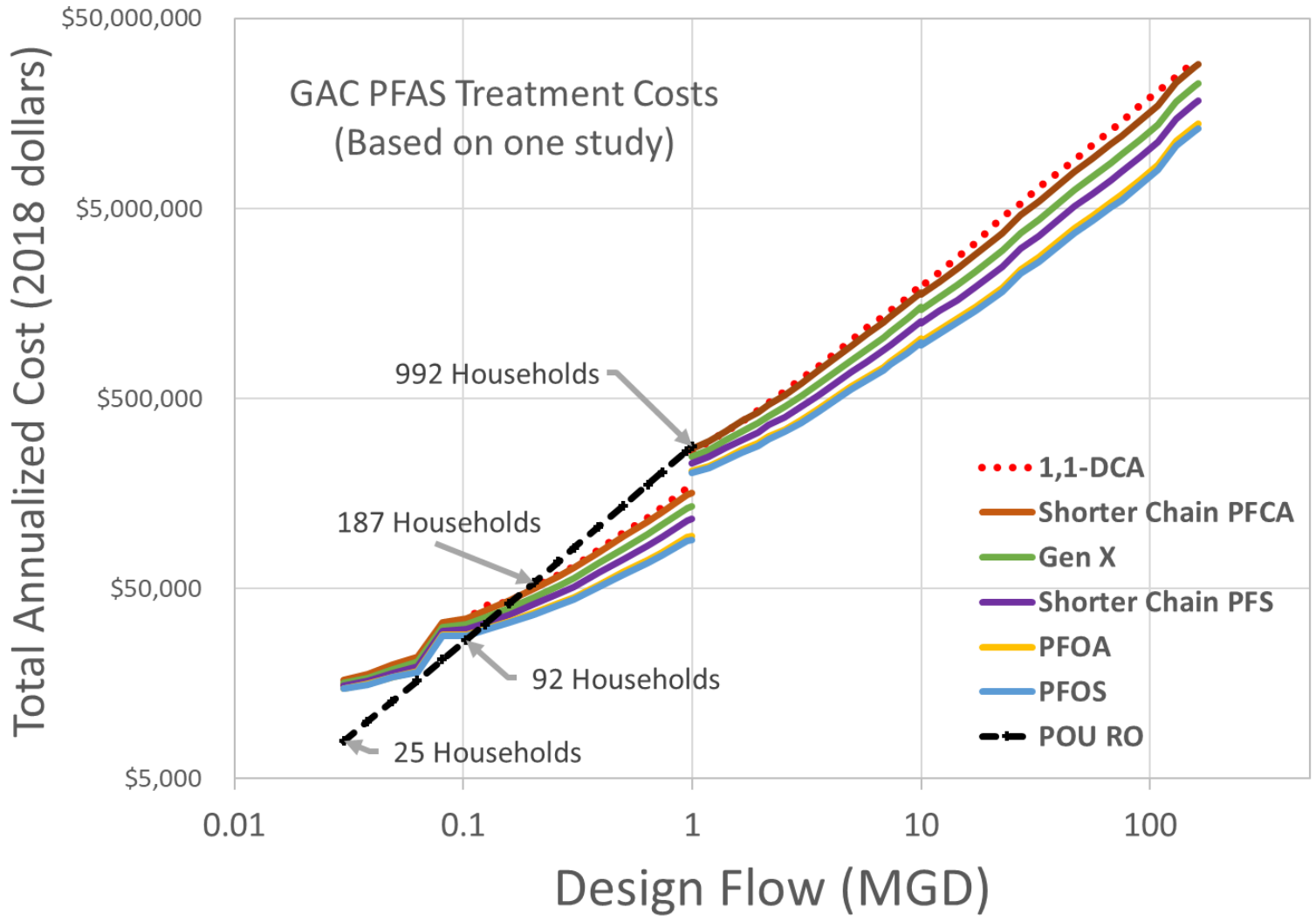
- Adsorptive media
- Anion exchange
- Biological treatment
- Cation exchange
- GAC
- Greensand filtration
- Microfiltration / ultrafiltration
- Multi-stage bubble aeration

- Non-treatment
- Packed tower aeration
- Point of Use (POU)/
- Point of Entry (POE)*
- Reverse Osmosis / Nanofiltration
- UV disinfection
- UV Advanced Oxidation

epa.gov/dwregdev/drinking-water-treatment-technology-unit-cost-models-and-overview-technologies
Search: EPA WBS

*POU/POE temporarily taken off web. Please contact Rajiv Khera

Costs for PFAS Treatment: One GAC Example

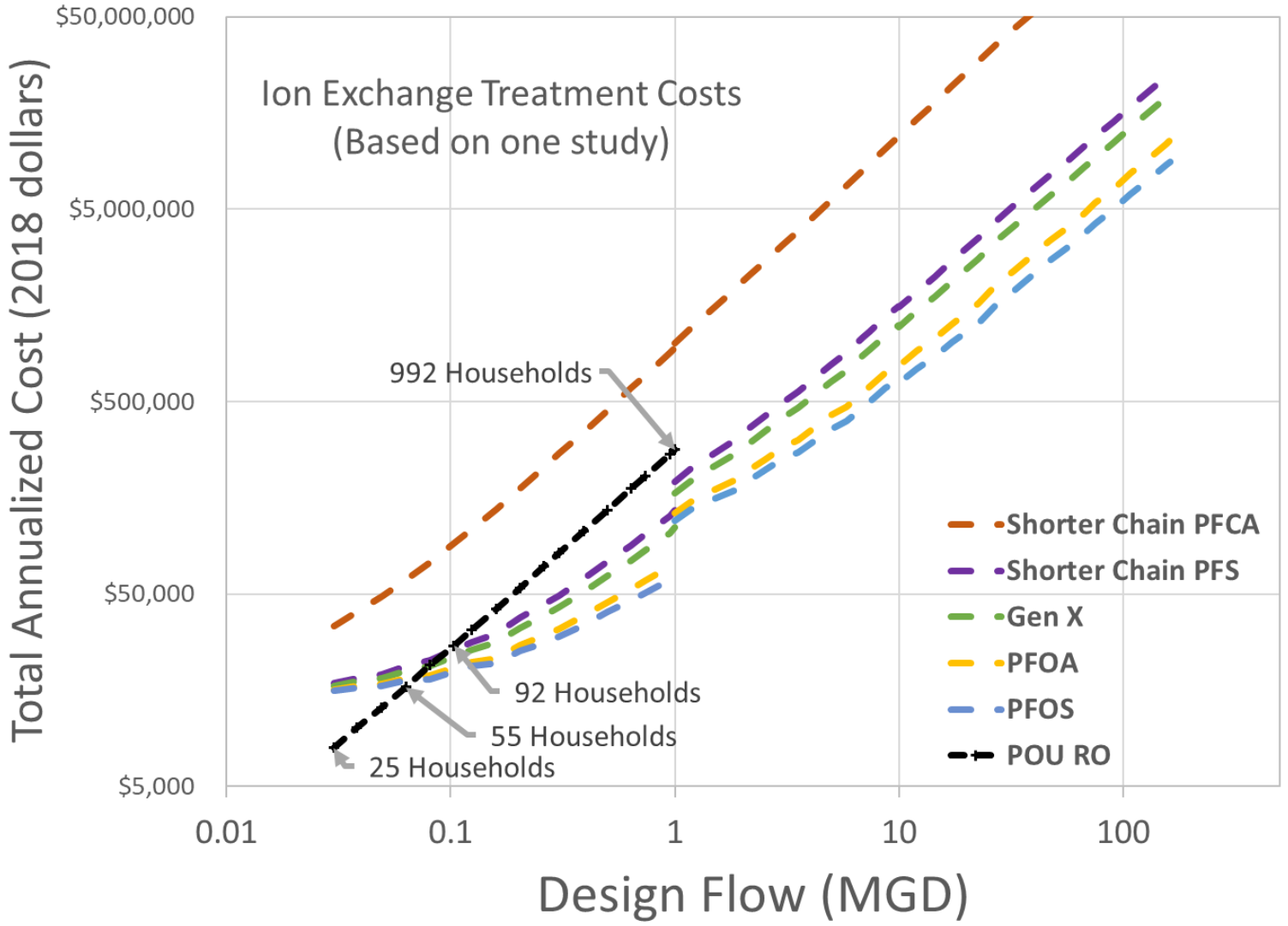


Costs can be generated for various sizes, contaminants, and even POU scenarios

Primary Assumptions:

- Two vessels in series
- 20 min Empty Bed Contact Time (EBCT) Total
- Bed Volumes Fed
  - 1,1-DCA = 5,560 (7.5 min EBCT)
  - Shorter Chain PFCA = 4,700
  - Gen-X = 7,100
  - Shorter Chain PFS = 11,400
  - PFOA = 31,000
  - PFOS = 45,000
- 7% Discount rate
- Mid Level Cost

Costs for PFAS Treatment: One IEX Example



Costs can be generated for various sizes, contaminants, and even POU scenarios

Primary Assumptions:

- Two vessels in series
- 3 min EBCT Total
- Bed Volumes Fed:
  - Shorter Chain PFCA = 3,300
  - Gen-X = 47,600
  - Shorter Chain PFS = 34,125
  - PFOA = 112,500
  - PFOS = 191,100
- 7% Discount rate
- Mid Level Cost

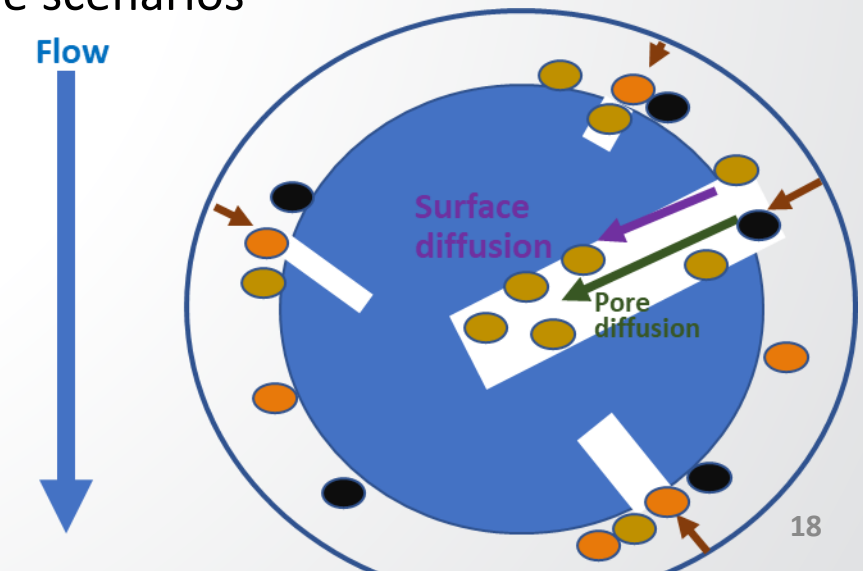
Future Plans

Treatability Database

- Further update treatability database with new references

Performance Models

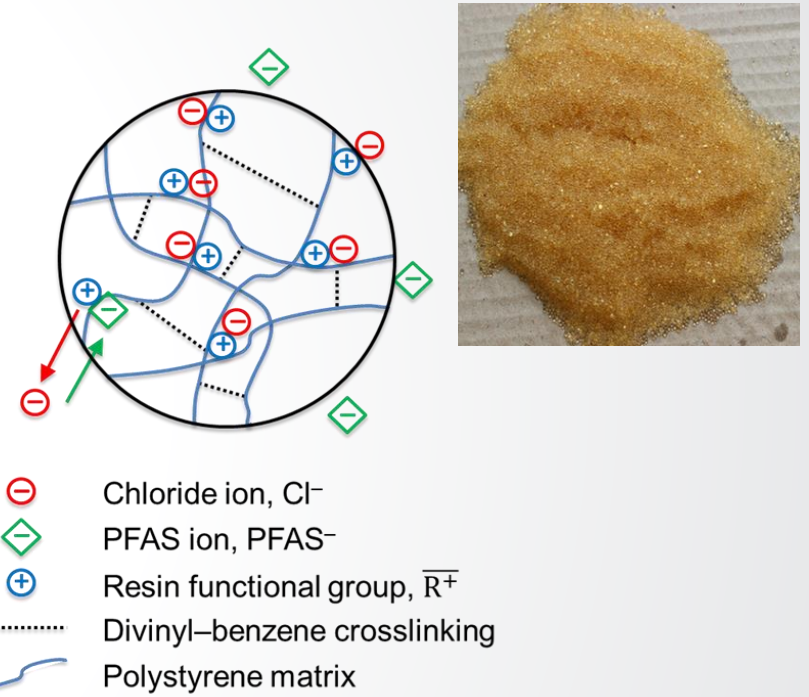
- Update Graphical User Interface to work with Windows 10
- Provide Python code for pore surface diffusion model (PSDM GAC) to automate the optimization routines for:
  - Specific throughput and carbon use rate calculations for multiple scenarios
  - Automated fitting of parameters
  - Automated optimal bed configuration
  - Automated optimal Empty Bed Contact Time (EBCT) selection
  - Automated evaluation of bed replacement frequency
  - Evaluation of multiple feed conditions
  - Evaluation of multiple flow conditions
  - Automated fitting and predicting lead/lag operations



Future Plans

Performance Models *(continued)*

- Provide code for ion exchange models for
  - Include competition (e.g., inorganic ions and PFAS)
  - Continuous flow (columns) and batch (isotherm and kinetics)
  - Gel (HSDM) and macro porous (PSDM) resins
  - with automation features



Cost Models

- Further updates to the cost models

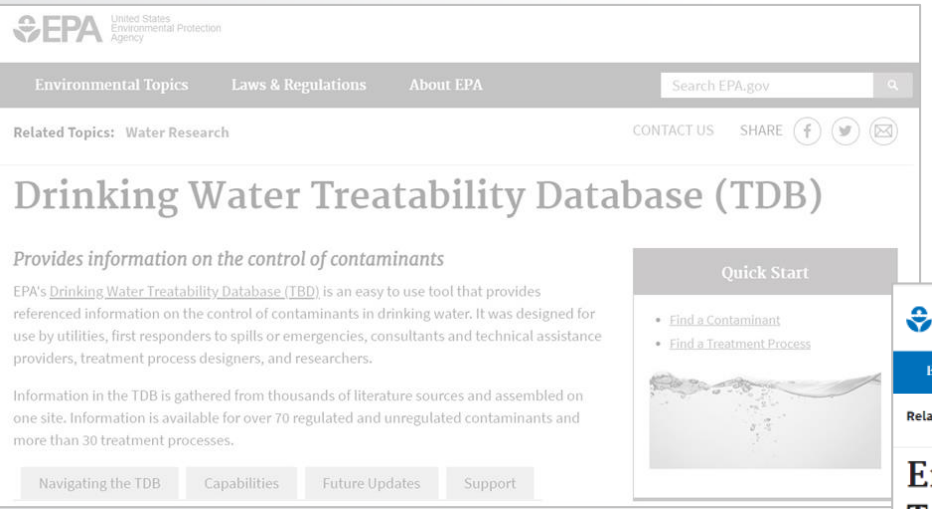
Combined Models

- Further merge Treatability Database, performance models, and cost models
- Further merge the Treatability Database with EPA's CompTox Chemicals Dashboard

Performance Model Demonstration

To provide tools to accurately predict the performance and cost of treating PFAS in drinking waters

Treatability Database



Performance Models

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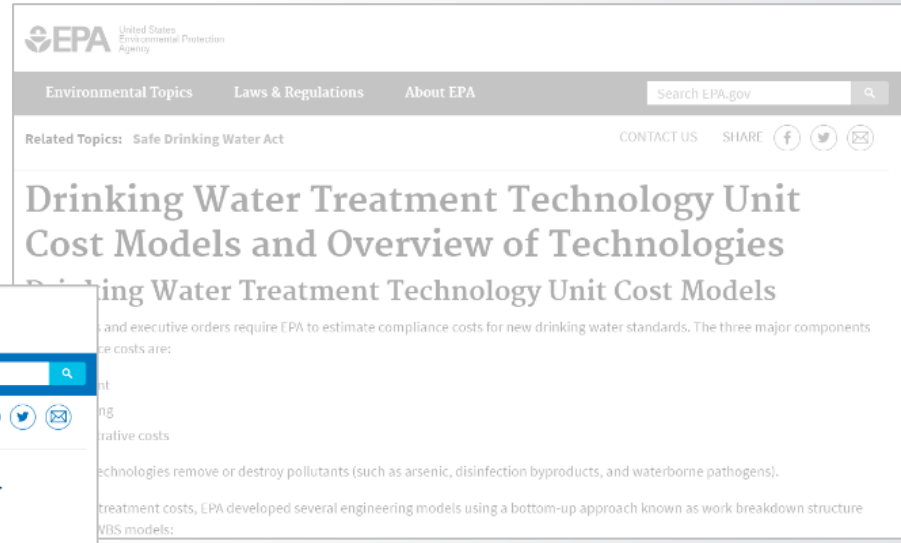
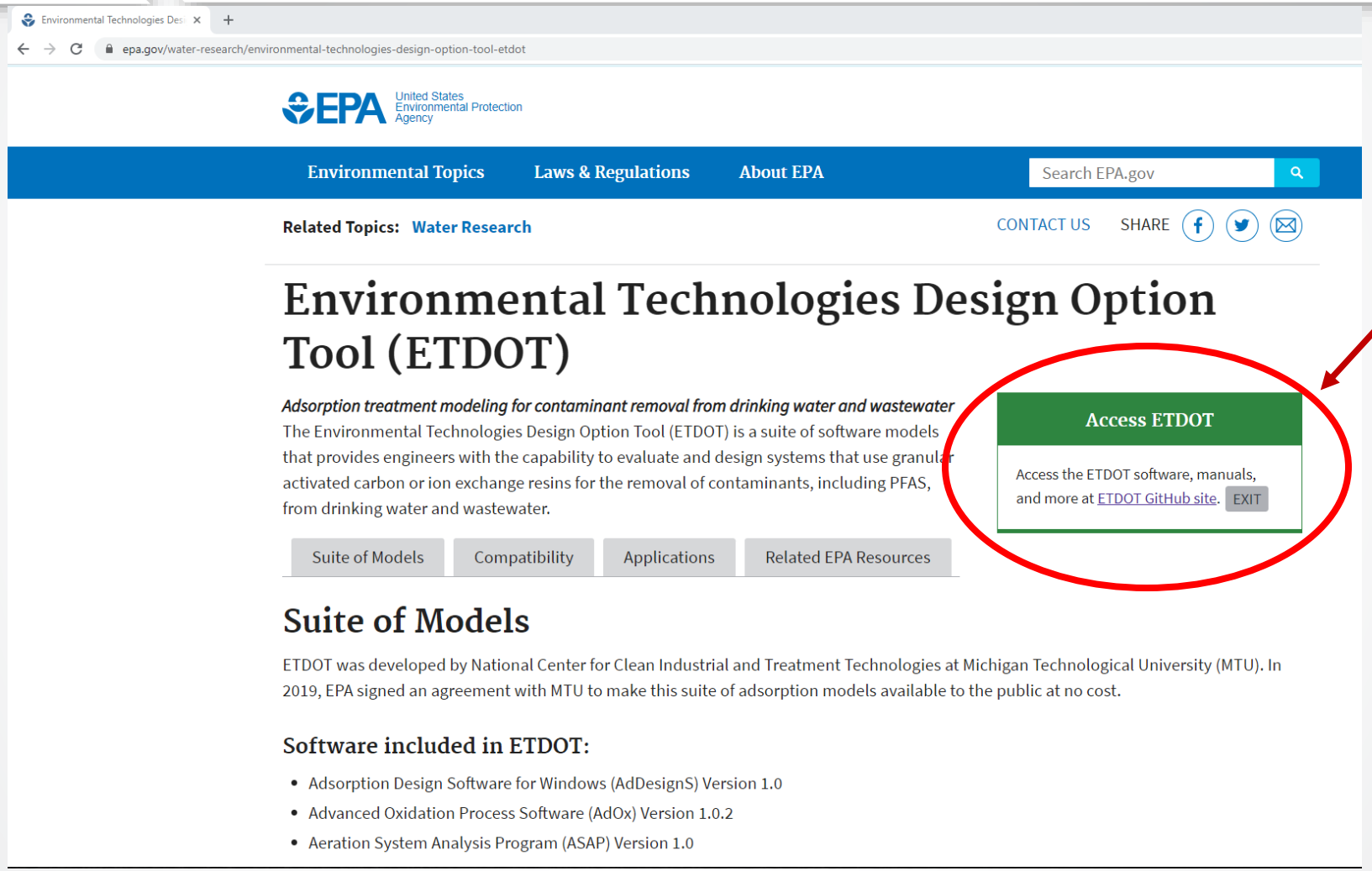


ETDOT Software

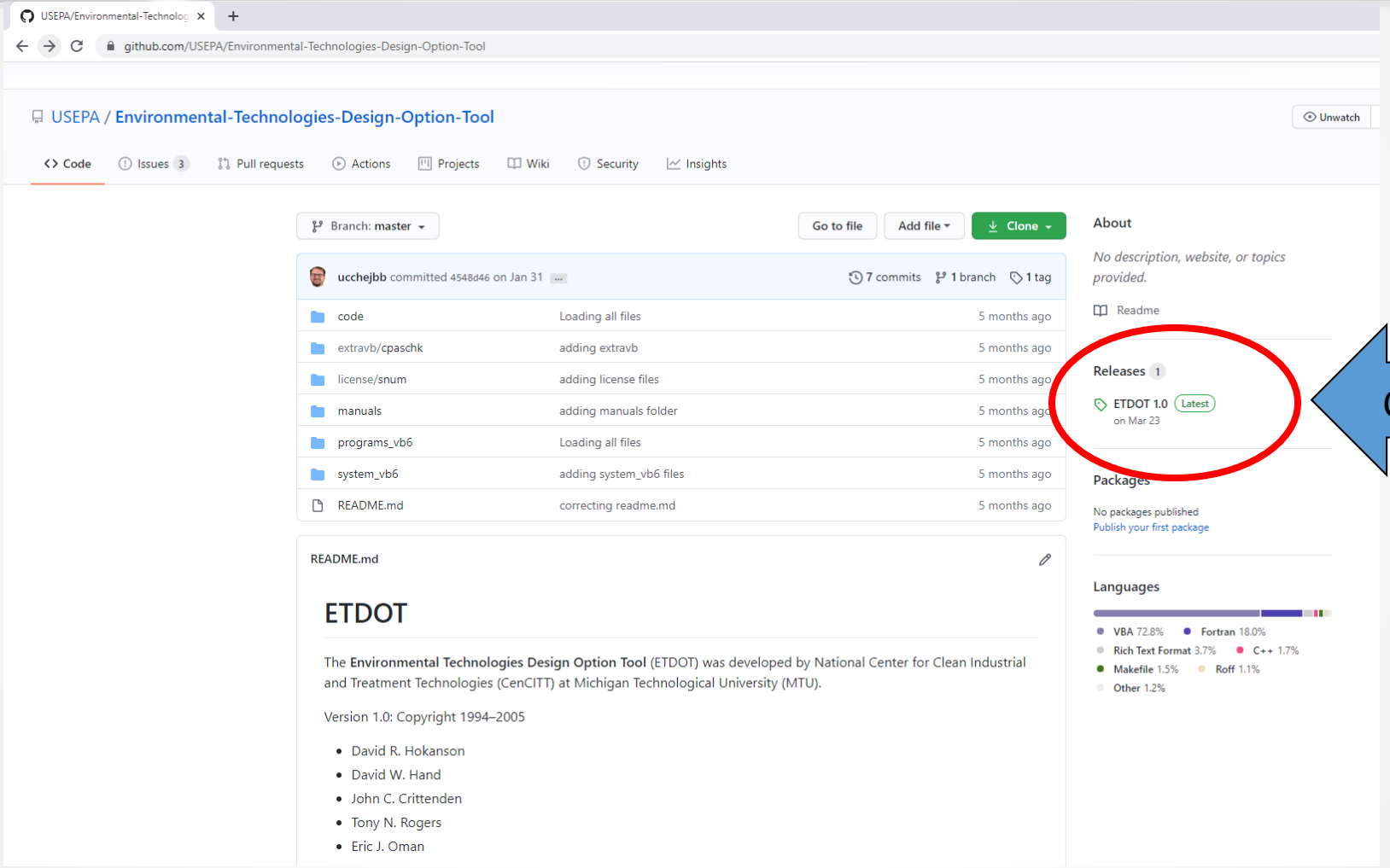


GitHub Site

https://www.epa.gov/water-research/environmental-technologies-design-option-tool-etdot

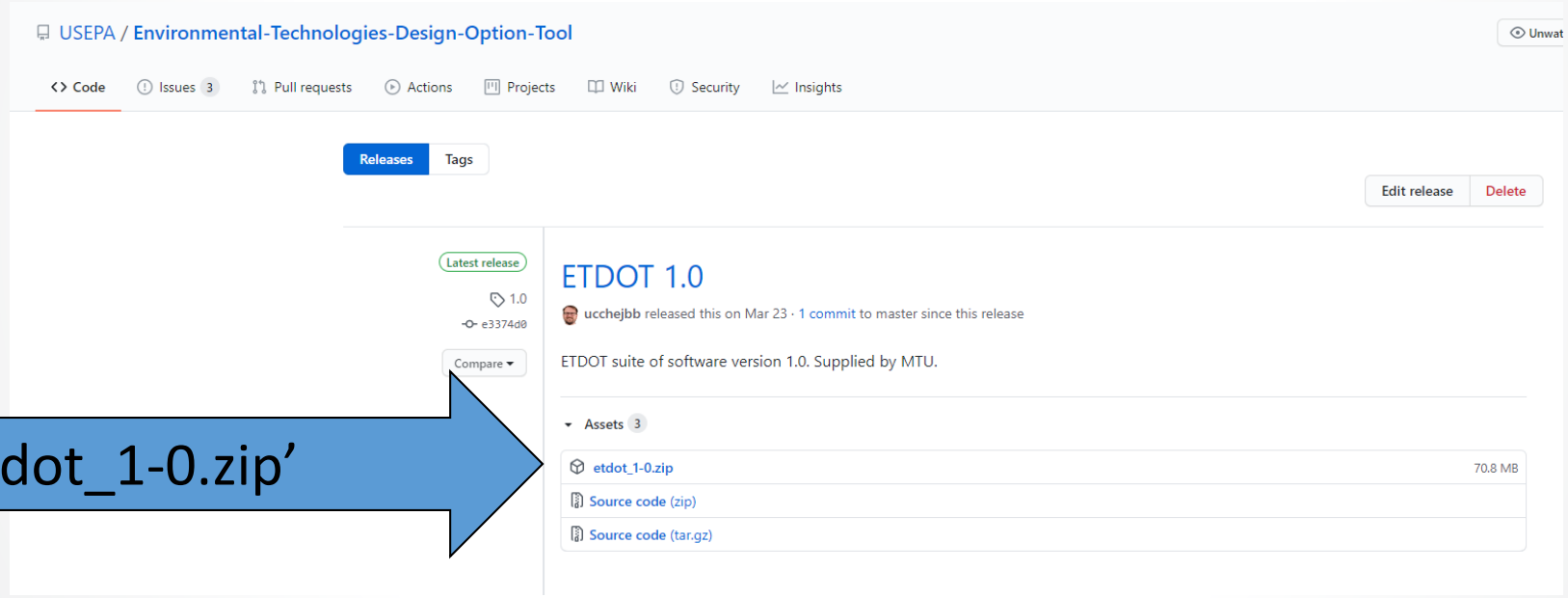
Search: EPA ETDOT

GitHub: ETDOT Software



https://github.com/USEPA/Environmental-Technologies-Design-Option-Tool

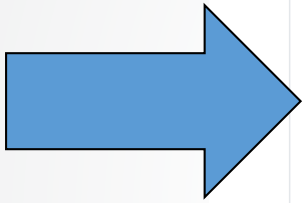
Releases on GitHub: ETDOT Software



Download ‘etdot_1-0.zip’

https://github.com/USEPA/Environmental-Technologies-Design-Option-Tool/releases/tag/1.0

Readme.md



Disclaimer:

The United States Environmental Protection Agency (EPA) GitHub project code is provided on an "as is" basis and the user assumes responsibility for its use. EPA has relinquished control of the information and no longer has responsibility to protect the integrity, confidentiality, or availability of the information. Any reference to specific commercial products, processes, or services by service mark, trademark, manufacturer, or otherwise, does not constitute or imply their endorsement, recommendation or favoring by EPA. The EPA seal and logo shall not be used in any manner to imply endorsement of any commercial product or activity by EPA or the United States Government.

Installation Instructions

This software requires *Administrator Rights* to a computer to install and to run. Files are installed directly to a folder X:\ETDOT10... where X is the system main drive.

1. Download zip file in the release tab.
2. Unzip/Unpack zip file
3. Run *setup.exe* and follow prompts
4. When prompted enter license key: CAADV0-R74JM-QXCNP-7EER9-1AT72
5. To run each module in Windows 7 or newer: Edit *properties* of the program to be run and select Compatibility Tab and "run in compatibility mode". Select Windows 98/Me from the Compatibility Mode dropdown menu.

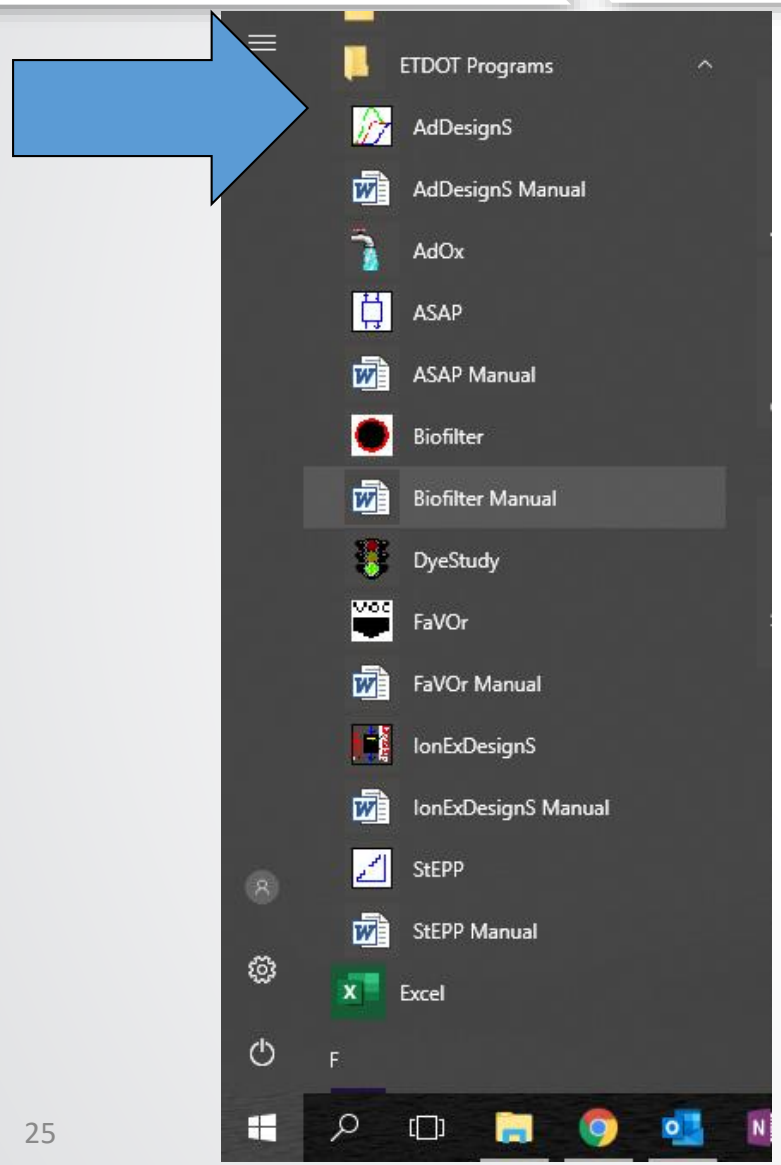
Available Users manuals will be located in the modules subfolder within the help folder.

Notes on current software

The **ETDOT** suite of software packages consists of a FORTRAN engine with a Visual Basic (version 6) graphical user interface. The VB6 portion of the code relies on ActiveX control files which are located in the repository, however, these are an older coding standard and no longer supported with current versions of Visual Studio 20##. Precompiled engine files are included.

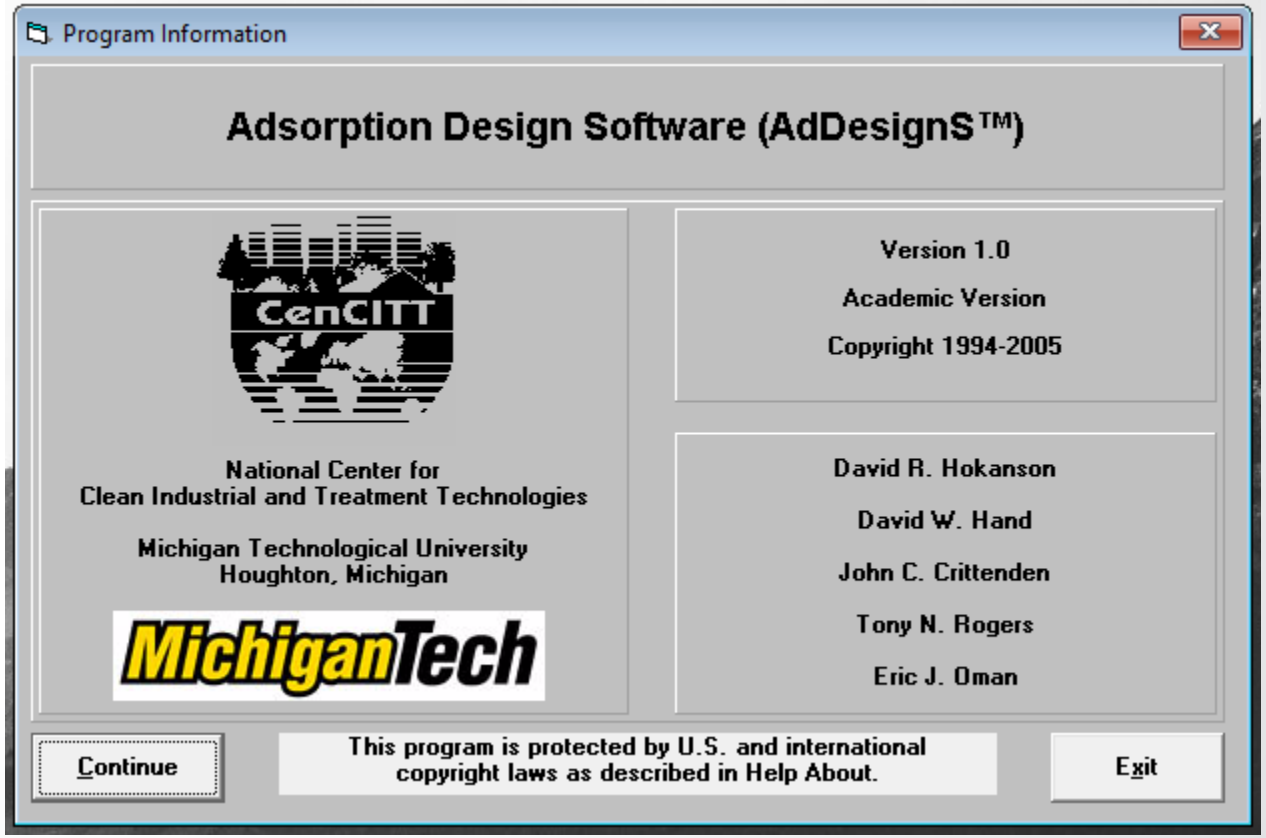
https://github.com/USEPA/Environmental-Technologies-Design-Option-Tool

Accessing ETDOT Software

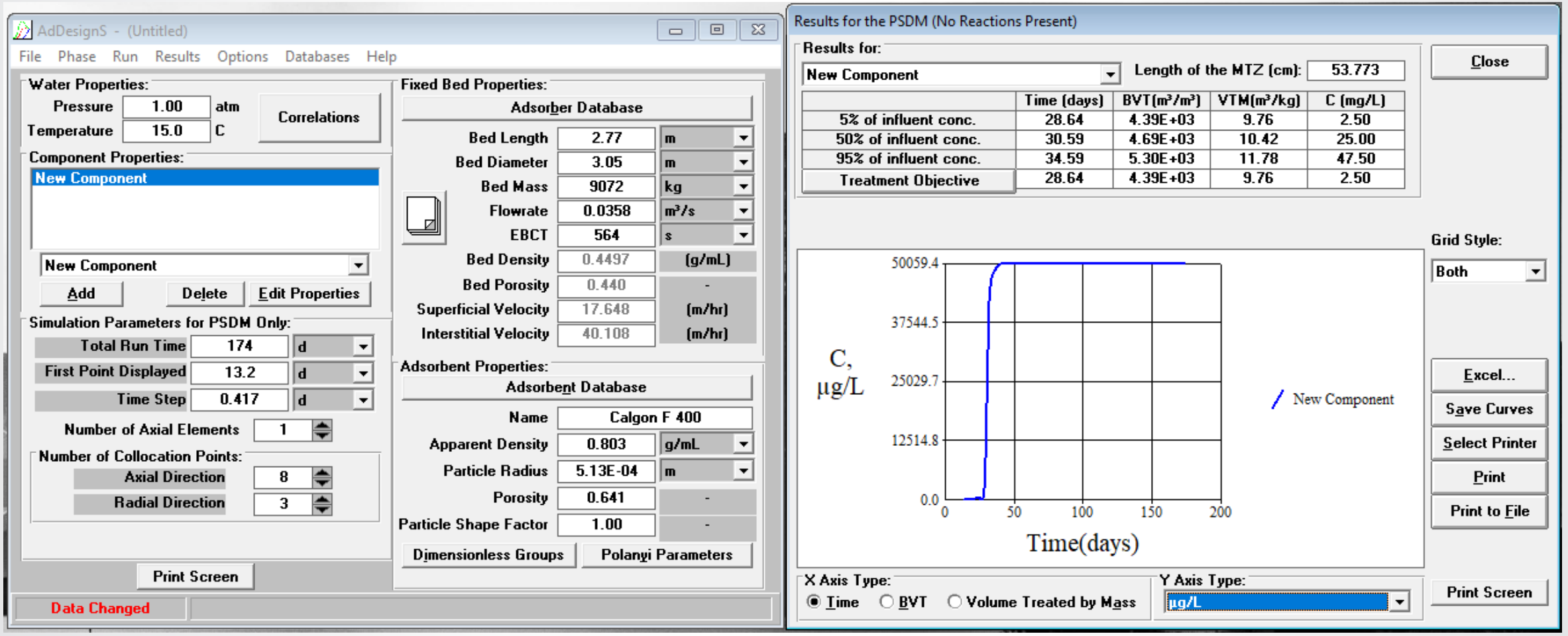


Start Menu:
'ETDOT Programs'

Software & Instruction Manuals are listed

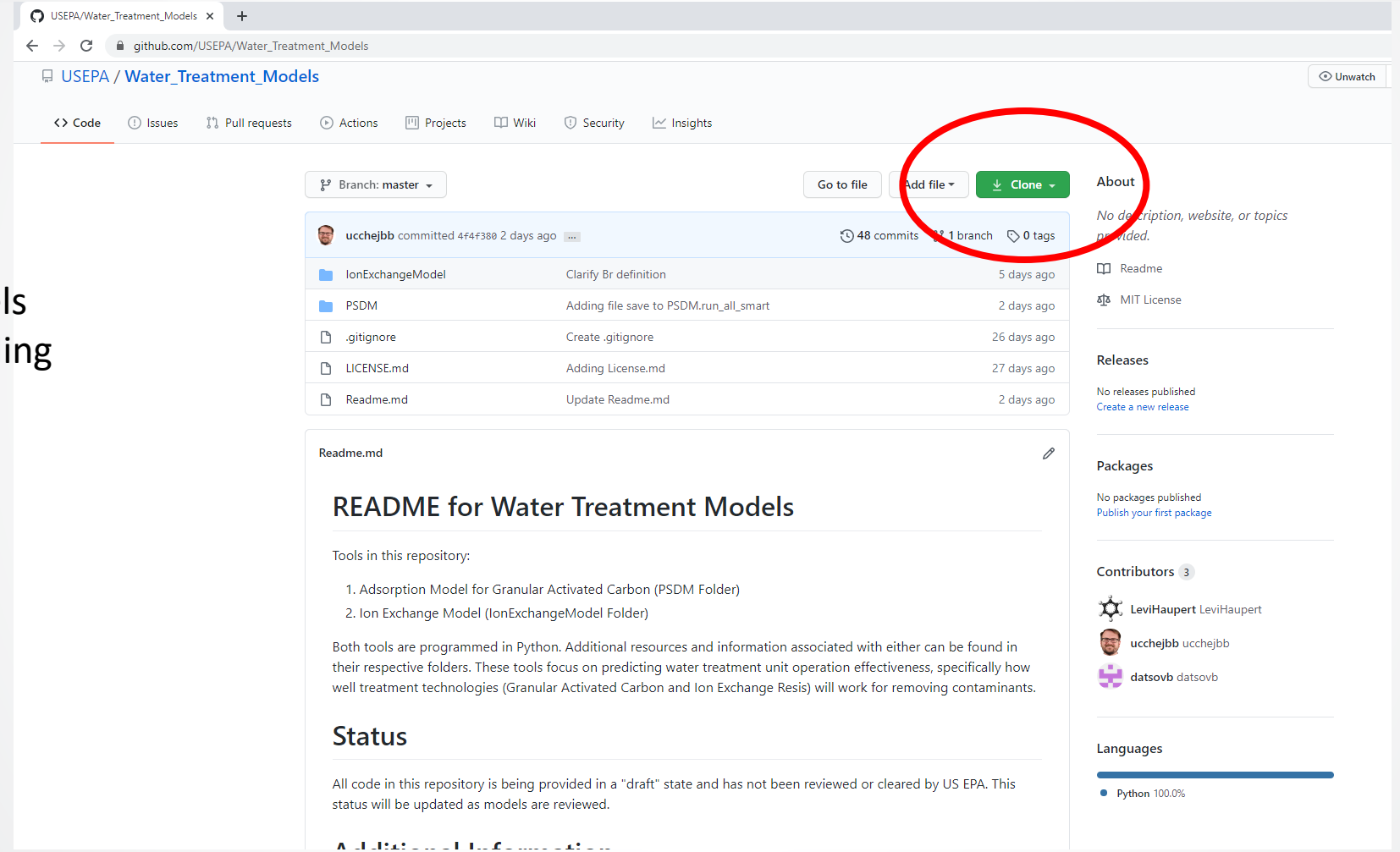


AdDesignS™ Software



Water Treatment Models

Python Tools:
Ion Exchange Models
PSDM – GAC Modeling



https://github.com/USEPA/Water_Treatment_Models

Water Treatment Models

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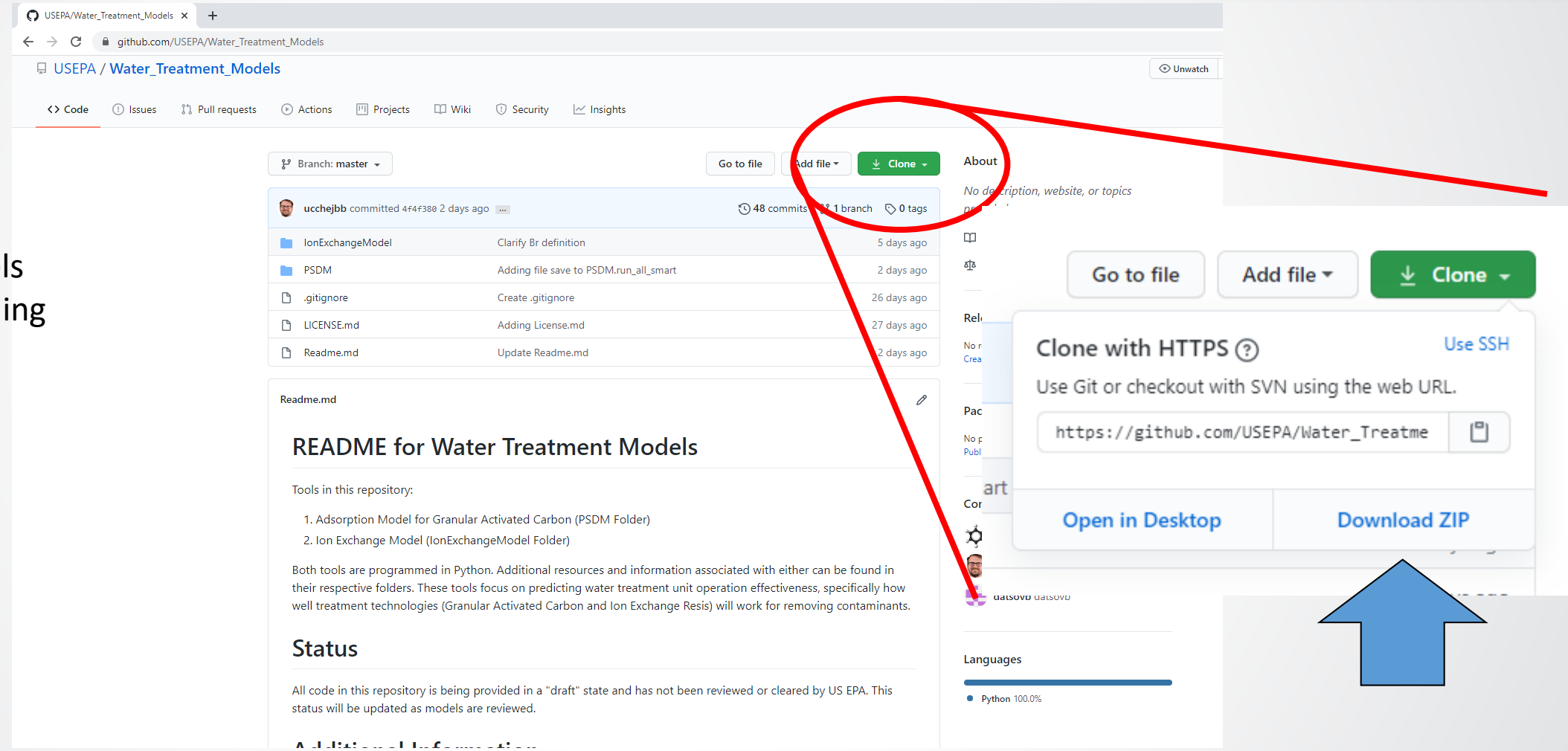
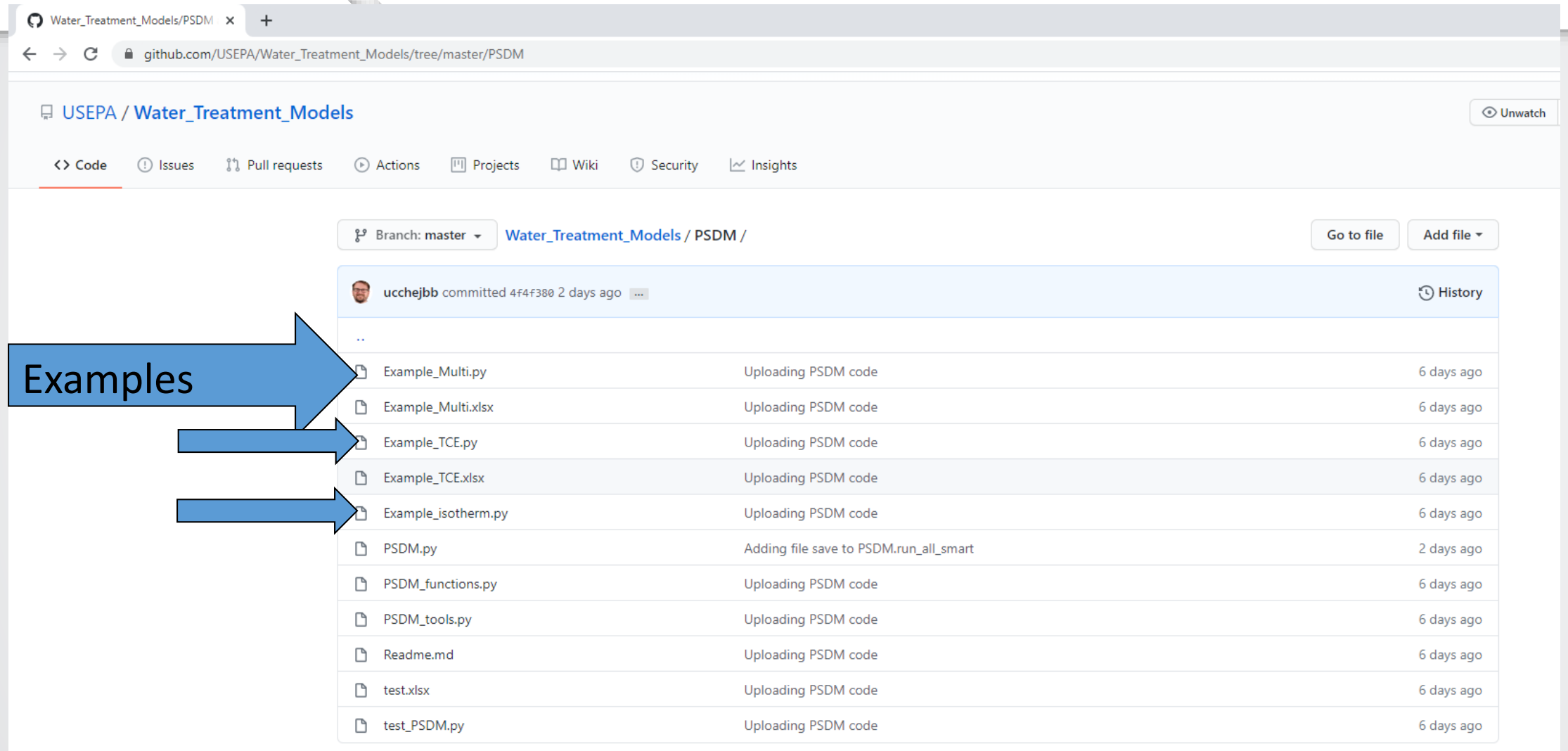


https://github.com/USEPA/Water_Treatment_Models

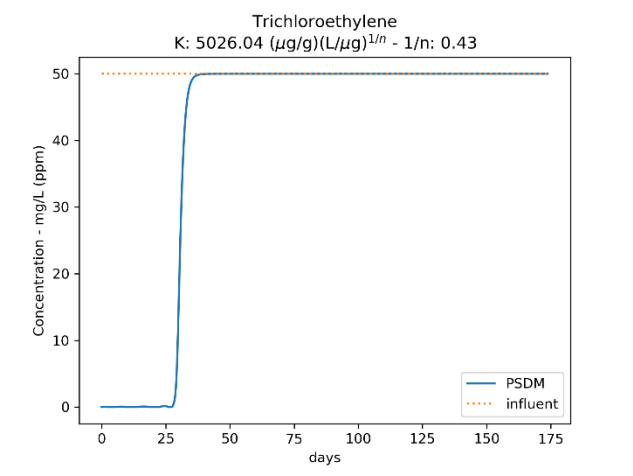
Pore and Surface Diffusion Model (PSDM)



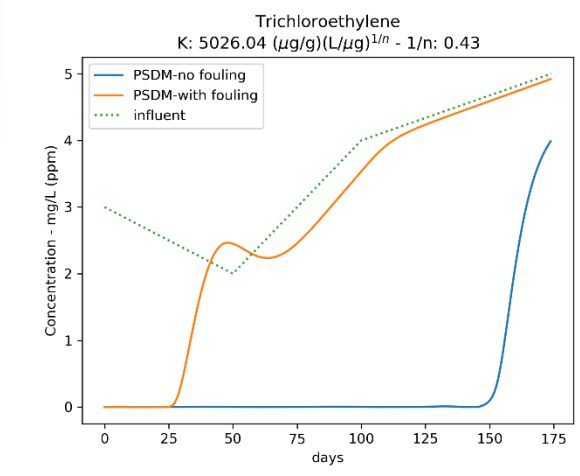
Examples

https://github.com/USEPA/Water_Treatment_Models

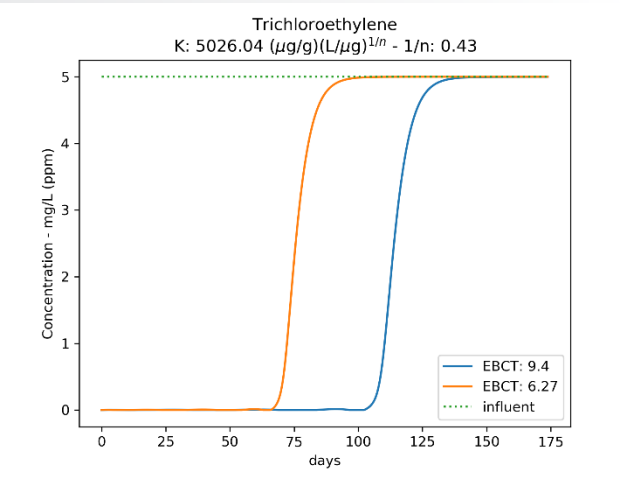
PSDM Model Examples



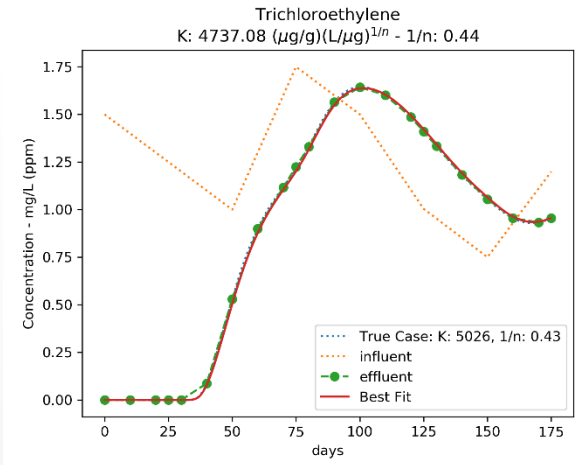
Single Compound



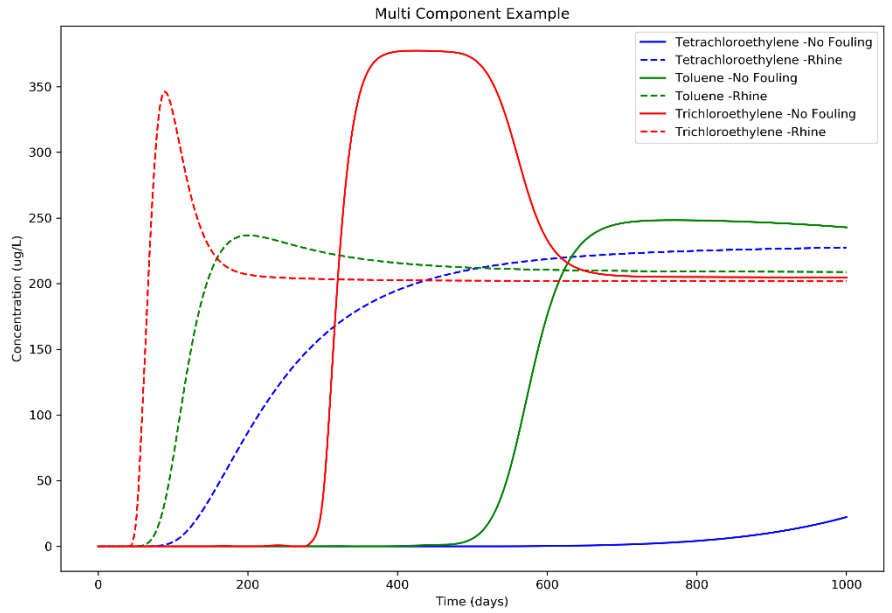
Modeling Fouling



Comparing EBCT



Fitting Pilot Data

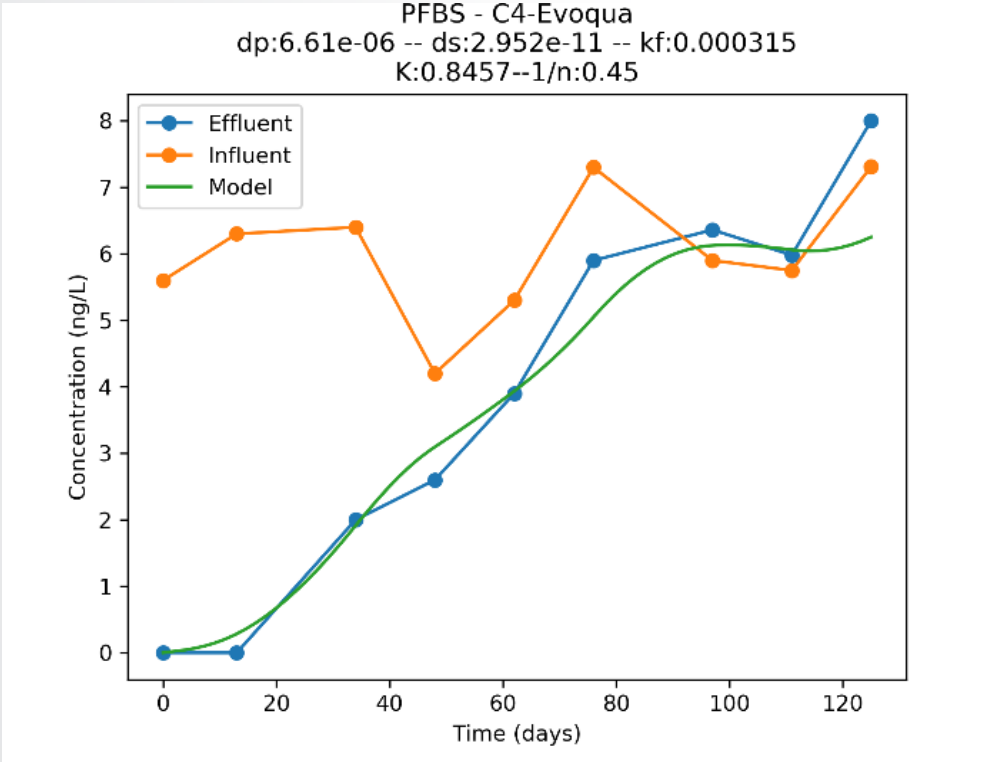


Multicomponent competitive modeling

Models can be used to perform a variety of different analyses or applications

Applying the PSDM Mode

Fitting Pilot / Full-scale Data



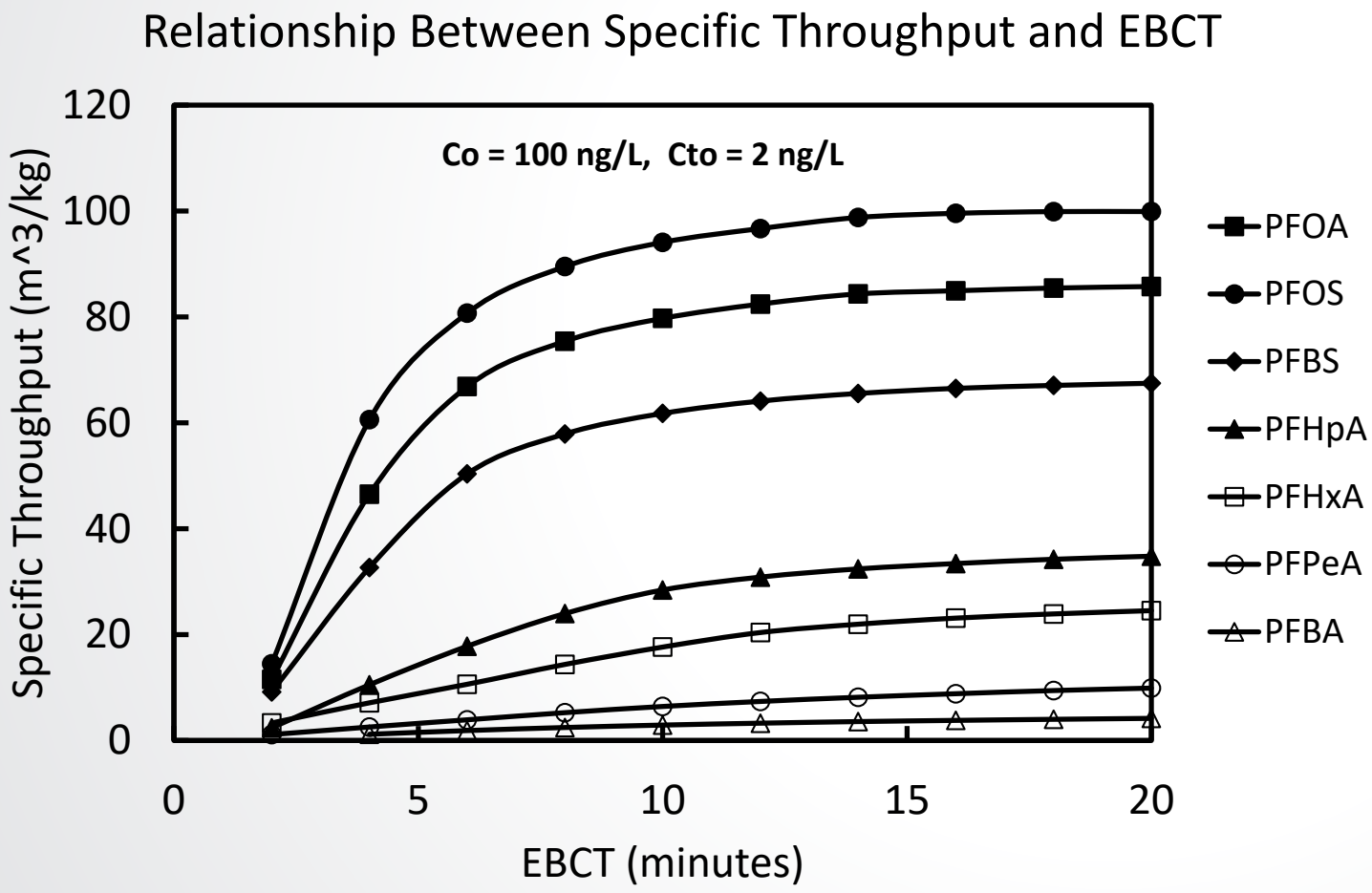
Predicting Results for Consistent Design

- Allows for comparison across technologies by cost

Allows for Predicting other Scenarios

- Other designs: number of contactors, contactor Empty Bed Contact Times (EBCTs), different treatment goals, etc.
- Other influent conditions: Changing concentrations of PFAS or background constituents, changing demand, etc.

Impact of Bed Size for Other Conditions



Example: What is the optimal Empty Bed Contact Time (EBCT) choice in the future?

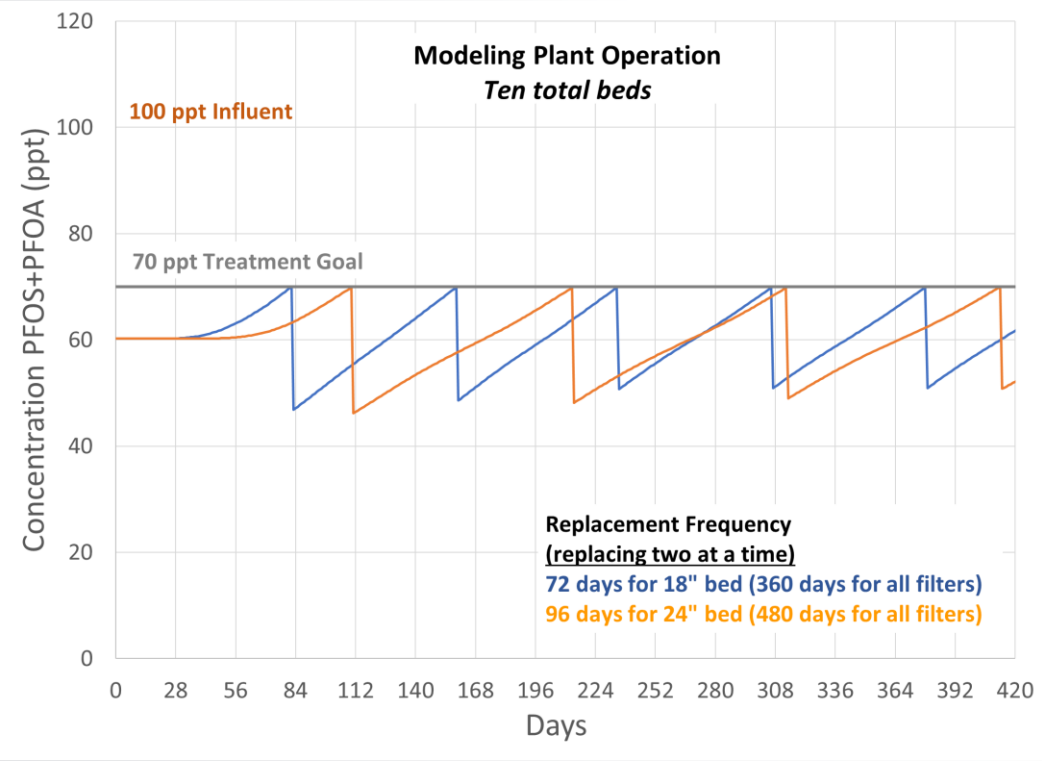
- The models can evaluate EBCT for various PFAS for different PFAS at different influent concentrations, effluent goals, etc.

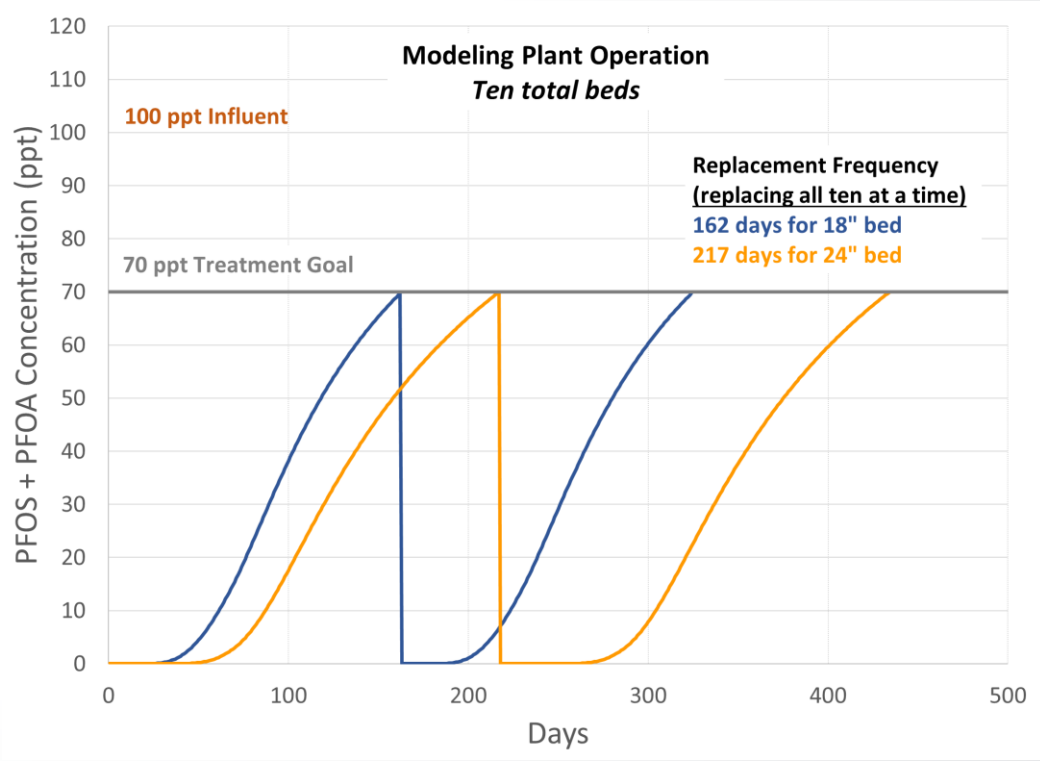
Modeled Specific Throughput can help determine EBCT or expected treatment volumes for single component treatment objectives

Design/Operation Evaluations

Example: How should the beds be deployed and replaced?

- The models can evaluate how many and how often beds need to be brought online or replaced

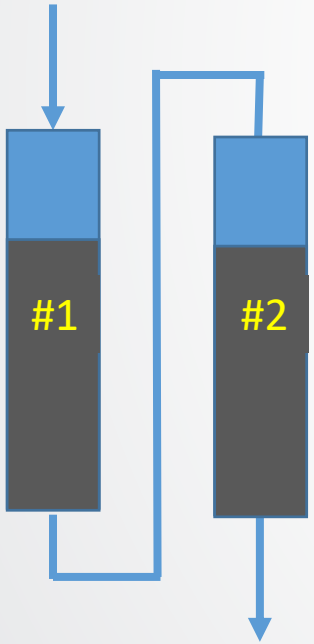




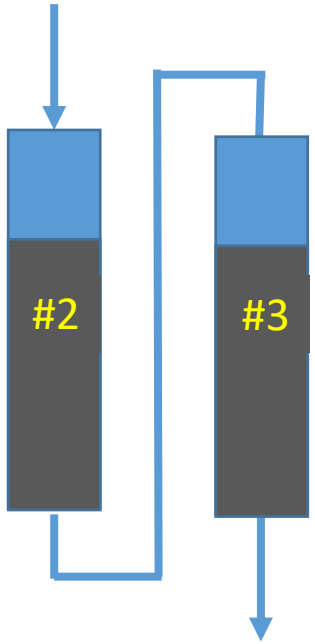
Lead/Lag Operation Evaluations

Example: What advantage can be gained with a lead/lag configuration?

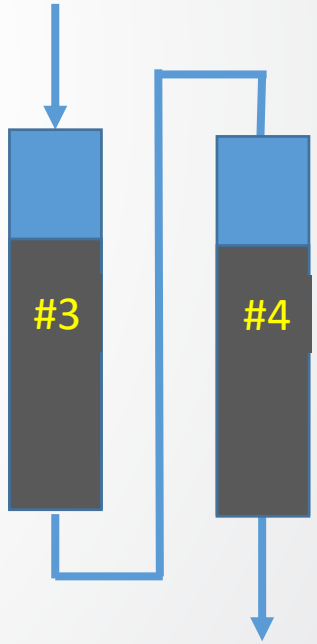
- The models can predict this increased carbon use rate.
- Note: Lead/lag operations can complicate modeling efforts, especially for those that take Natural Organic Matter (NOM) fouling/preloading into effect.



After a certain breakthrough (1st or 2nd column), a fresh column is added to the back of the train.



After a similar breakthrough point, a fresh column is added to the back of the train again.



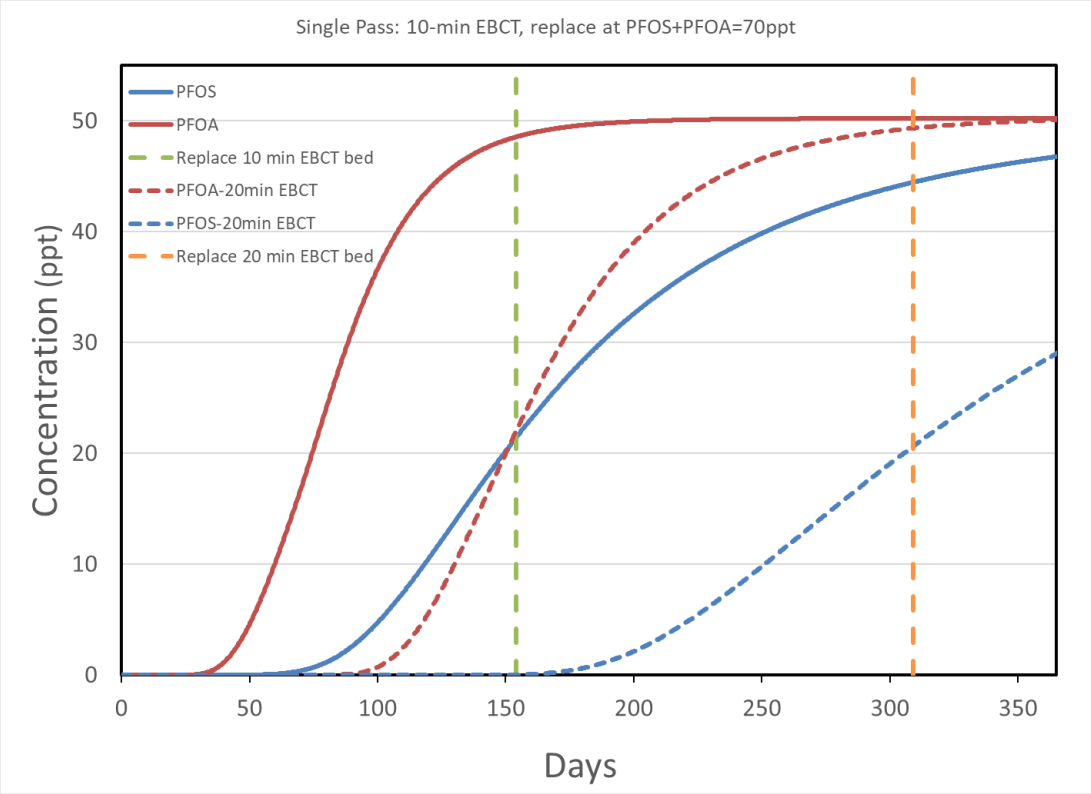
In an ideal situation, the first column would be completely saturated to maximize the use of the carbon.

Example: Lead/Lag Operation Evaluations

Single use:

Time to 70 ppt breakthrough (PFOA & PFOS)

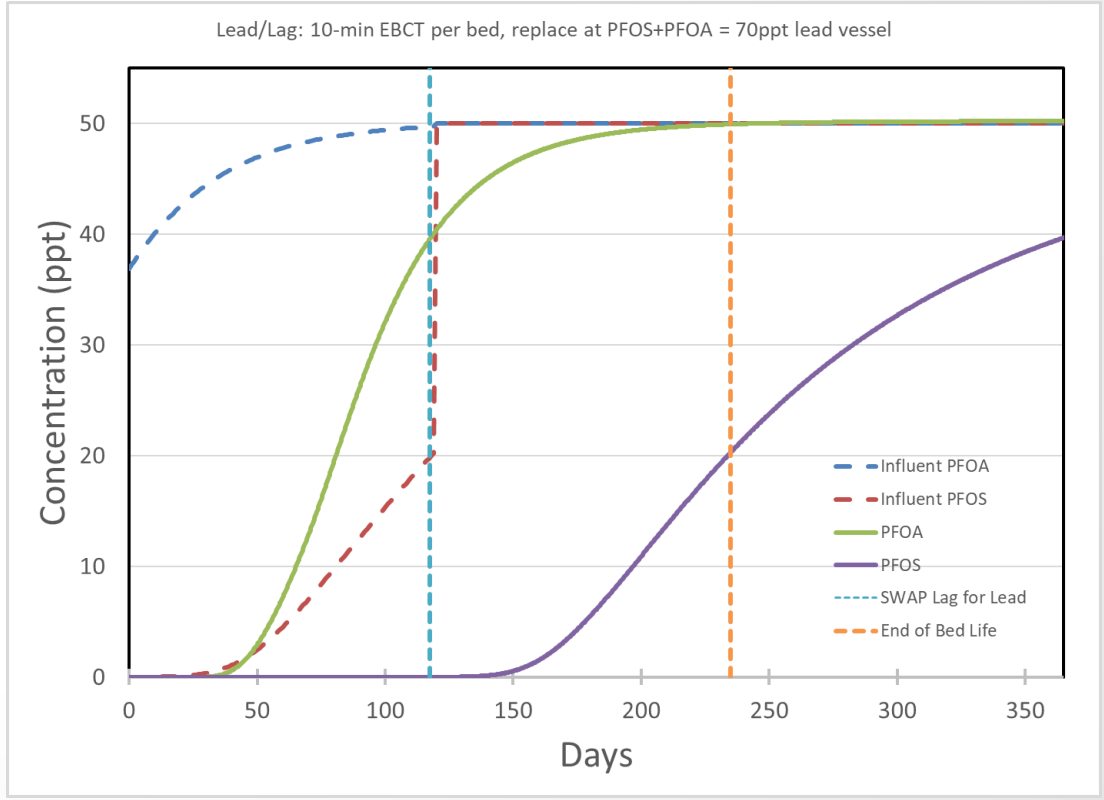
- 154 days (based on 1st column)



Lead/Lag:

Time to 70 ppt breakthrough (PFOA & PFOS)

- 236 days (based on 1st column)



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