Acute and Chronic Toxicity of PFAS-Free Firefighting Foams to Freshwater Organisms

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INTRODUCTION & OBJECTIVES

- PFAS has been widely incorporated into aqueous film-forming foams (AFFF) for firefighting purposes
- National Defense Authorization Act of 2022 required phase-out of fluorosurfactant foam by October 2024
- Novel fluorine-free foams (F3) require testing of firefighting performance and environmental toxicity
- This poster presents a synthesis of freshwater toxicity studies with a suite of 7 F3s and one reference PFAS-containing AFFF, Buckeye

Image From: Heiman Fire — Image From: Grainger

Fig. 1 AFFF in action (top) and example F3 commercially available products (bottom)

METHODOLOGY

Table 1: Foams Tested

Product Name	Formulation Type	Abbreviation
National Foam AVIO F3 Green KHC 3%	Commercial PFAS-free Formulation	Avio
Angus Fire ICAO-B JetFoam 3%	Commercial PFAS-free Formulation	Angus
Buckeye Platinum Plus C6 MILSPEC 3%	**Reference C6 Formulation**	**Buckeye**
Bio-Ex ECOPOL A 3% FFF	Commercial PFAS-free Formulation	ECOPOL
Fomtec ENVIRO 2–3% FFF	Commercial PFAS-free Formulation	Fomtec
National Foam NFD 20–391 Formulation – 1 L	SERDP Developmental Formulation	NFD
NRL 502 W Siloxane-based Formulation	SERDP Developmental Formulation	NRL 502W
Solberg Re-healing Foam RF3 3%	Commercial PFAS-free Formulation	Rehealing

Fig. 2 Foams tested

Table 2: Species and Test Methods

Species	Study Duration	Foams Assessed	Endpoints Measured	Guidance Method
Acute Studies				
Algae (*R. subcapitata*)	96 h	Angus, Avio, Buckeye, ECOPOL, Fomtec, NFD, NRL 502W, Rehealing	Cell Count	EPA 1003.0
Invertebrate (*C. dilutus*)	48 h	Angus, Avio, Buckeye, ECOPOL, Fomtec, NFD, NRL 502W, Rehealing	Survival	OECD 235
Fish (*P. promelas*)	96 h	Angus, Avio, Buckeye, ECOPOL, Fomtec, NFD, NRL 502W, Rehealing	Survival	OECD 203
Chronic Studies				
Invertebrate (*C. dilutus*)	Up to 60 d	Angus, Avio, Buckeye, ECOPOL, Fomtec, NFD, NRL 502W, Rehealing	Survival, Growth, Emergence	OECD 219
Fish (*P. promelas*)	7 d	Angus, Avio, Buckeye, ECOPOL, Fomtec, NFD, NRL 502W, Rehealing	Survival & Growth	EPA 1000.0

ACUTE AQUATIC TOXICITY TESTING

- Greater acute toxicity of novel F3s compared to the PFAS-containing AFFF, Buckeye
- Acute studies indicated the Avio formulation to be the most toxic F3 followed by Angus while Buckeye was least toxic
- Similar findings observed in multi-laboratory study from Jones et al. 2022[1]

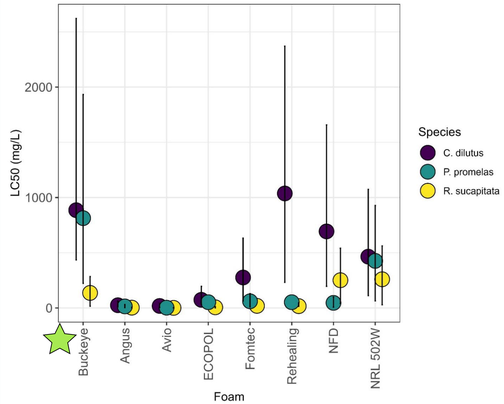
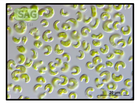


Fig 3. Comparison of EC50 (*R. subcapitata*) and LC50 values (*P. promelas* and *C. dilutus*) for all foams tested. Error bars represent 95% confidence intervals.

Fathead minnow, *Pimephales promelas* Photo: Illinois DNR



Green algae, *Raphidocelis subcapitata* Photo: SAG Culture Collection of Algae at Gottingen University

Midge Larvae *Chironomus dilutus* Photo: NC State Extension

Fig 4. Test species

CHRONIC AQUATIC TOXICITY TESTING

- For the chronic studies, midge emergence was found to be most sensitive endpoint in chronic aquatic studies (Table 3)
- Significant effects on midge growth identified in 6 out of 8 foams
- Toxicity ranking broadly consistent with acute studies, with ECOPOL, Angus, and Avio among the most toxic
- ECOPOL found to be highly toxic based on NOEC and EPA's Alternatives Assessment Criteria (Table 3)

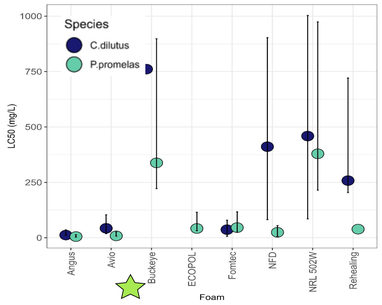


Fig 5. Comparison of chronic LC50 values in *C. dilutus* and *P. promelas*

Table 3. Effects of F3s on emergence of *C. dilutus*.

Foam	NOEC (mg/L)	LOEC (mg/L)	EC_{20} (mg/L)	EC_{50} (mg/L)	EPA Designation
ECOPOL	0.9	3	0.409	3.97	High
Angus	3	9	4.17	7.02	Moderate
Avio	0.9	3	9.36	15.6	Moderate
Fomtec	9	30	22.7	36.5	Moderate
NRL 502W	30	90	15.6	43.2	Low
Rehealing	30	90	21.0	64.3	Low
NFD	30	90	18.4	70.0	Low
Buckeye	**90**	**300**	**59.3**	**130**	**Low**

AQUATIC TOXICITY TESTING SUMMARY

- Overall, several of the tested F3s were more toxic than the reference PFAS-containing AFFF across acute and chronic studies and multiple species (Table 4).

Table 4. Summary of all aquatic toxicity data (acute and chronic studies).

Foam	Lowest EC_{50} or LC_{50} Value (mg/L)	Species	Endpoint
Avio	0.69	*R. subcapitata*	Cell Density EC_{50}
Angus	2.70	*R. subcapitata*	Cell Density EC_{50}
ECOPOL	3.97	*C. dilutus*	Emergence EC_{50}
Rehealing	16.3	*R. subcapitata*	Cell Density EC_{50}
Fomtec	18.9	*R. subcapitata*	Cell Density EC_{50}
NRL 502W	43.2	*C. dilutus*	Emergence EC_{50}
NFD	46	*P. promelas*	Acute LC_{50}
Buckeye	**130**	***C. dilutus***	**Emergence EC_{50}**

- Synthesis of data from interlaboratory effort with other aquatic species and endpoints found similar toxicity ranking (Fig 6)

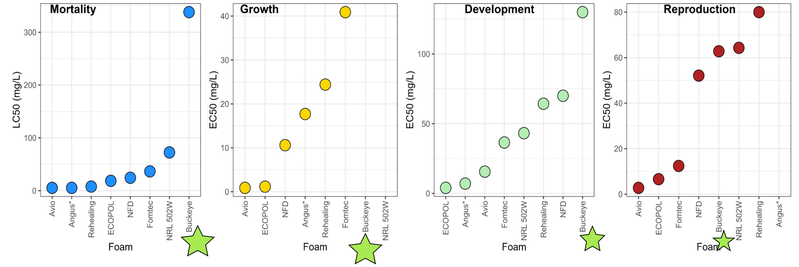


Fig 6. Summary of interlaboratory aquatic toxicity data.

SUMMARY

- Several F3s were toxic to aquatic species at concentrations equivalent to a 10,000-fold dilution of levels used in firefighting (30,000 mg/L or 3%).
- Avio and Angus F3s consistently among the most toxic, with NRL 502W exhibiting lower toxicity
- Findings will be used to support selection of an appropriate F3 with lower environmental impacts.

REFERENCES & ACKNOWLEDGEMENTS

- All analyses were supported by SERDP project ER20-1531

1. Jones, D.K., Quinlin, K.A., Wigren, M.A., Choi, Y.C., Sepulveda, M.S., Lee, L.S., Haskins, D.L., Lotufo, G.R., Kennedy, A., May, L., Harmon, A., Biber, T., Melby, N., Chanov, M.K., Hudson, M.L., Key, P.B., Chung, K.W., Moore, D.W., Suski, J.G., Wirth, E.F., and Hoverman, J.T. (2022). *Acute Toxicity of Eight Aqueous Film-Forming Foams to 14 Aquatic Species.* 56, (10) 6078-6090.