

Regulatory Arbitrage in Transboundary Per- and Polyfluoroalkyl Substances (PFAS) Governance: A Policy Alignment Index Analysis of the Merrimack River Basin

Anfeng Xie

St. Paul's School, Concord, USA
anfeng.xie@sps.edu

Abstract. Fragmented governance in transboundary river basins can create regulatory valleys in which persistent pollutants exploit jurisdictional asymmetry rather than technological uncertainty. Using the Merrimack River watershed as a subnational case with broader transboundary relevance, this article examines how uneven per- and polyfluoroalkyl substances (PFAS) rules, enforcement intensity, and policy timing shape incentives for regulatory arbitrage. It combines comparative policy analysis of New Hampshire, Massachusetts, and Maine with an operational PFAS Policy Alignment Index (PAI) that tracks scope, enforcement, monitoring, substitute governance, and responsiveness from 2015 to 2025. The analysis suggests that New Hampshire's narrower scope and lower enforcement intensity reduce deterrence relative to neighboring jurisdictions, while early improvements in some concentrations are better explained by federal voluntary programs and private supply-chain pressure than by state legislation alone. The article argues that mobile short-chain substitutes expose the limits of reactive, substance-by-substance governance. It proposes two institutional responses—an Automatic Adoption Clause and a regional Substitute Information Exchange—to create a regional minimum floor for basin protection. The findings speak to wider debates on environmental federalism, transboundary governance, and policy alignment for emerging contaminants.

Keywords: PFAS, regulatory arbitrage, transboundary river governance, environmental federalism, policy alignment

1. Introduction

1.1. PFAS, multi-level governance, and the basin problem

Per- and polyfluoroalkyl substances (PFAS) present not only a toxicological challenge but also a governance challenge. Because these highly persistent chemicals move through connected hydrological systems, the boundaries that matter for exposure and remediation rarely coincide with the boundaries that define legal authority. This mismatch is especially important in river basins, where one jurisdiction's narrower controls may externalize environmental and public-health burdens downstream. PFAS are often described as 'forever chemicals' because of the strength of their

carbon–fluorine bonds, their persistence in soil and water, and their capacity for bioaccumulation and transport. Epidemiological research has linked exposure to immune, endocrine, and carcinogenic risks even at very low concentrations. For environmental policy and law, the central question is therefore not only how dangerous PFAS are, but how fragmented institutions govern a mobile and persistent class of contaminants [1-3].

New Hampshire provides a revealing case study because PFAS regulation sits at the intersection of environmental protection, industrial competitiveness, and interstate spillovers. The state hosts specialized manufacturing sectors in southern New Hampshire and the Monadnock region that have historically relied on PFAS-related inputs or processes. At the same time, contamination events involving the Merrimack River watershed and public water supplies in communities such as Merrimack and Portsmouth have made PFAS a politically salient issue rather than a purely technical one. The resulting policy problem is not whether New Hampshire can regulate PFAS at all, but how far it can delay or narrow regulation without shifting part of the basin-wide burden to neighboring jurisdictions [4].

1.2. Environmental federalism, institutional fragmentation, and policy competition

Within the United States, PFAS governance has exposed a familiar problem of environmental federalism. Federal action has accelerated only recently, with the EPA's PFAS Strategic Roadmap and the 2024 National Primary Drinking Water Regulation providing a stronger national baseline. Before that shift, states were left to design their own mixes of product bans, drinking-water rules, monitoring obligations, and enforcement tools. In principle, decentralization can generate policy innovation by allowing jurisdictions to respond to local conditions. In practice, for mobile pollutants that cross political borders, decentralization can also produce uneven protections, timing gaps, and incentives for strategic under-enforcement [5-7].

This tension lies at the heart of environmental federalism. The literature shows that jurisdictional competition rarely operates only through formal repeal of rules; it may also work through narrower regulatory scope, weaker monitoring, broader exemptions, and lower penalty exposure. Those choices matter because firms compare compliance costs across jurisdictions, whereas river systems do not respect those comparisons. Where pollutants are persistent and hydrologically mobile, a jurisdiction that remains relatively permissive can function as a regulatory valley within an otherwise more precautionary region [8-10].

New Hampshire is particularly instructive because its political economy differs from that of neighboring Maine and Massachusetts. The state's limited-government political culture has encouraged a more incremental, risk-based approach to PFAS, whereas Maine has moved toward class-based restrictions and Massachusetts has paired narrower scope with comparatively stronger emission and enforcement tools. The significance of this contrast is institutional rather than merely descriptive: neighboring jurisdictions sharing an interconnected ecological space have adopted materially different governing philosophies for the same contaminant class.

1.3. Research gap and research question

Existing PFAS scholarship has concentrated on toxicology, exposure pathways, analytical detection, and remediation technologies. Legal and policy scholarship has documented regulatory fragmentation, but there remains limited work that operationalizes how differences in scope, enforcement, and timing create incentives for regulatory arbitrage in connected river basins. That

gap is especially important for emerging contaminants because short-chain substitution can outpace the cadence of conventional rulemaking [3, 11].

This article addresses that gap through a comparative policy analysis of New Hampshire, Maine, and Massachusetts over the period 2015–2025. Rather than asking only whether individual rules exist, it evaluates how combinations of legal coverage, enforcement intensity, substitute governance, and policy responsiveness shape basin-level governance outcomes. The empirical case is subnational, but the analytical problem—misalignment between ecological interdependence and fragmented jurisdictional authority—is relevant to wider debates in transboundary environmental governance.

The central question is whether New Hampshire's risk-based model preserves legitimate regulatory flexibility or instead creates a regulatory valley that enables arbitrage and weakens regional environmental security. Section 2 develops the analytical framework; Section 3 explains the comparative design and the Policy Alignment Index; Section 4 presents the empirical findings; and Sections 5 and 6 discuss the broader policy and institutional implications.

2. Literature review

This section develops the article's analytical framework by bringing together environmental federalism, private governance, chemical policy, and interstate externalities. The aim is not merely to describe differences among state PFAS regimes, but to explain how institutional asymmetries create incentives for systematic regulatory arbitrage. This framework also helps distinguish between reductions associated with binding state rules and those associated with softer forms of market and reputational governance.

2.1. Regulatory arbitrage and environmental federalism

The decentralization of environmental policy in the U.S. assumes that states are "laboratories of democracy". However, the environmental federalism literature has suggested that without uniform federal standards, decentralization could lead to a "race to the bottom." Oates [7] proposed a model that states local jurisdictions are incentivized to under-value environmental public goods in order to attract mobile capital and reduce production costs for industry. Although Oates suggested efficiency could exist in a theoretical sense, evidence suggests that competition between jurisdictions can lead to sub-optimal regulatory outcomes, in particular for trans-boundary pollutants (i.e., pollutants travelling across jurisdictional borders) where the cost of abatement is high.

A number of recent scholars have begun examining enforcement intensity rather than simply statutory enactments. Konisky [8] contends the "Race to the Bottom" is not usually evident in the visible repeal of environmental laws, but in the less visible reduction of enforcement such as decreased inspection rates and lowered penalty caps. Konisky argues that this model of strategic interaction describes states behaving strategically; when a state neighboring another state decreases the regulatory burden in its own jurisdiction, it will be statistically less likely to increase the regulatory burden in its own jurisdiction, thus avoiding placing its industries at a disadvantage relative to the neighboring state's industries.

The theoretical dynamic creates a landscape conducive to the practice of Regulatory Arbitrage, which Levinson [9] describes in his description of the Pollution Haven Hypothesis as the situation where firms organize their production processes so that they can benefit from lower compliance costs for their operations across various jurisdictions. In capital-intensive industries where PFAS represents an ongoing liability due to the long-term nature of the pollutant, the significant disparity

in civil penalties between NH and MA, as identified in this analysis, may serve as the price signal for the firms. Under the Rational Polluter Model proposed by Shimshack [10] to guide decision-making, rational firms whose expected penalty for non-compliance is greater than the cost of implementing abatement technology will be incentivized economically to stay within a lower-penalty jurisdiction, as they effectively view the penalties associated with being in that jurisdiction as a small tax on pollution rather than a punishment for violating environmental regulations.

2.2. Soft law and private governance

The fact that environmental improvement may precede formal legislation poses a problem for accounts that focus only on binding rules. The literature on soft law and private governance helps explain this pattern by showing how firms often adjust behavior in anticipation of litigation, regulation, procurement standards, or reputational pressure, rather than only after a statute takes legal effect [12].

The environmental governance literature also shows that private actors can become *de facto* regulators when supply-chain pressure and reputational risk push firms to exceed local legal requirements. Multinational corporations may impose stricter environmental expectations on suppliers than the host jurisdiction formally requires, and private contracting can therefore become a powerful channel of environmental governance [13, 14].

Research on PFAS suggests that the use of federal voluntary programs can be thought of as "soft law." The EPA has put into place a perfluorooctanoic acid (PFOA) Stewardship Program (which was established in 2010/2015) under which certain global companies made voluntary pledges to phase out their long chain PFOA products. Many authors cite this initiative as having a major impact on initial reductions of emissions of PFAS (short-chain and long-chain) pollutants, even though it was a voluntary program and not legally enforceable. In effect, by establishing a voluntary program, the EPA created an environment where the upstream sources of PFAS products were eliminated, thereby creating an opportunity for downstream users in states such as NH to transition away from using these chemicals. As a result, these companies experienced pressure from their suppliers to stop using PFAS products in anticipation of future regulatory action. Therefore, this body of literature serves to clarify the "policy lag" experienced in NH [15].

2.3. Regrettable substitution and the precautionary principle

This section also evaluates the limits of risk-based, substance-by-substance chemical regulation through the concept of regrettable substitution. Under the conventional U.S. model, individual substances are often regulated only after evidence accumulates for each chemical, which can allow structurally similar substitutes to enter the market faster than regulators can respond. For PFAS, this sequential logic has been criticized as a 'whack-a-mole' approach because it can suppress one compound while leaving room for functionally related replacements [1].

Many short-chain substitutes appear to retain the persistence and mobility that made legacy PFAS so difficult to govern, which is why they are widely discussed as regrettable substitutions from a public-health perspective. The 'essential use' concept responds to this problem by shifting the burden toward justification of use and away from endless chemical-by-chemical listing, thereby highlighting the institutional difference between New Hampshire's limited list and Maine's broader class-based approach [3, 16].

2.4. Interstate externalities, collective action, and the case for a regional minimum floor

The previous research identifies three major structural motivating factors leading to regulatory fragmentation associated with PFAS at the federal level; these are inter-state competition among jurisdictions in terms of their environmental policies, the increase in influence from "soft" (or nonlegally binding) laws on how people govern and interact with one another, and the limitations of regulating on a substance-by-substance basis due to rapid substitution processes. A key aspect that must be highlighted in linking these findings to the key empirical risk that has been raised in this paper is the concept of cross-jurisdictional displacement of pollution and/or regulatory arbitrage occurring within a networked eco-region. This element relates to the fact that when dealing with persistent, mobile pollutants, the states have to deal with externalities that are generated by each state affecting other states, therefore requiring collective action to resolve this problem [3, 7, 8, 13].

PFAS have characteristics that exacerbate interstate externalities when contrasted with typical local pollutants. In the first instance, the physical property of PFAS promotes long-term contamination through transportation pathways (connected watersheds and aquifers) across multiple jurisdictions. Therefore, jurisdictional boundaries are a poor proxy for exposure boundaries in the PFAS situation due to the manner in which PFAS travel through water systems. From a hydrological perspective, the unidirectional flow of the Merrimack River transports persistent PFAS loads from 'low-penalty' upstream jurisdictions to downstream receptors, rendering static political boundaries ineffective for pollution control. Second, the time lags associated with PFAS governance from initial detection to regulation and ultimately observable improvements in the environment create a value proposition in the prevention phase that grows with time; this means that there are significant political and cost consequences associated with delays in responding to potential PFAS environmental issues. Finally, since both prevention and remediation of PFAS contamination require high fixed costs along with a highly specialized analytical capability, the economies of scale associated with this class of contaminants create significant barriers for smaller jurisdictions acting independently [1-3, 17, 18].

These characteristics lead to an uneven distribution of the economic costs and environmental benefits resulting from federalism in a decentralized regulatory system, particularly regarding how the geography of environmental regulation impacts the relationship between the economic costs of compliance and the environmental benefits resulting from compliance. When states impose more stringent PFAS regulations, those states bear a portion of the compliance costs incurred by local businesses and government regulators, while some of the environmental benefits may accrue to neighbouring states. On the other hand, when states use a narrower scope of regulation or a lower level of enforcement, those states can retain a near-term economic advantage while transferring part of the environmental burden to other states; this is the classic example of the "under-provision" of public goods that results from externality-driven regulation in a federalized system. In this situation, regulatory competition will most likely occur, not through the outright elimination of legislation, but through a reduction in the scope and intensity of enforcement of existing legislation, as this will create economic incentives for regulatory arbitrage [7-10].

The implication is not that all authority over PFAS must be centralized. Rather, the case for a regional minimum floor is that jurisdictions sharing a connected hydrological system need some common baseline on coverage, enforcement credibility, and information sharing. Such a floor preserves room for local variation above the baseline while reducing incentives to externalize harms through regulatory delay, narrow scope, or weak implementation [7-10, 17].

3. Research design and methods

3.1. Comparative policy analysis and case selection

This article uses a comparative policy analysis design rather than predictive modelling. The objective is to evaluate how different legal and institutional choices shape regulatory alignment within a shared ecological setting. A 'most similar systems' logic is employed for New Hampshire, Maine, and Massachusetts: the states share regional proximity, overlapping industrial histories, and hydrological interdependence, yet differ materially in PFAS governance. This comparison makes it possible to isolate how variation in scope, enforcement, substitute governance, and timing relates to different incentives for regulatory arbitrage.

3.2. Data collection and sources

The analysis draws on triangulated secondary sources for the period 2015–2025, the decade in which PFAS contamination became a salient policy issue in New England. Three categories of material are used. First, statutes, administrative rules, and agency documents establish the formal legal architecture of PFAS governance. Second, enforcement records and compliance materials provide proxies for implementation strength, including penalty levels, monitoring density, and exemptions. Third, state monitoring databases and watershed evidence are used as outcome-oriented indicators to examine whether policy timing and concentration trends move together. This design does not claim direct causality; rather, it identifies institutional patterns consistent with regulatory arbitrage and delayed response [19-21].

3.3. Analytical framework and index design

The regulatory gap is assessed through five dimensions that can be compared across jurisdictions: scope, enforcement intensity, monitoring capacity, substitute governance, and responsiveness. Together these dimensions capture not only whether a jurisdiction regulates PFAS, but how credible, comprehensive, and timely that governance is relative to neighboring states. The Policy Alignment Index (PAI) operationalizes these dimensions as a transparent diagnostic tool rather than a predictive or causal model.

3.4. Operationalizing policy alignment: the PFAS policy alignment index (PAI)

To complement the qualitative analysis, the article develops a PFAS Policy Alignment Index (PAI). The PAI is designed as a transparent composite indicator that summarizes the degree to which New Hampshire's PFAS governance aligns with neighboring jurisdictions across legally and institutionally relevant dimensions. Its purpose is diagnostic: it identifies where the regulatory valley is deepest and which governance levers are most likely to improve alignment.

3.4.1. Dimensions and indicator selection

The PAI is constructed around five governance dimensions, chosen to match the paper's empirical structure:

1. Scope (SCOPE): Breadth of regulated PFAS.
2. Enforcement Intensity (ENF): Penalty caps and exemption breadth.
3. Monitoring Capacity (CAP): Monitoring point density.

4. Substitute Governance (SUB): Substitute assessment coverage.
5. Responsiveness (RESP): Speed at which binding rules follow warning signals.

3.4.2. Normalization and scoring

Each indicator is normalized to a 0–1 scale. For 'more-is-better' indicators, the score for jurisdiction i is defined as:

$$Score_i = \frac{x_i}{\max(x)} \quad (1)$$

For "less-is-better" indicators (e.g., number of exemption clauses), an inverse min–max transform is used:

$$Score_i = \frac{(\max(x) - x_i)}{(\max(x) - \min(x))} \quad (2)$$

For responsiveness (RESP), the time lag between a warning signal and a binding rule (Δt) is converted into the categorical scores shown in Table 1.

Table 1. Scoring criteria for the policy responsiveness (RESP) dimension based on temporal lag

Policy lag (L) in years	Responsiveness score	Interpretation of governance speed
≤ 5 years	1.00	Proactive / best practice
6 – 10 years	0.75	Moderate lag
11 – 15 years	0.50	Significant delay
16 – 20 years	0.25	Severe regulatory inertia
No binding rule	0.00	No effective response

4. Results

4.1. The policy design gap: risk-based vs. precautionary frameworks

Comparison across neighboring states suggests a substantial design gap in PFAS governance. As Table 2 shows, New Hampshire uses a risk-based partial restriction model under which regulation depends on the listing of specific substances. In the configuration examined here, this yields coverage of 12 PFAS compounds, concentrated on well-documented legacy substances. Maine, by contrast, has moved toward a phased comprehensive approach to intentionally added PFAS, while Massachusetts applies a stricter emission-control model with broader priority coverage than New Hampshire.

Table 2. Comparison of PFAS regulatory policy frameworks in NH and neighboring states (2025)

State	Regulatory model	Number of substances covered	Key regulated industries/areas	Key time nodes	Main legal basis
NH	Risk-based partial restriction	12 (intentionally added PFOS/PFOA and 10 short-chain PFAS)	Food packaging, public drinking water, former industrial sites	2023.09 Food packaging ban takes effect; 2025.06 Proposed textile facility limits	NHDES PFAS Management Rules (2023); NH PFAS Task Force Act (2021)

Table 2. (continued)

ME	Phased comprehensive ban	28 (all intentionally added PFAS)	Food packaging, cosmetics, textiles, outdoor gear	2024.01 Food packaging ban takes effect; 2032.01 Comprehensive ban	ME Statewide PFAS Ban Act (2021)
MA	Strict emission control + product restrictions	15 (priority PFAS including PFOS/PFOA/PFHxS)	Industrial emission sources (textiles, electronics), drinking water	2024.03 Industrial wastewater limits take effect; 2025.01 Cosmetics ban	MA PFAS Emission Standards (MassDEP 2024); MassDEP Drinking Water Rules (2023)
Vermont	Voluntary industry guidelines + monitoring	8 (key PFAS)	Agricultural runoff, drinking water	2025.01 Mandatory drinking water monitoring starts	Vermont PFAS Monitoring and Assessment Act (2023)

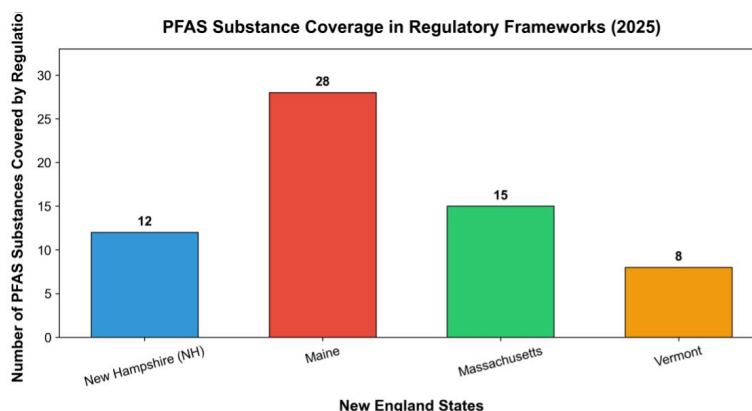


Figure 1. Comparative regulatory scope: PFAS substance coverage in New England regulatory frameworks (2025)

Figure 1 translates this difference into a simple scope comparison. The point is not merely that New Hampshire covers fewer substances, but that its design leaves greater space for the continued use of substitutes that are functionally relevant but not yet listed. In a connected basin, that narrower legal scope can shift risk downstream even when neighboring jurisdictions adopt more precautionary controls.

4.2. The enforcement intensity gap: incentives for regulatory arbitrage

The scope of regulated chemicals goes well beyond those identified in this analysis; however, when looking solely at enforcement, data indicates that states with more stringent enforcement regimes impose higher penalties than those with less stringent regimes. Table 3 compares the statutory maximum penalties in each state based upon the implementation strength of the statute (statutory limit), as well as the exemption clauses. The gap in enforcement intensity indicates that NH's maximum administrative civil penalty for violations is about \$250,000 (Table 3), while MA establishes maximum penalties for comparable industrial violations of up to \$1.5 million.

Table 3. Comparison of PFAS regulatory implementation mechanism strength: penalty caps and exemption clauses across New England states

Evaluation dimension	NH	ME	MA	Evaluation method
Maximum penalty amount	\$250,000 per violation (or 2% of annual revenue for repeat offenders)	\$500,000 per violation	\$1.5 million per violation	Extracted from state environmental laws
Number of exemption clauses	5 items (e.g., medical devices, small-scale textile manufacturers)	3 items (only medical essential uses)	2 items (medical devices, aerospace components)	Statistical analysis of state regulatory texts
Monitoring point density	0.6 per 100 km ² (focused on Merrimack River and public water systems)	1.0 per 100 km ² (statewide drinking water + industrial sites)	1.3 per 100 km ² (industrial zones + rivers + groundwater)	Public data from state environmental agencies (2025)
Number of judicial cases	8 cases (2020–2025; mainly industrial remediation lawsuits)	15 cases (2020–2025; product ban violations + contamination claims)	22 cases (2020–2025; emission violations + drinking water lawsuits)	Statistical analysis of state court records (NH Superior Court, ME District Court)

Table 3 shows that NH provides five different exemption categories (to accommodate the needs of small-scale textile manufacturers) while MA allows only two very limited exemptions (for medical purposes). This six-fold difference in the penalty cap (\$250,000 vs. \$1.5 million), along with the more lenient exemption policies, results in a clear economic disparity. With regard to capital-intensive sectors like electronics manufacturing, where the cost of pollution control systems can run into the millions, this economic disparity results in a lower "shadow price" of pollution in NH. Therefore, it is not surprising that there seems to be a "Regulatory Valley" that exists in the state, which provides a tangible financial incentive for firms engaged in high levels of pollution to continue to do business in NH in order to limit their compliance costs. This is consistent with the explanation of regulatory arbitrage.

4.3. Temporal lag analysis: evidence of soft law precedence

This study compared PFAS concentration trends to the enactment of state laws, as identified in Table 4. The data illustrates how much PFAS concentrations decreased in the Merrimack River watershed for specific groundwater contaminants. Table 4 shows that PFOS's peak concentration occurred in 2008, and it has continued to decrease since then. Since 2008, PFOS concentrations have decreased by 42% as of 2025 (Table 4). The decrease prior to the establishment of mandatory state-level PFAS regulations, including the food packaging ban and public drinking water standards establishing limits on PFAS and other groundwater contaminants, may be attributable in part to the effects of various federal voluntary programs on market-based sources of PFAS-contaminated products.

Table 4. Correlation analysis between historical PFAS environmental concentration changes and policy intervention timing in NH (2000–2025)

Substance type	Year of peak environmental concentration in NH	Major local industry actions	NH regulation effective time	Concentration reduction (peak to 2025)
PFOS	2008 (Merrimack River)	Local textile firm voluntary phase-out (2016)	Food packaging ban (2023); drinking water standard (2024)	42%

Table 4. (continued)

PFOA	2010 (Concord drinking water)	Electronics manufacturer remediation (2019)	Public water system monitoring (2021); industrial guidance (2023)	38%
PFHxS	2012 (Exeter groundwater)	No major industry action	Proposed groundwater limits (2025)	15%
Short-chain PFAS	2018 (Souhegan River)	No collective industry action	No formal regulation (under review)	8%

4.4. Substitution risks: the consequence of narrow scope

As the last element of analysis, the market response to NH's limited regulatory scope has been examined by aggregating data from the EPA Substitute Assessment Report and local industrial surveys. This analysis of aggregate data provides insights into the safety profile of PFAS alternatives currently used in the NH market. As such, it was revealed that the majority of PFAS alternatives were found to be associated with a very high incidence of "Regrettable Substitution" risk.

MA has safety review requirements for 60% of fluoropolymer substitutes used in electronics, whereas NH does not have pre-market assessments for these alternatives. Consequently, only 25% of short-chain PFAS substitutes currently used in NH's textile sector have been classified as hazardous at the state level. This information gap is the result of the "Risk-Based" approach detailed in "The policy design gap: Risk-based vs. precautionary frameworks" subsection; NH's policy framework, focused solely on the well-documented "legacy" PFAS (C8) as the primary concern, has incentivized the use of unassessed short-chain alternatives (C6), which Table 5 shows to be heavily used but not well monitored. Therefore, unless NH adopts a class-based expansion of its classification system similar to ME, NH's environmental improvements may be limited and will not lead to true reductions of toxicity but rather a shift of chemical burden.

Table 5. Comparison of regulatory completeness and risk assessment coverage for PFAS substitutes in key industrial sectors

Substitute type	NH assessment coverage	ME assessment coverage	MA assessment coverage	Main application areas in NH
Fluoropolymers (industrial)	30%	45%	60%	NH electronics manufacturing (e.g., Nashua firms)
Short-chain PFAS (textiles)	25%	50%	55%	NH outdoor textile production (e.g., Manchester)
Fluorine-free substitutes (coatings)	18%	32%	40%	NH automotive and marine coatings

4.4.1. Illustrative calculation (2025 baseline)

Using the coded values reported in Tables 2–5, Table 6 summarizes the illustrative 2025 alignment profile for NH. The baseline PAI uses equal weights across the five dimensions.

Table 6. Illustrative PFAS Policy Alignment Index (PAI) component scores for NH (2025 baseline, computed from Tables 2–5)

Dimension	Operational indicator(s) (source)	NH value (2025)	Benchmark used for normalisation	Dimension score (0–1)
SCOPE	Number of PFAS covered (Table 2)	12	28 (ME)	0.43
ENF	Penalty cap + exemptions (Table 3)	\$0.25M + 5 exemptions	\$1.5M (MA) + 2 exemptions	0.08
CAP	Monitoring density (Table 3)	0.6 / 100 km ²	1.3 / 100 km ² (MA)	0.46
SUB	Substitute assessment coverage (Table 5)	30% / 25% / 18%	60% / 55% / 40% (MA)	0.47
RESP	NH policy-lag score (Table 4)	0.31 (avg.)	1.00 (ideal)	0.31
Overall PAI	Equal-weighted sum			0.35

In this illustrative decomposition, NH's most prominent gap arises in enforcement intensity (ENF), driven by both lower penalty caps and broader exemptions relative to neighboring benchmarks.

To enhance replicability, the intermediate calculations underlying Table 6 are summarised here. SCOPE is computed as the ratio of NH's current coverage (12 substances) to the broadest benchmark in Table 2 (28 substances in ME), yielding $12/28 = 0.43$. ENF is calculated as the unweighted mean of two components: a penalty-cap ratio of $0.25/1.5 = 0.17$ and an exemption-breadth score based on the 2–5 range in Table 3, $(5-5)/(5-2) = 0.00$, giving $ENF = (0.17+0.00)/2 = 0.08$. CAP is computed as $0.6/1.3 = 0.46$. SUB is the mean of three substitute-category ratios in Table 5: $30/60 = 0.50$, $25/55 \approx 0.45$, and $18/40 = 0.45$, yielding $SUB \approx 0.47$. RESP applies the lag-to-score mapping in Table 1 to the four substance categories in Table 4: PFOS (2008→2024) scores 0.25, PFOA (2010→2021) 0.50, PFHxS (2012→2025) 0.50, and short-chain PFAS with no binding rule 0.00; the average is 0.31. With equal weights, the overall index is $PAI = (SCOPE+ENF+CAP+SUB+RESP)/5$, which equals 0.35. This decomposition clarifies that enforcement reforms (penalty caps and exemptions) are the highest-leverage alignment lever, while the proposed Automatic Adoption Clause (AAC) and New England Substitute Information Exchange (NE-SIE) instruments are expected to improve RESP and SUB by shortening review lags and reducing substitute-information asymmetry over time.

5. Discussion

The discussion interprets the results as a problem of institutional misalignment. Taken together, the findings suggest that New Hampshire's regulatory posture is less precautionary, less deterrent, and slower to respond than neighboring regimes, despite shared hydrological interdependence. The case therefore speaks to broader questions in environmental policy and law about how fragmented authority governs mobile contaminants whose effects do not stop at administrative borders.

5.1. The role of soft law: explaining the pre-legislation improvement

In the "Temporal lag analysis" section, the findings counter-intuitively revealed that the levels of PFAS in the Merrimack River watershed were decreasing at a substantial rate from 2010 to 2015, almost ten years prior to when NH passed its main Food Packaging Ban (2023) or created its mandatory drinking water standards for the state. The existence of "policy lag" indicates that it was other forms of policy intervention that contributed to early-stage remediation efforts, rather than state laws being the primary force behind such efforts.

Soft-law scholarship helps explain why firms may react before binding state rules take effect. Non-binding guidance, anticipated regulation, and private governance mechanisms can all alter behavior in advance of formal statutory change, which is consistent with the early-stage decline observed for some legacy PFAS in the Merrimack watershed [13, 15].

A complementary explanation is supply-chain governance. In sectors such as textiles and electronics, major buyers can pressure suppliers to remove high-profile compounds even when state law is still lagging. In that sense, private contracting may temporarily narrow the governance gap created by slow public regulation, although it does not eliminate the institutional vulnerability created by unregulated substitutes [14].

Soft law has failed to adequately respond to the emergence of new substitutes for traditional "long-chain" (C8) and "short-chain" (C6) PFAS, due to differences in physicochemical properties of the substitutes and the C8 chemicals that they are replacing. Many existing "soft law" tools, such as the use of contaminant visibility to generate reputational pressure, are based on the use of C8 chemicals. However, short-chain PFAS, like PFHxA and PFBS, are more soluble in water than C8 chemicals and partition less strongly to organic matter (K_{oc}) than C8 chemicals, allowing them to be much more mobile within aquifers than C8 chemicals and to more easily pass through standard Granular Activated Carbon (GAC) filters, making them effectively "invisible" to existing detection systems. Therefore, the spotlight effect created by "soft law" in the successful phase-out of C8 chemicals was not sufficient to prevent the widespread, diffuse distribution of C6 substitutes [22-25].

5.2. Economic incentives for arbitrage: the rational polluter calculation

The enforcement results are most significant not because they prove firm relocation directly, but because they illuminate the incentive structure facing regulated actors. In a basin characterized by cross-border externalities, lower penalties and broader exemptions can make delayed compliance economically rational even when formal rules exist. The rational-polluter framework therefore helps interpret the penalty gap as an institutional design problem rather than a purely administrative detail [10, 26].

A simplified compliance condition can be stated as follows: a firm has an incentive to remain non-compliant when the cost of abatement (C_a) exceeds the expected penalty ($p \times F$), where p is the probability of detection and F is the applicable sanction.

Non-compliance if $C_a > p \times F$

On the data used here, New Hampshire combines a lower statutory penalty ceiling with lower monitoring density than Massachusetts. This configuration depresses the expected penalty relative to the likely cost of advanced treatment or process substitution. The article does not claim to observe firm decisions directly, but the structure of the incentives is consistent with regulatory arbitrage becoming more attractive at the margin.

The familiar 'race to the bottom' formulation is therefore useful here not as a slogan, but as a description of how inter-jurisdictional competition can weaken deterrence without formal deregulation. In the New Hampshire case, the relevant mechanism is a combination of lower sanctions, broader exemptions, and slower policy adaptation, all of which make the jurisdiction relatively more attractive to risk-tolerant actors [8, 9].

5.3. The failure of risk-based approach: the trap of regrettable substitution

The "Scope gap", as stated in the "The policy design gap: Risk-based vs. precautionary frameworks" subsection, evidences the structural limitations of NH's Risk-Based regulatory framework. The state participates in a regulatory form of "Whack-a-Mole" as it limits regulation to just 12 specific substances. Data presented in "Substitution risks: The consequence of narrow scope" indicate that in response to narrow bans, some industries are shifting to short-chain unregulated variants (e.g., C6 fluorotelomers) and engaging in a process known as "Regrettable Substitution" [1].

The scientific and policy concern is therefore not simply substitution, but the governance trap that substitution creates. If short-chain replacements retain persistence and mobility, then a jurisdiction that regulates only listed legacy compounds may appear active while leaving the central regulatory loophole intact. That is why the contrast between risk-based listing and class-based or essential-use governance matters so much in this case [3, 16].

5.4. Limitations and avenues for further research

This study has several limitations that should be considered when interpreting the findings. First, the analysis relies on triangulated secondary sources (statutes, agency summaries and monitoring databases). Although this approach supports transparency and replicability, cross-state comparisons can be affected by differences in analytical methods, reporting practices and monitoring coverage, which may introduce measurement error into both the enforcement and outcome proxies. Second, the PAI is intentionally designed as a diagnostic index rather than a causal model. The equal-weighting scheme and the aggregation of diverse indicators inevitably simplify complex legal provisions and institutional practices; future work could explore alternative weighting (e.g., expert elicitation) and conduct sensitivity analysis. Third, the paper infers incentives for regulatory arbitrage from scope and enforcement differentials, but does not directly observe firm relocation decisions or facility-level compliance strategies. Linking the index to firm behaviour would require additional micro-level evidence (e.g., permitting histories, enforcement records or interviews). Finally, the environmental outcome analysis focuses on available long-run concentration summaries in key watersheds and drinking water systems; broader media (e.g., soils, biosolids) and additional water bodies may show different lag structures. Future research should therefore test whether the proposed AAC and NE-SIE mechanisms measurably reduce policy lag and substitution risk over time, using longitudinal post-implementation evaluation.

6. Policy and institutional implications

6.1. Local recommendation: from reactive to adaptive governance

The analysis in the Results section identified a persistent "Policy lag" in NH's governance, where state mandates trailed environmental turning points by nearly 15 years. To close this temporal gap

and mitigate the risk of becoming a permanent "Regulatory Valley," NH should transition from its current reactive, chemical-by-chemical approach to an Adaptive Governance model.

Two institutional reforms follow from this analysis. First, New Hampshire could adopt a Statutory Trigger Mechanism—framed here as an Automatic Adoption Clause (AAC)—requiring expedited review when two or more neighboring New England jurisdictions classify a PFAS substance as hazardous or impose a material control. Such a mechanism would not automatically copy neighboring rules, but it would remove default inaction and force a reasoned public response. Second, the state could narrow the enforcement-intensity gap by revisiting penalty ceilings and exemption breadth so that non-compliance is not systematically cheaper than compliance.

6.2. Regional recommendation: a substitute information exchange

The "Scope gap" studied in the "Substitution risks" subsection shows that NH has no administrative capability to evaluate the thousands of short-chain fluorinated substances being introduced into the marketplace independently. The lack of information creates the conditions for "Regrettable Substitution." To address these issues without incurring tremendous costs on a state's budget, NH should spearhead the development of the NE-SIE.

This regional body acts as a technical shared clearinghouse. NE-SIE also provides access for NH to use the pre-market safety reviews that ME and MA currently require for many industrial chemicals. Scientific resources can be pooled to create a common Red List of regrettable substitutes. NE-SIE will reduce the technical barriers for NH to transition from its narrow list of 12 substances, as well as to a broader class-based approach consistent with the Precautionary Principle.

6.3. Implementation roadmap (2026–2032): operationalizing a regional minimum floor

The analysis in Tables 2–5 and the PAI decomposition Table 6 provide evidence to develop a roadmap for implementing an established framework for building a regional baseline. This entails creating a practical approach, while still supporting the appropriate balance of political and administrative considerations throughout the region. To that end, a phased approach is proposed to implement a foundational level, which will be carried out through two primary tools focused on addressing regulatory arbitrage.

1. The AAC: A provision that requires that when two or more neighbouring states in New England adopt major PFAS controls, these controls must be reviewed quickly by the NHDES. This will address the Responsiveness gap between neighbouring states (RESP).

2. The NE-SIE: A web-based technical platform for sharing assessments of PFAS substitutes. This addresses issues with substitute governance (SUB).

Developing the backbone will occur in Phase I, which begins in 2026. Deliverables for this phase will be to create a list of all components that will become standard under the PFAS regulations; to provide for development of an annual report to establish a clear baseline indication of what is in development; and to institutionalise the rapid review process as part of the AAC.

Phase II (2027–2028) will see the continual improvement of the AAC as the identified method for ensuring that NH, as a minimum floor, is kept up to date on the current status of substitutes. NE-SIE will transition from the design to the operational phase by establishing a "watch list" concept under which a final decision will be made collectively and shared by all states participating in this regional initiative. In addition, NH will implement "essential use" exemptions for specific applications under tightly defined timelines that will be granted only if all potential substitutes are disclosed to the public.

Phase III of NE-SIE outputs in 2029–2032 aims to unify and integrate NE-SIE outputs into permitting and procurement practices. This phase involves negotiating and signing agreements with other states (and hopefully the Federal Government) for mutual recognition of analytical protocols. It also includes making reforms to enforcement credibility (penalty caps) to create a comparable level of expected costs of non-compliance within NH and its neighbouring states.

6.4. Feasibility and political economy

A recurring challenge in NH is not only technical capacity but also political economy. A feasible alignment strategy therefore needs instruments that preserve local discretion while targeting arbitrage mechanisms.

The AAC is designed to meet political feasibility by being able to have a regulated process for the review of inter-state changes rather than just adopting the neighbouring states' rules. The NE-SIE meets capacity limitations by pooling resources and allowing small and medium businesses to receive guidance for transition without doing their own toxicology work. To keep competitive and restore an effective deterrent to illegal behaviour, enforcement reforms must go along with clear timing and compliance milestones. This will ensure non-compliance doesn't have a lower cost than compliance. This is consistent with the interpretation of "higher vs. lower" environmental federalism, also known as "the race to the top" [10].

7. Conclusion

This article asked whether New Hampshire's risk-based PFAS model operates as a defensible form of regulatory flexibility or as a source of regional vulnerability. On the evidence assembled here, the second interpretation is more persuasive. Differences in policy scope, enforcement intensity, substitute governance, and timing collectively suggest that New Hampshire functions as a regulatory valley within a connected basin.

The key implication is institutional. Basin protection cannot be secured solely through the efforts of the stricter jurisdiction if a neighboring jurisdiction maintains lower deterrence, narrower coverage, and slower adaptation. Early concentration declines also appear to owe part of their trajectory to soft-law dynamics—federal voluntary programs and supply-chain pressure—rather than to state legislation alone.

The Merrimack case illustrates a general lesson in environmental policy and law: where ecological connectivity outruns jurisdictional coordination, fragmented governance creates incentives for arbitrage. A regional minimum floor, coupled with faster rule-updating and shared substitute information, offers one way to reduce that gap without eliminating local autonomy.

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