



UK Health
Security
Agency

The health impacts from industrial sources of PFAS: a rapid evidence review

Annexes B and C

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Annexe B. Evidence synthesis: supporting information

Considerations to inform judgements on evidence during evidence synthesis were based on U.S EPA guidance in their Systematic Review Protocol for the PFBA, PFHxA, PFHxS, PFNA, and PFDA (anionic and acid forms) IRIS Assessments (6). Used criteria are outlined below:

Table 1. Considerations to inform judgements regarding strength of evidence

Consideration	Increased evidence strength	Decreased evidence strength
Critical appraisal outcome	An evidence base of high or medium confidence studies increases strength. Typically, medium confidence in only a single study is not a factor that increases certainty, whereas high confidence in a single, extensive or rigorous study is such a factor.	An evidence base of mostly low confidence studies decreased strength. Decisions to increase strength for other considerations in this table should generally not be made if there are serious concerns for risk of bias
Consistency	Similarity of findings for a given outcome (for example, of a similar magnitude, direction) across independent studies increases strength, particularly when consistency is observed across populations (for example, geographical location) or exposure scenarios.	Unexplained inconsistency, for example, conflicting evidence decreases strength. Generally, strength should not be decreased if discrepant findings can be reasonably explained by study confidence conclusions; variation in population, sex, or life stage; exposure patterns (for example, intermittent or continuous); exposure levels (low or high); or exposure duration.
Strength (effect magnitude)	Evidence of a large magnitude effect (considered either within or across studies) can increase strength. Effects of a concerning rarity or severity can also increase strength, even if they are of a small magnitude.	Strength may be decreased if effect sizes that are small in magnitude are concluded not to be biologically significant.

Table 2. Summary of evidence judgements

Strength of evidence judgement	Descriptive terminology	Description
Robust (strong evidence of effect with little residual uncertainty)	Evidence demonstrates	<p>A set of high or medium confidence independent studies reporting an association between the exposure and the health outcome, with reasonable confidence that alternative explanations, including chance, bias, and confounding, can be ruled out across studies.</p> <p>The set of studies is primarily consistent, with reasonable explanations when results differ; and an exposure- response gradient is demonstrated. Supporting evidence, such as associations with biologically related endpoints within or across human studies (coherence) or large estimates of risk or severity of the response, may help to rule out alternative explanations.</p> <p>Mechanistic evidence, if available, may add support by informing considerations such as exposure response, temporality, coherence, and biological plausibility (that is, evidence consistent/inconsistent with mechanistic understanding of how chemical exposure could cause the health effect based on current biological knowledge), thus raising the level of certainty to robust for a set of studies that otherwise would be described as moderate.</p>
Moderate (evidence of effect with some uncertainty)	Evidence indicates (likely)	<p>A smaller number of studies (at least one high or medium confidence study with supporting evidence) that do not reach the certainty required for robust. For multiple studies, there is primarily consistent evidence of an association, but with some residual uncertainty due to potential chance, bias, or confounding (for example, effect estimates of low magnitude or small effect sizes given what is known about the endpoint; uninterpretable patterns with respect to exposure levels).</p> <p>For a single high or medium confidence study, there is supporting evidence increasing certainty in the findings such as a large magnitude or severity of the effect, a dose-response gradient, or other factors that increase the evidence strength, without serious residual uncertainties</p>

Strength of evidence judgement	Descriptive terminology	Description
Slight (evidence of effect with large amount of uncertainty)	Evidence suggests	<p>One or more studies reporting an association between exposure and the health outcome, where considerable uncertainty exists. In general, the evidence is limited to a set of consistent low-confidence studies, a single high or medium confidence study without supporting evidence, or higher confidence studies with unexplained heterogeneity (for example, comparable studies of similar confidence and sensitivity provide conflicting evidence, or the differences cannot be reasonably explained by, for example, the populations or exposure levels studied).</p> <p>This includes scenarios in which there are serious residual uncertainties across studies (these uncertainties typically relate to exposure characterization or outcome ascertainment, including temporality) in a set of largely consistent medium or high confidence studies.</p>
Indeterminate (evidence cannot be determined for or against an effect)	Inadequate evidence	<p>No studies of exposed human, or situations when the evidence is highly inconsistent and primarily of low confidence. In addition, this may include situations where higher confidence studies exist, but unexplained heterogeneity exists, and there are additional outstanding concerns such as effect estimates of low magnitude, uninterpretable patterns with respect to exposure levels, or uncertainties or methodological limitations that result in an inability to discern effects from exposure.</p> <p>A set of largely null studies could be concluded to be indeterminate if the evidence does not reach the level required for compelling evidence of no effect.</p>
Compelling evidence of no effect	Strong evidence supports no effect critical	<p>Several high confidence studies showing null results (for example, an odds ratio of 1.0), ruling out alternative explanations including chance, bias, and confounding with reasonable confidence.</p> <p>Each of the studies should have used an optimal outcome and exposure assessment and adequate sample size (specifically for higher exposure groups and for susceptible populations). The overall set should include the full range of levels of exposures that human beings are known to encounter, and an evaluation of an exposure-response gradient.</p>

Annexe C. Exposure categorisation methods and concentrations

Numbers in round brackets in column one refer to references. They are numbered according to the full set of 90 references which can be found in [the main report](#).

Table 3. Summary of exposure categorisation methods and concentrations for Mid-Ohio Valley based papers from which statistically significant data was assessed in this review

Paper	Categorisation method	Concentrations
Barry V and others (2013) (14)	Modelled PFOA serum concentration (per unit for all outcomes with no lag and a 10 year lag, and in quartiles for some select outcomes (thyroid, kidney and testicular cancer).	<p>Specific concentrations are not provided by the authors for modelled PFOA serum concentration (no lag and a 10-year lag), nor for quartiles of exposure which were considered in the analysis of some select outcomes (thyroid, kidney and testicular cancer).</p> <p>For the community cohort, estimated median annual PFOA serum levels (ng/mL) and measured median (measurements taken in 2005 to 2006) PFOA serum levels (ng/mL) of:</p> <ul style="list-style-type: none"> • estimated: 19.4 • measured: 24.4
Darrow LA and others (2013) (21)	Quintiles of measured maternal serum levels of PFOA and PFOS.	<p>PFOA (ng/mL)</p> <ul style="list-style-type: none"> • Q1(reference): 0 to <6.9 • Q2: 6.9 to <11.1 • Q3: 11.1 to <18.9 • Q4: 18.9 to <37.2 • Q5: ≥37.2 <p>PFOS (ng/mL)</p> <ul style="list-style-type: none"> • Q1(reference): 0 to <8.6

Paper	Categorisation method	Concentrations
		<ul style="list-style-type: none"> • Q2: 8.6 to <12.1 • Q3: 12.1 to <15.9 • Q4: 15.9 to <21.4 • Q5: ≥21.4
Savitz D and others (2012a) (13)	Percentiles (combined into 4 exposure categories) of modelled PFOA serum concentration.	Percentiles (ng/mL) <ul style="list-style-type: none"> • less than 40th percentile (reference): 3.9 to <6.8 • 40th to <60th percentile: 6.8 to <16.6 • 60th to <80th percentile: 16.6 to <63.1 • ≥80th percentile: 63.1 to 934.3.
Simpson C and others (2013) (20)	Quintiles of modelled PFOA serum concentration, unlagged and with a 5 year lag period.	Retrospective cohort – unlagged (ng/mL) <ul style="list-style-type: none"> • Data for Q1 (reference) not provided. • Q2: >178 to 319 • Q3: >319 to 912 • Q4: >912 to 4490 • Q5: >4490 Retrospective cohort – lagged (ng/mL) <ul style="list-style-type: none"> • Data for Q1 (reference) not provided. • Q2: >130 to 217 • Q3: >217 to 560 • Q4: >560 to 3420 • Q5: >3,420

Paper	Categorisation method	Concentrations
Steenland K and others (2013) (25)	Quartiles of modelled PFOA serum concentration, unlagged and with a 10 year lag period	<p>Retrospective analysis of ulcerative colitis; cut points (ng/mL/ per year) of:</p> <ul style="list-style-type: none"> • 158 • 586 • 3,500 <p>Cut points are based on cumulative exposure at age of first diagnosis, for instance for a 50-year-old participant, the cut points correspond to average exposure (ng/mL per year) of:</p> <ul style="list-style-type: none"> • Q1 (reference): < 3 • Q2: 3 to 11 • Q3: 11 to 70 • Q4: >70 <p>Corresponding average exposures would differ for lagged and unlagged exposure; authors do not specify if above is for lagged or unlagged exposure data.</p>
Stein C and others (2013) (26)	Quartiles of exposure modelled in utero PFAS serum concentrations	<p>Quartiles (ng/mL)</p> <ul style="list-style-type: none"> • Q1 (reference): 4.5 to <11.7 • Q2: 11.7 to <43.7 • Q3: 43.7 to <110.8 • Q4: 110.8 to 649.2
Winqvist A and others (2014a) (28)	Quintiles of modelled PFOA serum concentration	<p>Cut points (µg/mL per year) for coronary artery disease</p> <ul style="list-style-type: none"> • Q1 (reference): less than 0.147 • Q2: 0.14 to <0.248 • Q3: 0.248 to <0.717

Paper	Categorisation method	Concentrations
		<ul style="list-style-type: none"> • Q4: 0.717 to <5.058 • Q5: ≥5.058 <p>Cut points (µg/mL per year) for hypertension</p> <ul style="list-style-type: none"> • Q1 (reference): <0.111 • Q2: 0.111 to <0.191 • Q3: 0.191 to <0.471 • Q4: 0.471 to <2.763 • Q5: ≥2.763
Winqvist A and others (2014b) (29)	Quintiles of modelled PFOA serum concentration	<p>Retrospective analysis, cumulative exposure (combined cohort and community only cohort) (µg/mL per year)</p> <ul style="list-style-type: none"> • Q1 (reference): 0.0001 to <0.1147 • Q2: 0.1147 to <0.2022 • Q3: 0.2022 to <0.4973 • Q4: 0.4973 to <2.676 • Q5: 2.676 to 97.396 <p>Retrospective analysis, yearly exposure (combined cohort and community only cohort) (ng/mL)</p> <ul style="list-style-type: none"> • Q1 (reference): 0.1061 to <4.7424 • Q2: 4.7424 to <8.4889 • Q3: 8.4889 to <21.583 • Q4: 21.583 to <100.14 • Q5: 100.14 to <3303.3

Table 4. Summary of exposure categorisation methods and concentrations for Ronneby based papers from which statistically significant data was assessed in this review

Paper	Categorisation method	Concentrations
Ebel M and others (2025) (39)	Mothers' residential address history in the 5 years prior to childbirth used as a proxy for prenatal exposure	<p>Hierarchical categorisation of 'very high', 'high', 'intermediate' or 'background' (the reference group) exposure, validated against measured serum levels. Median serum concentrations (ng/mL) for the exposure groups of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • high: 169 • intermediate: 48 • background: 4 <p>PFHxS</p> <ul style="list-style-type: none"> • high: 129 • intermediate: 40 • background: 0.8 <p>PFOA</p> <ul style="list-style-type: none"> • high: 9 • intermediate: 3 • background: 2
Engström K and others (2022) (40)	Mothers' residential address history in the 5 years prior to childbirth used as a proxy for in utero exposure	<p>Hierarchical categorisation of 'high', 'low' or background (the reference group) exposure, validated against measured serum levels. Average serum concentrations (ng/mL) for exposure groups of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • exposed: 239 • Ronneby background: 40 • reference neighbouring municipality: 3.9

Paper	Categorisation method	Concentrations
		<p>PFHxS</p> <ul style="list-style-type: none"> • exposed: 210 • Ronneby background (Ronneby): 30 • reference neighbouring municipality: 0.84 <p>PFOA</p> <ul style="list-style-type: none"> • exposed: 13 • Ronneby background: 3.5 • reference neighbouring municipality: 1.5
Hammarstrand S and others (2021) (37)	Residential address-based exposure assessment	<p>Categorisation of ‘never-high’ or ‘ever-high’ exposure (and additional time-based categorisation of ‘never-high’, ‘early-high’ or ‘late-high’ exposure), validated against measured serum levels. Median serum concentrations (ng/mL) for the exposure groups of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • never-high: 34.7 • ever-high: 227 • early-high: 38.3 • late-high: 279 • background (reference): 4.3 <p>PFHxS</p> <ul style="list-style-type: none"> • never-high: 26.8 • ever-high: 194 • early-high: 37.9 • late-high: 243 • background (reference): 0.9

Paper	Categorisation method	Concentrations
		<p>PFOA</p> <ul style="list-style-type: none"> • never-high:3.2 • ever-high: 12.7 • early-high: 2.9 • late-high:15.2 • background (reference): 1.6
<p>Li H and others (2022) (33)</p>	<p>Residential address-based exposure assessment</p>	<p>Categorisation of ‘never-high’ or ‘ever-high’ exposure (and an alternative additional time-based categorisation of ‘never-high’, ‘early-high’ or ‘late-high’ exposure), validated against measured serum levels. Geometric mean serum concentrations (ng/mL) for the exposure groups of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • never-high: 40 • ever-high: 199 • early-high: 48 • late-high: 239 • background (reference): 3.9 <p>PFHxS</p> <ul style="list-style-type: none"> • never-high:30 • ever-high: 176 • early-high: 43 • late-high: 210 • background (reference): 0.84 <p>PFOA</p> <ul style="list-style-type: none"> • never-high: 3.5

Paper	Categorisation method	Concentrations
		<ul style="list-style-type: none"> • ever-high: 11 • early-high: 3.6 • late-high: 13 • background (reference): 1.5
Nielsen C and others (2022) (31)	Mothers' residential address history in the 5 years prior to childbirth used as a proxy for childhood exposure	Categorisation of 'high', 'low' or 'background' (the reference group) exposure, validated against measured serum samples from a different study. Concentration data not provided.
Stübner C and others (2023) (41)	Mothers' residential address history in the 5 years prior to childbirth used as a proxy for prenatal exposure	<p>Hierarchical categorisation of 'high', 'intermediate' or 'background' exposure, validated against measured serum concentrations. Median serum concentrations (ng/mL) for the exposure groups of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • high: 169 • intermediate:48 • background:4 <p>PFHxS</p> <ul style="list-style-type: none"> • high: 129 • intermediate: 40 • background: 0.8 <p>PFOA</p> <ul style="list-style-type: none"> • high: 9 • intermediate: 3 • background: 2

Paper	Categorisation method	Concentrations
Xu Y and others (2020) (35)	Exposure assessed based on participants yearly residence addresses	Categorisation of ‘never-high’ or ‘ever-high’ exposure (and additional time-based categorisation of ‘not exposed’, ‘early’, ‘mid’ or ‘late’ exposure). Details of PFAS serum concentrations corresponding to these categories is not provided by the authors
Xu Y and others (2023a) (30)	Exposure assessed based on participants yearly residence address/es	<p>Categorisation of ‘never-high’ or ‘ever-high’ exposure (with the ‘ever-high’ exposure group being divided into ‘early-high’ and ‘late-high’ exposure for some analyses), validated against measured serum concentrations. Median serum concentrations (ng/mL) for the exposure groups of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • never-high: 42 • early-high: 50 • late-high: 253 • reference: 4 <p>PFHxS</p> <ul style="list-style-type: none"> • never-high: 34 • early-high: 48 • late-high: 226 • reference: 1 <p>PFOA</p> <ul style="list-style-type: none"> • never-high 4 • early-high 3 • late-high 14 • reference 2 <p>Concentrations for the ‘ever-high’ exposure group were not provided by the authors.</p>

Paper	Categorisation method	Concentrations
Xu Y and others (2023b) (36)	Exposure assessed based on participants yearly residence address/es	Categorisation of 'never-high' or 'ever-high' exposure (with the 'ever-high' exposure group being divided into 'early-high' and 'late-high' exposure for some analyses). Details of the PFAS serum concentrations corresponding to these categories is not provided by the authors.

Table 5. Summary of exposure categorisation methods and concentrations for Veneto based papers from which statistically significant data was assessed in this review

Paper	Categorisation method	Concentrations
Berti M and others (2025) (45)	Quartiles of modelled PFOA serum concentration	Retrospective analysis (ln-ng/mL) <ul style="list-style-type: none"> • Q1 (reference): 1.15 to 48.3 • Q2: 48.3 to 110 • Q3: 110 to 223 • Q4: 223 to 1070
Manea S and others (2020) (44)	Maternal residential address-based exposure assessment (according to maternal residence reported on birth certificates)	<p>Categorisation of 'contaminated area' or 'control area', validated against measured serum concentrations. Median serum concentrations (ng/g) for the exposure groups of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • exposed: 8.69 • non-exposed: 5.84 <p>PFOA</p> <ul style="list-style-type: none"> • exposed: 13.77 • non-exposed: 1.64

Table 6. Summary of exposure categorisation methods and concentrations for Australia based papers from which statistically significant data was assessed in this review

Paper	Categorisation method	Concentrations
Law HD and others (2023a) (46)	Binary exposure assessment with 3 different exposed communities..	<p>Binary exposure assessment (exposed or not exposed). Ranges of geometric means of serum PFAS concentrations (ng/mL) the 3 exposed study areas of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • 4.9 to 6.6 <p>PFHxS</p> <ul style="list-style-type: none"> • 2.9 to 3.7 <p>PFOA</p> <ul style="list-style-type: none"> • 1.3 to 1.8
Law HD and others (2023b) (47)	Binary exposure assessment with 3 different exposed communities.	<p>Binary exposure assessment (exposed or not exposed). Ranges of median serum PFAS concentrations (ng/mL) for the 3 exposed study areas of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • 4.8 to 6.1 <p>PFHxS</p> <ul style="list-style-type: none"> • 2.9 to 3.9 <p>PFOA</p> <ul style="list-style-type: none"> • 1.3 to 1.9

Table 7. Summary of exposure categorisation methods and concentrations for the Minnesota-based paper from which statistically significant data was assessed in this review

Paper	Categorisation method	Concentrations
Waterfield G and others (2020) (50)	Mothers' residential zip code at time of infants' birth used as proxy for PFAS exposure	<p>In 2008 residents in affected areas known to have elevated serum concentration, geometric means (ng/mL) of:</p> <p>PFOS</p> <ul style="list-style-type: none"> • 35.9 <p>PFOA</p> <ul style="list-style-type: none"> • 15.4 <p>No further information around exposure concentrations provided by the authors.</p>

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These references are cited in the tables above. The numbering is based on the complete set of 90 references which can be found in [the main report](#).

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