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Environmental impacts to soil and groundwater at airports: origin, contaminants of concern and environmental risks

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SUPPLEMENTARY MATERIAL

Table I. Origins of the contaminants of concern at airports

Airport identification	Matrix	Origin								In use	Reference	
		Surface runoff			Fuel leaks			Dir. Dep. ARFF	Accidental releases			Atm. dep.
		Runoff and piping	ADAF	Repair shops	Fuel farm	Fuel hydrant system	Fuel distr.					
Castle AFB, USA	S, Gw	X		X				X			1941–1995	1
Crystal City Airport, USA	S	X									1945-1987	2
Middletown, USA	S, Gw			X							1942-	3
Unspecified airport	S, Gw							X			-	4
Tyndall Air Force Base, USA	Gw							X			1941-	5
Wurtsmith Air Force Base, USA	Gw							X			1923-1993	6
Tri-County P. Airport, USA	Gw			X							1942-1948	7
Seattle-Tacoma I.A., USA	S, Gw				X	X	X				1944-	8
Yakima Airport, USA	S, Gw				X						1928-	9
New Hanover CNTY Airport, USA	S, Gw							X			1968-1979**	10
Twin Cities Res. AFB, USA	S, Gw			X	X	X	X				1940-	11
George AFB, USA	S, Gw			X	X	X					1941–1992	12
Marine Corps AS Yuma, USA	S, Gw			X	X			X			1959-	13
El Toro Marine C. Air Station, USA	Gw			X							1943 - 1999	14
Hanscom AFB, USA	Gw										1942-	15
Travis AFB, USA	Gw				X			X			1942-	16
Vandenberg AFB, USA	Gw				X			X			1957-	16
Minneapolis I.A., USA	S					X					1921-	17
Toronto I.A. Canada	S					X					1939-	18
Kai Tak Airport, Hong Kong	S	X			X		X				1925-1998	19

Airport identification	Matrix	Origin							Accidental releases	Atm. dep.	In use	Reference
		Surface runoff			Fuel leaks			Dir. Dep.				
		Runoff and piping	ADAF	Repair shops	Fuel farm	Fuel hydrant system	Fuel distr.	ARFF				
Hradcany army AB, Czech Rep.	S									1945-	20	
Portland-Troutdale Airport, USA	S			X						1942-	21	
Sangster I.A., Jamaica	S, Gw					X				1947-	22	
Deblin, military airfield, Poland	S								X	-	23	
Delhi I.A., India	S								X	1940s-	24	
Monchegorsk air base, Russia	S								X	-	25	
French airport	S								X	-	26	
Santa Monica Airport, USA	S								X	1920s-	27	
Oslo Gardermoen I.A., Norway	S, Gw							X		1998-	28	
Gaiziunai M.A., Lithuania	Gw	X								1939-	29	
Fornebu Airport, Norway	S									1940s-1998	30	
4 airports in Croatia	S	X(4)							X(4)	X(4)	-	31
Airport near Berlin, Germany	S	X									-	32
Fairchild AFB, USA	Gw		X								1942-	33
North American I.A., USA	Gw	X	X								-	34
Bellingham I.A., USA	S		X							X	1940-	35
Fairchild AFB, USA	S, Gw		X							X	1942-	35
General Mitchell I.A., USA	S		X							X	1920-	35
Fornebu Airport, Norway	S, Gw		X								1940s-1998	36
Perth Airport, Australia	S, Gw	X			X	X	X	X			1943-	37
5 Air Force Bases, USA	Gw				X(5)						-	38
Kluczewo military airport, Poland.	S, Gw				X						1935-	39
Genève I.A., Switzerland	S	X								X	1920-	40
Berlin, military airfield, Germany	Gw				X						-	41
Hradcany AFB, Czech Republic	S				X						1945-	42
Sum of subtype origin		12	6	8	17	7	7					
%		23.0	11.5	15.5	32.7	13.5	13.5					
Sum of origin*			24			20		7	4	13		
%			46.2			38.5		13.5	7.7	25.0		

Gw: groundwater; S: soil. *: when any of the origin subtypes occur; **: refers to the facility, not the airport

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Table II. Contaminants found in soil and groundwater at airports

Airport identification	Contaminants																			
	Petroleum hydrocarbons			Solvents						Pesticides	ADAF	ARFF		Heavy Metals						
	BTEX	Fuel & Oil	PAH	TCE	PCE	cis-1,2-DCE	PCB	CCl ₄	PFC			Cd	Cr	Cu	Ni	Hg	As	Pb	Zn	
Castle AFB, USA	X	X		X	X	X						X	X	X	X		X	X	X	
Crystal City Airport, USA		X								X										
Middletown, USA				X						X										
Unspecified airport												X								
Tyndall Air Force Base, USA												X								
Wurtsmith Air Force Base, USA												X								
Tri-County P. Airport, USA				X																
Seattle-Tacoma I.A., USA	X	X																		
Yakima Airport, USA	X	X																		
New Hanover CNTY Airport, USA	X	X	X			X							X							
Twin Cities Res. AFB, USA	X			X																
George AFB, USA	X	X		X																
Marine Corps AS Yuma, USA	X	X		X	X	X				X									X	
El Toro Marine C. Air Station, USA				X	X			X												
Hanscom AFB, USA	X	X	X	X	X	X														
Travis AFB, USA	X	X																		
Vandenberg AFB, USA	X	X																		
Minneapolis I.A., USA		X																		
Toronto I.A. Canada		X																		
Kai Tak Airport, Hong Kong	X	X																		
Hradcany army AB, Czech Rep.		X																		
Portland-Troutdale Airport, USA				X									X						X	
Sangster I.A., Jamaica		X																		
Deblin, military airfield, Poland			X																	
Delhi I.A., India			X																	
Monchegorsk air base, Russia			X																	
French airport			X																	
Santa Monica Airport			X																	
Olso Gardermoen I.A., Norway	X	X	X																	
Gaiziunai M.A., Lithuania		X																		
Fornebu Airport, Norway			X																	
4 airports in Croatia								X(4)												
Berlin Airport, Germany								X												
Fairchild AFB, USA											X									
North American I.A.												X								
Bellingham I.A., USA												X								
Fairchild AFB, USA												X								

Airport identification	Contaminants																			
	Petroleum hydrocarbons			Solvents						Pesticides	ADAF	ARFF		Heavy Metals						
	BTEX	Fuel & Oil	PAH	TCE	PCE	<i>cis</i> -1,2-DCE	PCB	CCl ₄	PFC			Cd	Cr	Cu	Ni	Hg	As	Pb	Zn	
General Mitchell I.A., USA											X									
Fornebu Airport, Norway											X									
Perth Airport, Australia													X	X	X	X	X	X	X	
5 Air Force Bases, USA	X(5)	X(5)																		
Kluczewo military airport, Poland.	X	X																		
Genève I.A., Switzerland													X		X				X	
Berlin, former military airfield	X	X	X																X	
Hradcany AFB, Czech Republic		X																		
Total	19	25	10	9	4	4	5	1					2	4	3	2	1	2	5	
%	36.5	48.1	19.2	17.6	7.8	7.8	9.8	2.0					3.9	7.8	3.9	3.9	2.0	3.9	7.8	
Total		33				15			3	6	3				6					
%		63.5				29.4			5.9	11.8	5.9				11.8					

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Table III. Health and ecological hazards for contaminants found at airports

Chemical	Ecological hazard	Health hazard	
TCE	$PNEC_{\text{water}}=115 \mu\text{g/l}$, $PNEC_{\text{sediment}}=316 \mu\text{g/g}$, $PNEC_{\text{soil}}=202 \mu\text{g/kg}$ ⁴³ .	Probably carcinogenic ⁴³⁻⁴⁵ .	
PCE	$PNEC_{\text{water}}= 51 \mu\text{g/l}$, $PNEC_{\text{sediment}}=318 \mu\text{g/kg}$ and $PNEC_{\text{soil}}=10 \mu\text{g/kg}$, ⁴³ .	Toxic at high concentrations ⁴³⁻⁴⁵ , carcinogenicity not yet determined.	
<i>cis</i> -1,2-DCE	$PNEC_{\text{water}}=45 \mu\text{g/l}$, $PNEC_{\text{sediment}}=318 \mu\text{g/kg}$ and $PNEC_{\text{soil}}=10 \mu\text{g/kg}$ ⁴⁶ .	Mild toxicity ^{43,44} . 1,1-DCE: subchronic NOAEL of 0.09 mg/kg bw/d ⁴⁷ ; <i>cis</i> -1,2-DCE: subchronic NOAEL of 3.2 mg/kg bw/d (trans-1,2-DCE: NOAEL of 1.7 mg/kg bw/d) ⁴⁸ .	
1,1,-DCE			
PCB	PNEC for compartments not available.	Probable human carcinogen ^{43,44} .	
MtBE	$PNEC_{\text{water}}=2.6 \text{ mg/l}$, $PNEC_{\text{sediment}}=2.05 \text{ mg /kg}$ ⁴⁹	Mild toxicity ⁵⁰ . Oral NOAEL of 300 mg /kg and respiratory NOAEL of 800 ppm. Human cancer risk is presumed to be low ⁴⁹ .	
Benzene	$PNEC_{\text{water}}=80 \mu\text{g/l}$ and $PNEC_{\text{soil}}=200 \mu\text{g/kg}$ ⁴³ .	Human carcinogen ⁴³⁻⁴⁵ .	
Toluene	$PNEC_{\text{water}}=74 \mu\text{g/l}$ and $PNEC_{\text{soil}}=0.3 \text{ mg/kg}$ ⁴³ , $PNEC_{\text{sediment}}= 343 \mu\text{g/kg}$ ⁵¹ .	Mild toxicity: subchronic NOAEL of 625 mg/kg bw/d ⁴³⁻⁴⁵ .	
Ethylbenzene	$PNEC_{\text{water}}=100 \mu\text{g/l}$, $PNEC_{\text{sediment}}=1017 \mu\text{g/kg}$ and $PNEC_{\text{soil}}=776 \mu\text{g/kg}$ ⁴³ .	Mild toxicity ⁴³⁻⁴⁵ . Limited data on humans.	
Xilenes	PNEC for compartments not available.	Mild toxicity, data are still inadequate for an assessment of the carcinogenic potential of xylenes ^{43,44} . Subchronic NOAEL of 17.9 mg/kg bw/d ⁴⁴ .	
Acenaphthylene	$PNEC_{\text{soil}}= 2.3 \text{ mg/kg}$ *.	Insufficient data ⁴⁴ .	
2-Methylnaphthalene	-		
Acenaphthene	$PNEC_{\text{water}}= 3.7 \mu\text{g/l}$ ⁵² ; $PNEC_{\text{soil}}=1300 \mu\text{g/kg}$ ⁵³ .		
Fluorene	$PNEC_{\text{water}}= 0.25 \mu\text{g/l}$ ⁵² ; $PNEC_{\text{soil}}= 77.0 \mu\text{g/kg}$ ⁵³ .		
Anthracene	$PNEC_{\text{water}}= 0.12 \mu\text{g/l}$, $PNEC_{\text{sediment}}= 11.9 \mu\text{g/kg}$, and $PNEC_{\text{soil}}= 130 \mu\text{g/kg}$ ⁴³ .		
Benzo[g,h,i]perylene	PNEC for compartments not available		
Fluoranthene	$PNEC_{\text{sediment}}= 129 \mu\text{g/kg}$ ⁵¹ , $PNEC_{\text{soil}}= 1.3 \text{ mg/kg}$ ⁵⁴ .		
Pyrene	$PNEC_{\text{water}}= 0.024 \mu\text{g/l}$ ⁵² , $PNEC_{\text{soil}}=1.0 \text{ mg/kg}$ ⁵⁴ .		
Perylene	$PNEC_{\text{soil}}= 56.0 \text{ mg/kg}$ *.		
Phenanthrene	$PNEC_{\text{water}}= 1.34 \mu\text{g/l}$ ⁵² , $PNEC_{\text{soil}}= 2.3 \text{ mg/kg}$ ⁵⁴ .		
Benzo[a]anthracene (B[a]a)	$PNEC_{\text{soil}}= 97.5 \text{ mg/kg}$ *.		Probable human carcinogen ^{44,55} .
Benzo[a]pyrene (B[a]p)	$PNEC_{\text{water}}= 0.005 \mu\text{g/l}$ ⁵⁶ and $PNEC_{\text{soil}}= 84.4 \text{ mg/kg}$ *, and $PNEC_{\text{sediment}}= 543 \mu\text{g/kg}$ ⁵¹ .		
Benzo[b]fluoranthene (B[b]f)	$PNEC_{\text{soil}}= 36.0 \text{ mg/kg}$ *.		
Benzo[k]fluoranthene (B[k]f)	$PNEC_{\text{soil}}= 56.0 \text{ mg/kg}$ *, and $PNEC_{\text{sediment}}= 0.0 \mu\text{g/kg}$ ⁵¹ .		
Chrysene	$PNEC_{\text{soil}}= 102.5 \text{ mg/kg}$ *		
Dibenzo[a,h]anthracene (D[a,h]a)	$PNEC_{\text{water}}= 0.024 \mu\text{g/l}$, and $PNEC_{\text{soil}}= 77.5 \text{ mg/kg}$ * ⁵² .		

Chemical	Ecological hazard	Health hazard
Indeno[1,2,3-cd]pyrene (I[1,2,3-cd]p)	PNEC _{soil} = 91.3 mg/kg *	
Naphtalene	PNEC _{water} = 2.24 µg/l, PNEC _{sediment} = 67.2 µg /kg and PNEC _{soil} = 53.3 µg /kg ⁴⁵ .	Mild toxicity; carcinogenic effects not probable ^{44, 45} . Subchronic NOAEL of 7.1 mg/kg bw/d ⁴⁴ .
CCl ₄	PNEC _{sediment} = 5.8 µg/kg ⁵¹ .	Probable human carcinogen ^{43, 44} .
ADAF ((Benzo)triazoles)	Toxic to some species; PNEC not available for compartments.	Mild toxicity ^{57, 58} . No NOAEL available.
ADAF (nonylphenol ethoxylates, alkylphenol polyethoxylate)	Endocrine disruptors ^{45, 59-63} . Nonylphenol: PNEC _{sediment} = 39 µg/kg ⁵¹ .	Have been shown to degrade to produce byproducts, namely nonylphenol and octylphenol, known endocrine disruptors on animals and possibly also on humans ⁵⁹⁻⁶² .
Perfluorchemicals	PFOS: PNEC _{water} = 19.0 µg/l ⁶⁴ , and PNEC _{sediment} = 67.0 µg/kg ⁵¹ .	Endocrine disruptors ⁶⁵⁻⁶⁹ . Limited data.
Cd	PNEC _{water} = 0.19 µg/l, PNEC _{sediment} = 2.3 mg/kg, and PNEC _{soil} = 0.9 mg/kg, ⁴³ .	Probable human carcinogen ^{44, 55} .
Cr	PNEC _{sediment} = 31.0 mg/kg (Cr(III)) ⁵¹ .	Cr(VI): Human carcinogen, group 1 ⁷⁰ .
Cu	PNEC _{water} = 1.6 µg/l ⁵² , and PNEC _{soil} = 2700 µg/kg ⁵³	Long-term studies yet unavailable ^{43, 44} .
Ni	PNEC _{water} = 2.74 µg/l, and PNEC _{soil} = 29.9 mg/kg ⁴⁵ .	Mild toxicity ^{43, 44} . Subchronic NOAEL of 5.0 mg/kg bw/d ⁴⁴ .
As	PNEC _{water} = 0.5 µg/l (total dissolved) ⁷¹ , and PNEC _{soil} = 1.8 mg/kg (both trioxide and total) ⁵³ .	Human carcinogen ^{43, 44} .
Pb	PNEC _{soil} = 53.4 mg/kg (lead and compounds) ⁵³ .	Probable human carcinogen ^{43, 44} .
Zn	PNEC _{water} = 7.8 µg/l, PNEC _{sediment} = 49 mg/kg, and PNEC _{soil} = 26 mg/kg ⁴⁵ .	Mild toxicity ⁴³⁻⁴⁵ . Subchronic NOAEL of 0.83 mg/kg bw/d ⁴⁵ .
Pesticides	Variable according to active principle ^{43, 44} .	Variable according to active principle ^{43, 44} .

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PNEC = predicted no-effect concentrations; NOAEL = no observed adverse effect level

*Based on EC₁₀ data for springtail *Folsomia fimetaria* included in Jensen and Sverdrup ⁵⁴ and considering an assessment factor (AF) of 10 (see Falk-Filipsson et al. ⁷² for a discussion on AF) and PNEC=EC₁₀/10.

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