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Aquatic Global Passive Sampling (AQUA-GAPS) Revisited – First Steps towards a Network of Networks for Organic Contaminants in the Aquatic Environment

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1 **Aquatic Global Passive Sampling (AQUA-GAPS) Revisited – First**
2 **Steps towards a Network of Networks for Organic Contaminants in**
3 **the Aquatic Environment**

4
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34

35 **ABSTRACT**

36 Organic contaminants, in particular persistent organic pollutants (POPs), adversely affect water
37 quality and aquatic food webs across the globe. As of now, there is no globally consistent
38 information available on concentrations of dissolved POPs in water bodies. The advance of
39 passive sampling techniques has made it possible to establish a global monitoring program for
40 these compounds in the waters of the world, which we call the Aquatic Global Passive Sampling
41 (AQUA-GAPS) network. A recent expert meeting discussed the background, motivations, and
42 strategic approaches of AQUA-GAPS, and its implementation as a network of networks for
43 monitoring organic contaminants (e.g., POPs and others contaminants of concern). Initially,
44 AQUA-GAPS will demonstrate its operating principle via two proof-of-concept studies focused

45 on the detection of legacy and emerging POPs in freshwater and coastal marine sites using both
46 polyethylene and silicone passive samplers. AQUA-GAPS is set-up as a decentralized network,
47 which is open to other participants from around the world to participate in deployments and to
48 initiate new studies. In particular, participants are sought to initiate deployments and studies
49 investigating the presence of legacy and emerging POPs in Africa, Central and South America.

50

51 ■ INTRODUCTION

52 Recognizing the achievements of the Global Atmospheric Passive Sampling program (GAPS),^{1,2}
53 Lohmann and Muir (2010) called for the establishment of Aquatic Global Passive Sampling
54 (AQUA-GAPS), aiming to understand better the geographical distributions and temporal trends
55 of organic contaminants, such as persistent organic pollutants (POPs), polycyclic aromatic
56 hydrocarbons (PAHs), novel flame retardants and other contaminants of emerging concern.³
57 AQUA-GAPS has the potential to facilitate the implementation of the Stockholm Convention
58 (SC) on POPs, a global treaty under the United Nations Environmental Programme (UNEP) with
59 the objective to protect human health and the environment from hazardous, long-lasting,
60 bioaccumulative chemicals with long-range transport potential by restricting and ultimately
61 eliminating their production, use, trade, and release.⁴ Yet the scope of AQUA-GAPS goes
62 beyond existing POPs by enabling studies into a wide range of organic contaminants.

63 So far, the SC, through its Global Monitoring Plan, measures POPs in air (active and
64 passive samplers) for capturing their status of emissions and long-range transport, and in human
65 samples (blood, milk) for assessing exposure status. Water monitoring was added to the Global
66 Monitoring Plan for PFOS, which is far more water-soluble than legacy POPs; unlike other
67 POPs, its emission and transport through water and not just air are thought to be significant.⁵⁻⁷

68 Reliance upon passive samplers has already been established via the GAPS program, as well as
69 the Europe/Africa/Asian Monitoring NETWORKS (MONET), Latin American Passive
70 Atmospheric Sampling (LAPAN), and UNEP/Global Environmental Facility (GEF) projects, all
71 of which utilize passive air sampling devices at monitoring sites on all continents, mostly in
72 remote regions, demonstrating the potential for global coverage.^{7,8} While data from GAPS does
73 address the atmospheric compartment and potentially plants and soils exchanging with air, it
74 does not readily address prevailing concentrations or trends in aquatic environments. The
75 aquatic environment represents a key compartment for many POPs, most notably for the HCH
76 isomers and endosulfan⁹, and dissolved concentrations can be used to estimate human and
77 wildlife exposure using bioaccumulation factors and food chain models.¹⁰⁻¹²

78 Passive samplers offer key benefits for global monitoring of aqueous contaminants,
79 because of their high enrichment of their target analytes, and the ability to measure time-
80 weighted average concentrations.¹³⁻¹⁵ Most importantly, a key benefit consists of being able to
81 expose the same sampler in all waters of the world, which cannot be achieved with any
82 biological or other abiotic matrix. Passive samplers are also more cost-effective and relatively
83 easier to handle for shipment and deployment than active sampling of large volumes of water.

84 The atmospheric GAPS program is based on monitoring sites at a defined height above
85 ground that are relatively easy to access. The logistic requirements for AQUA-GAPS sites are
86 inherently more challenging for on- and off-shore deployments and retrieval, requiring moorings
87 and boat time, among other practical issues. The biggest hurdle for establishing a realistic
88 AQUA-GAPS program is perhaps whether enough willing and capable participants from around
89 the world can be secured to agree on and perform the logistics of field and laboratory work.
90 GAPS samplers are often deployed at already established and protected atmospheric monitoring

91 sites that are part of the World Meteorological Organization (WMO) network.¹⁶ In parallel,
92 AQUA-GAPS intends to deploy passive samplers at selected remote/background sites in water
93 bodies around the globe. Similar to the GAPS program, though, AQUA-GAPS will also monitor
94 selected urban/industrially impacted sites in an attempt to examine the impacts of anthropogenic
95 activities on aquatic environments at a global scale.¹⁷

96 A meeting of 15 passive sampling and monitoring experts from 10 countries covering 5
97 continents was organized at Jinan University, Guangzhou, China, on 21–22 January, 2016,
98 aiming to make progress towards the establishment of AQUA-GAPS. In particular, the group
99 was tasked with addressing whether and how it will be feasible to make the assessment of global
100 POP distributions through an analysis of global passive sampling devices in waters. The group
101 then outlined the key steps for implementing them during the meeting. The aim of this feature
102 article is to detail the framework, approach, and expectation of AQUA-GAPS, and solicit
103 additional participation to cover extended sampling areas and initiate new global studies.

104

105 ■ THE MOTIVATIONS BEHIND AQUA-GAPS

106 To launch AQUA-GAPS successfully, it was the consensus of the workshop participants that
107 prior experiences of GAPS must be learned and assimilated. The GAPS program has
108 demonstrated that a global monitoring network using passive samplers is feasible and can be
109 successfully implemented. GAPS was successful in establishing spatial distributions of targeted
110 chemicals, while the identification of temporal trends requires longer time and continuing
111 resource commitment. GAPS has been particularly impressive by making use of their samples
112 for a wide range of contaminants, such as polychlorinated biphenyls (PCBs), polychlorinated
113 naphthalenes (PCNs), polybrominated diphenylethers (PBDEs), neutral and ionic perfluoroalkyl

114 substances (PFASs).^{2,18,19} GAPS has also demonstrated flexibility with their sampling matrix.
115 Initially, GAPS relied on the use of polyurethane foam (PUF) disks, which were later modified
116 to include sampling of compounds with higher volatility in accordance with the increase of list of
117 POPs under the SC.^{20,21} The key lesson here is that flexibility in the type of passive samplers
118 may be required to respond to changing regulatory and scientific needs and interests (new
119 compounds of emerging concern, novel samplers, etc.).

120 The success of GAPS and its relevance to the SC are a prime motivating factor for
121 establishing AQUA-GAPS. Although the current priority sampling matrices under the SC are
122 limited to air and human samples (and water in the case of PFOS), the workshop participants felt
123 that AQUA-GAPS would have significant added value in yielding highly comparable
124 concentration data that allow for better assessing and understanding of the role of water in the
125 global fate of POPs, and in human and wildlife exposure to these chemicals. Both the data
126 collection and the enhanced understanding of global distributions and trends in the aquatic
127 environment would be beneficial for the SC, its Regional Organizational Groups and potentially
128 to other international conventions such as the International Marine Organization's London
129 Convention on prevention of marine pollution by dumping of wastes²², and Convention on the
130 Control of Harmful Anti-fouling Systems on Ships.²³ The data would also benefit regional and
131 national legislative frameworks, such as the EU Water Framework Directive²⁴ and Marine
132 Strategy Framework Directive²⁵, and the 18 Regional Sea Programs under UNEP²⁶, the United
133 States Toxic Substances Control Act (recently updated and renamed the Frank R. Lautenberg
134 Chemical Safety for the 21st Century Act)²⁷, the EU REACH legislation²⁸, and environmental
135 protection and clean water legislation in many other countries.

136 The workshop proposed to have AQUA-GAPS focus on legacy and emerging POPs, as well as
137 on other compounds of emerging concern both hydrophilic (e.g., pharmaceuticals and personal
138 care products) and hydrophobic (novel flame retardants). Currently, the SC's main interest
139 would be the development and deployment of passive samplers for perfluorinated compounds,
140 such as PFOS and PFOA (which is currently under review for inclusion in the SC)²⁹ in waters
141 around the globe. The SC has developed guidance for sample collection and determination of
142 baseline levels of PFOS in water, caused by global dispersion/diffusion.³⁰ Yet the availability of
143 high quality, consistent global concentration maps and trends on POPs and other contaminants
144 will certainly support the SC and its regional programs.

145

146 ■ A NETWORK OF NETWORKS

147 The GAPS program has been established around one central laboratory at Environment Canada,
148 from which samplers are prepared, shipped, returned to, analyzed, and interpreted. This model is
149 unlikely to be repeatable for AQUA-GAPS¹. Instead, we propose to establish a '**network of**
150 **networks**' open to anybody to participate in, but clustered around a central laboratory for sampler
151 preparation and core analysis, the Research Center for Toxic Compounds in the Environment
152 (RECETOX, Masaryk University, Czech Republic). Initially, the network consists of a group of
153 scientists with experience in working with passive samplers. The proposed *modus operandi* of the
154 AQUA-GAPS network consists of in-kind contributions of participating scientists to deploy
155 passive samplers to the best of their abilities, and share ancillary data with respect to their sites.
156 In return, the expectation is one of data sharing by the leading team and inclusion in the data
157 discussion and interpretation. Possible authorship will depend on contributions to the interpretation

158 and discussion of results. We foresee AQUA-GAPS to be a platform in which scientists offer
159 mutual help in deploying samplers at specified locations (e.g., wastewater treatment plants, rivers,
160 freshwater lakes, coastal seas, and oceans) and site characterization (e.g., urban, industrial, and
161 remote). Examples of potential aquatic networks include:

162 *An oceans network.* This is logistically the most challenging, and would often require
163 deployment time of several months up to 1 year, which is typical for open ocean mooring
164 turnaround time.^{31,32} In view of low concentrations, samplers would need to be designed to
165 maximize the uptake of the target compounds to overcome detection limits for as many
166 compounds as possible. Most likely target compounds are legacy POPs, non-polar current use
167 pesticides, organophosphorus flame retardants, perfluorinated compounds, and other chemicals
168 of interest that accumulate in samplers for hydrophobic POPs, such as hydrocarbons or natural
169 halogenated compounds. The benefits of working with the oceanographic community's set of
170 moorings is the general availability of ship-time and access to ancillary data.

171 *A coastal/estuarine network.* Coastal and estuarine sites are easier to reach for
172 deployments, and often coincide with major fishing grounds, which makes them relevant for
173 human exposure and links to biomonitoring data. Deployment time can be shorter, in view of
174 greater concentrations and challenges linked to biofouling of samplers during deployments in
175 productive water bodies.

176 *A lakes network.* Lakes and reservoirs are of high relevancy for human and ecosystem
177 exposure as they are regularly used for aquaculture and irrigation, and often serve as a source of
178 drinking water. Remote lakes (e.g., Experimental Lakes Area in Canada) can serve to quantify
179 background concentrations associated with minimal anthropogenic impacts.³⁰ For both estuarine

180 and freshwater, sampler deployment at near-shore sites is straightforward, but carries a risk of
181 sampler loss through theft, vandalism and loss from accidental ship strikes and fishing efforts.

182 *A network of source waters (waste water treatment plant effluents and rivers).* This
183 network could be used to identify the compounds being introduced into lakes and oceans, before
184 they become of concern. This network could act as an early warning system to identify
185 chemicals of concern through their release to the aquatic environment from human activity and
186 global spread. As concentrations of contaminants in such a network are likely to be much
187 greater than in the other networks mentioned, this network would lend itself to target less
188 persistent compounds, including breakdown products. Identification of major sources and
189 establishment of reliable inventories are indispensable for the efficient and effective management
190 of chemicals on the national, regional and global scale. The various AQUA-GAPS networks
191 should each aim to collaborate and communicate with relevant stakeholders in local, national, or
192 regional levels.

193

194 ■ TECHNICAL FOUNDATION FOR AQUA-GAPS

195 Passive sampling in the water gives a direct measure of a chemicals' activity (or fugacity) in the
196 water, as only freely dissolved contaminants diffuse into the passive sampler material.³³ Thus the
197 freely dissolved concentration derived for passive sampler accumulated pollutants can be used to
198 assess the gradient of chemical activities between different media (air, water, sediment, and
199 biota), and these freely dissolved contaminant concentrations and chemical activities are more
200 useful to assess net fluxes among environmental compartments and bioaccumulation in
201 organisms.³⁴⁻³⁸ Passive sampling derived dissolved pollutant concentrations are therefore

202 fundamentally different from total concentrations reported for e.g., sediment or active water
203 samples.

204 The novelty that AQUA-GAPS introduces is a coordinated effort at pollutant sampling
205 with a chosen passive sampler for worldwide deployments towards the generation of globally
206 comparative data sets. Passive sampling with a well-characterized polymer/sampler can help
207 achieve a level of standardization on a global scale that cannot really be obtained with other
208 environmental matrices (e.g. biota, sediments, etc.) due to their variable properties. Nowadays,
209 silicone rubber and polyethylene are the two most widely used polymers for passive sampling of
210 hydrophobic organic contaminants in water.³⁹ The increased use of these polymers is partly due
211 to the availability of calibration data, i.e., polymer diffusion coefficients and polymer-water
212 partition coefficients for a number of non-ionised hydrophobic chemicals ^{33,40–42} including
213 chemicals of emerging concern.⁴³ These absorption-based passive samplers offer the opportunity
214 to use performance reference compounds (PRCs) to assess contaminant exchange kinetics
215 between water and the polymer in situ for every deployment location and exposure period.⁴⁴ In
216 addition, these polymers facilitate the comparison of contaminant levels in different
217 environmental compartments (i.e. air, biota, sediment or water). The critical review by Booij et
218 al. demonstrated that absorption-based passive sampling is today the best available tool for
219 chemical monitoring of non-ionised hydrophobic chemicals in the aquatic environment.⁴⁵ While
220 a lack of robust quality assurance was identified as a weakness of passive sampling in water,
221 recent results from the QUASIMEME Proficiency Testing schemes conducted using silicone
222 rubber were very encouraging.³⁹ These results show that the analysis of passive samplers within
223 the AQUA-GAPS network may not ultimately require analysis of all samplers by a single
224 laboratory, so long as proficiency testing schemes are organized regularly to evaluate the

225 performance of participating laboratories. At least initially, though, AQUA-GAPS studies will be
226 organized around one central laboratory, RECETOX, for the above mentioned legacy and
227 emerging pollutants from using SR and PE passive samplers prepared and analyzed there.

228

229 ■ STRATEGIES FOR FIELD SAMPLING AND DATA ASSIMILATION

230 The unique feature of AQUA-GAPS is that studies can be initiated by anybody with an interest
231 in answering a global question linked to contaminants in water. The lead team initiating an
232 AQUA-GAPS sampling campaign needs to have sufficient resources to organize sampler
233 preparation, distribution/retrieval, analysis, and interpretation. AQUA-GAPS is intended to be
234 flexible on which sampler to use, how to deploy it, for how long, and where. This will all be
235 decided by the leading team, who will ask others to participate in-kind by deploying in their
236 water body (Figure 1). It may be cost efficient to deploy different types of samplers targeting a
237 wide range of compounds simultaneously (e.g., nonpolar, hydrophilic neutral, positively and
238 negatively charged, etc.).⁴⁶ Passive samplers are relatively inexpensive, and have the potential to
239 be archived.⁴⁷

240 Similar to the GAPS deployments, AQUA-GAPS' challenge will be on how to identify
241 sites in aquatic environments suitable for evaluating spatial and temporal changes in contaminant
242 levels, that would therefore help assess the effectiveness of the control measures implemented
243 under the SC and/or regional efforts. AQUA-GAPS networks will benefit greatly by selecting
244 sites overlapping with other continuous sampling efforts and programs, such as existing GAPS
245 stations. Many GAPS samplers were strategically placed at WMO sites, such that GAPS had
246 site-specific meteorological data available. It will be important to work with sites and groups that
247 are capable of conducting repeatable, long-term deployments.

248 Beyond GAPS sites, other examples for AQUA-GAPS include lakes, ocean and coastal sea
249 monitoring initiatives using regularly serviced buoys and moorings, which can provide ancillary
250 data (temperature profiles, salinity, and current data), and potentially ships of opportunity. There
251 are also on-going contaminant sampling initiatives or networks (Canada's National Water
252 Quality Monitoring Program ⁴⁸, The Great Barrier Reef Marine Monitoring Program ⁴⁹, etc.)
253 which can contribute to AQUA-GAPS for mutual benefits. AQUA-GAPS will of course be open
254 to other programs as it evolves.

255 Across the globe various types of passive samplers have been successfully used for the
256 detection of a range of organic contaminants in waters, resulting in a global ISO standard
257 protocol.⁵⁰ Semi-Permeable Membrane Devices (SPMDs) were arguably the first passive
258 samplers that were used on a wide geographical scale in water sampling.⁵¹ Over time, other
259 sampler types, often single-phase polymers, have become more commonplace. Notable
260 examples include the use of silicone rubber (SR) in an OSPAR-lead initiative across Europe and
261 Australia ⁵², The Great Barrier Reef Marine Monitoring Sampling Campaign ⁵³, and several
262 years of polyethylene (PE) deployments across the Great Lakes ^{54,55} and in the Canadian
263 Arctic.⁵⁶

264

265 ■ **PROOF OF CONCEPT STUDIES: FRESHWATER AND COASTAL AQUA-GAPS**

266 Initially, it will be necessary to establish a proof of concept for AQUA-GAPS to show that this
267 network of networks can actually achieve meaningful results and global coverage. At the proof
268 of concept stage, we aim to demonstrate that it is feasible to ship and deploy passive samplers to
269 participating volunteers around the globe, have them deployed, returned for analysis, and yield
270 meaningful results. At this stage, two proof-of-concept studies are being planned and performed

271 (Figure 1). In both cases, both polyethylene (PE) and silicone rubber (SR) samplers will be co-
272 deployed, such that spare samplers are available for archiving. While actual sampler designs
273 differ between the proof-of-concept studies (Figure 2), both are designed to be easily deployed,
274 provide basic shelter and house several PE and SR sheets simultaneously. Initially, the analytical
275 target compounds include polychlorinated biphenyls (PCBs), organochlorine pesticides (OCPs),
276 polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs) and various
277 hydrophobic novel flame retardants (NFRs). The first proof-of-concept study will focus on
278 legacy and emerging POPs in lakes (Figure 3); the second study will focus on global passive
279 sampling deployments at coastal sites. The two proof-of-concept studies illustrate the flexibility
280 within the AQUA-GAPS network. The first freshwater study shares the responsibilities of
281 logistics, analysis and interpretation among three research groups, while the coastal study will be
282 performed by two academic/research laboratories (Figure 1).

283

284 ■ **BEYOND ROUTINE MONITORING**

285 Beyond its focus on sampling of contaminants in water, AQUA-GAPS could be well positioned
286 to address additional research questions, such as air–water exchange and/or sediment porewater–
287 overlying water gradients by including additional samplers in adjacent media. As mentioned
288 above, expected or measured equilibrium polymer concentrations are directly proportional to the
289 activity of the chemical in the medium being sampled, and can help compare contaminant levels
290 and gradients in/between various environmental media.⁵⁷ This holds true whether equilibrium
291 between the contaminant concentration in the medium being sampled and the polymer is reached
292 (e.g. during sediment or biota exposures) or not (e.g. when sampling air or water).^{58,59} Having
293 passive samplers measure freely dissolved concentrations in close proximity to biomonitoring

294 locations can help understand bioaccumulation potential and chemical concentration gradients.
295 Passive samplers can also be used for non-target screening to detect the presence of other
296 chemicals, derived from industrial, natural or transformation products. Linking to regional
297 efforts, particularly biomonitoring programs (e.g., Mussel Watch⁶⁰), AMAP⁶¹ or GAPS¹ seems
298 particularly useful to enable a comparison of POP concentrations across media. Results from
299 passive sampling will represent time-weighted-average concentrations in water and thus support
300 model development and validation, while biological monitoring has a longer history including
301 archived samples and is often better suited for assessing human exposure (particularly in the case
302 of edible fishes, shellfish, and other aquatic biota).

303 GAPS has derived part of its strength by having a centralized laboratory (i.e., Environment
304 Canada) initiating deployments and analyzing all samples within a particular study, in order to
305 enhance data comparability. As noted, AQUA-GAPS will operate slightly differently, though
306 RECETOX will perform the sampler preparation and analysis for the routine suite of
307 hydrophobic compounds (PAHs, PCBs, OCPs, PBDEs and NFRs). Yet AQUA-GAPS will have
308 different research groups leading deployments, and potentially extra analyses for a specific
309 project. The leading group will provide passive samplers that are suitable for the specific
310 compounds of interest to all participating scientists; the samplers will be returned to the same
311 lead group and analyzed in a single laboratory. Additional samplers can be shared with the local
312 deploying groups, as a secondary aim of enhancing QA/QC, to enable cross-validation of results,
313 and the assessment of inter-laboratory variability. This can also lead to capacity-building (see
314 below). An AQUA-GAPS deployment can be shared/initiated by 2 or more groups, such that
315 different samplers can be exposed during the same deployment. The leading group needs not
316 perform all tasks themselves; it could finance another team to produce samplers and deployment

317 cages, organize the distribution, perform the analysis, and calculate the dissolved concentrations,
318 etc.

319 For AQUA-GAPS to become successful and global, it should lead to global capacity
320 building linked to passive sampling. There are several regions where little to no information
321 exists on organic contaminants in water, in particular from Africa, South Asia, Central and South
322 America. Additionally, non-traditional deployment opportunities can also be leveraged,
323 including ferrybox samplers, towing samplers and ships of opportunity (expedition vessels;
324 regular cargo or ferry routes) to target remote locations.^{62,63} The network will become more
325 useful in addressing scientific questions only if more support of AQUA-GAPS deployments is
326 secured. It would be ideal if the Stockholm Convention could support the capacity building with
327 their own efforts, via the Global Environment Facility, or other funding systems. For the GEF
328 passive sampling of PFOS and PFOA could be of interest, as these are compounds for which
329 water is a matrix of concern.

330

331 ■ GOING FORWARD

332 The organization of sampler deployments, and the deployments themselves are among the
333 biggest cost for AQUA-GAPS. Hence the more samplers can be deployed at the same time, the
334 better. Spare samplers should be archived to enable retrospective analysis. Expansion to include
335 passive samplers designed for other contaminants (e.g., polar and nonpolar chemicals of
336 emerging concern) would enhance the utility of the program. Samplers, and/or extracts, could be
337 analyzed for possible temporal trends later. Spare samplers will be stored in a specimen bank
338 operated by RECETOX. To enable quality control over time, specific samplers for QA/QC
339 purposes will also be made available. Scientists interested in new studies, retrospective analysis

340 of extracts or samplers can request this by contacting the AQUA-GAPS co-chairs (email: aqua-
341 gaps@passivesampling.net).

342 A welcome side-effect of AQUA-GAPS is the opportunity to increase awareness of the
343 benefits and uncertainties of passive sampling of aqueous organic contaminants on the global
344 scale. This might help regulatory agencies, academics, and industries still unfamiliar or hesitant
345 to use passive sampling techniques for their own monitoring programs and other purposes. The
346 roster of AQUA-GAPS thus also becomes a network of experts who can serve as points of
347 contact within their regions. News and results from AQUA-GAPS will be shared via its own
348 website (www.aqua-gaps.passivesampling.net), publications, and presentations.

349

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355

356 ■ **REFERENCES**

- 357 (1) Pozo, K.; Harner, T.; Wania, F.; Muir, D. C. G.; Jones, K. C.; Barrie, L. A. Toward a
358 global network for persistent organic pollutants in air: Results from the global atmospheric
359 passive sampling study. *Environ. Sci. Technol.* **2006**, *40* (16), 4867–4873.
- 360 (2) Pozo, K.; Harner, T.; Lee, S. C.; Wania, F.; Muir, D. C. G.; Jones, K. C. Seasonally
361 resolved concentrations of persistent organic pollutants in the global atmosphere from the
362 first year of the GAPS study. *Environ. Sci. Technol.* **2009**, *43* (3), 796–803.
- 363 (3) Lohmann, R.; Muir, D. Global aquatic passive sampling (AQUA-GAPS): Using passive
364 samplers to monitor POPs in the waters of the world. *Environ. Sci. Technol.* **2010**, *44* (3),
365 860–864.
- 366 (4) UNEP. *Final act of the plenipotentiaries on the Stockholm Convention on persistent*
367 *organic pollutants.*; Geneva, Switzerland, 2001 (accessed Sep 29, 2016).
- 368 (5) UNEP. *Global monitoring plan for persistent organic pollutants as amended after the*

- 369 *fourth meeting of the Conference of the Parties to the Stockholm Convention.*
370 *UNEP/POPS/COP.6/INF/31/Add.1.*; Geneva, Switzerland, 2013 (accessed Sep 29, 2016).
- 371 (6) UNEP. *Guidance on the global monitoring plan for persistent organic pollutants.*
372 *UNEP/POPS/COP.6/INF/31.*; Geneva, Switzerland, 2015 (accessed Sep 29, 2016).
- 373 (7) UNEP. *Global Monitoring Plan For Persistent Organic Pollutants Under The Stockholm*
374 *Convention Article 16 On Effectiveness Evaluation. Second Global Monitoring Report. In*
375 *preparation.*; Geneva, Switzerland, 2016 (accessed Sep 29, 2016).
- 376 (8) Conference of Parties to the Stockholm Convention. Global Monitoring Report
377 <http://www.pops-gmp.org/index.php?pg=gmp-data-warehouse>. (accessed Sep 29, 2016).
- 378 (9) Muir, D.; Lohmann, R. Water as a new matrix for global assessment of hydrophilic POPs.
379 *TrAC - Trends Anal. Chem.* **2013**, *46*, 162–172.
- 380 (10) Czub, G.; McLachlan, M. S. A food chain model to predict the levels of lipophilic organic
381 contaminants in humans. *Environ. Toxicol. Chem.* **2004**, *23* (10), 2356–2366.
- 382 (11) Arnot, J. A.; Gobas, F. A. P. C. A review of bioconcentration factor (BCF) and
383 bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms.
384 *Environ. Rev.* **2006**, *14* (4), 257–297.
- 385 (12) Borgå, K.; Fisk, A. T.; Hargrave, B.; Hoekstra, P. F.; Swackhamer, D.; Muir, D. C. G.
386 Bioaccumulation Factors for PCBs Revisited. *Environ. Sci. Technol.* **2005**, *39* (12), 4523–
387 4532.
- 388 (13) Vrana, B.; Mills, G. A.; Allan, I. J.; Dominiak, E.; Svensson, K. .; Knutsson, J.; Morrison,
389 G.; Greenwood, R. Passive sampling techniques for monitoring pollutants in water. *TrAC*
390 *- Trends Anal. Chem.* **2005**, *24*, 845–868.
- 391 (14) Mayer, P.; Tolls, J.; Hermens, J. L. M.; Mackay, D. Equilibrium sampling devices: An
392 emerging strategy for monitoring exposure to hydrophobic organic chemicals. *Environ.*
393 *Sci. Technol.* **2003**, *37* (9), 184A– 191A.
- 394 (15) Lohmann, R.; Booij, K.; Smedes, F.; Vrana, B. Use of passive sampling devices for
395 monitoring and compliance checking of POP concentrations in water. *Environ. Sci. Pollut.*
396 *Res.* **2012**, *19*, 1885–1895.
- 397 (16) Hung, H.; MacLeod, M.; Guardans, R.; Scheringer, M.; Barra, R.; Harner, T.; Zhang, G.
398 Toward the next generation of air quality monitoring: Persistent organic pollutants. *Atmos.*
399 *Environ.* **2013**, *80*, 591–598.
- 400 (17) Bao, L.; Zeng, E. Y. Comment on “Global Aquatic Passive Sampling (AQUA-GAPS):
401 Using Passive Samplers to Monitor POPs in the Waters of the World.” *Environ. Sci.*
402 *Technol.* **2010**, *44* (12), 4385–4385.
- 403 (18) Lee, S. C.; Harner, T.; Pozo, K.; Shoeib, M.; Wania, F.; Muir, D. C. G.; Barrie, L. A.;
404 Jones, K. C. Polychlorinated naphthalenes in the Global Atmospheric Passive Sampling
405 (GAPS) study. *Environ. Sci. Technol.* **2007**, *41* (8), 2680–2687.
- 406 (19) Genualdi, S.; Lee, S. C.; Shoeib, M.; Gawor, A.; Ahrens, L.; Harner, T. Global Pilot Study
407 of Legacy and Emerging Persistent Organic Pollutants using Sorbent-Impregnated
408 Polyurethane Foam Disk Passive Air Samplers. *Environ. Sci. Technol.* **2010**, *44* (14),

- 409 5534–5539.
- 410 (20) Schuster, J. K.; Gioia, R.; Harner, T.; Lee, S. C.; Breivik, K.; Jones, K. C. Assessment of
411 sorbent impregnated PUF disks (SIPs) for long-term sampling of legacy POPs. *J. Environ.*
412 *Monit.* **2012**, *14* (1), 71–78.
- 413 (21) Koblizkova, M.; Genualdi, S.; Lee, S. C.; Harner, T. Application of Sorbent Impregnated
414 Polyurethane Foam (SIP) Disk Passive Air Samplers for Investigating Organochlorine
415 Pesticides and Polybrominated Diphenyl Ethers at the Global Scale. *Environ. Sci.*
416 *Technol.* **2012**, *46* (1), 391–396.
- 417 (22) IMO. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other
418 Matter. [http://www.imo.org/en/About/conventions/](http://www.imo.org/en/About/conventions/listofconventions/pages/convention-on-the-prevention-of-marine-pollution-by-dumping-of-wastes-and-other-matter.aspx)
419 [listofconventions/pages/convention-](http://www.imo.org/en/About/conventions/listofconventions/pages/convention-on-the-prevention-of-marine-pollution-by-dumping-of-wastes-and-other-matter.aspx)
420 [on-the-prevention-of-marine-pollution-by-dumping-of-wastes-and-other-matter.aspx](http://www.imo.org/en/About/conventions/listofconventions/pages/convention-on-the-prevention-of-marine-pollution-by-dumping-of-wastes-and-other-matter.aspx).
(accessed Sep 28, 2016).
- 421 (23) IMO. Convention on the Control of Harmful Anti-fouling Systems on Ships.
422 [http://www.imo.org/en/About/conventions/listofconventions/pages/international-](http://www.imo.org/en/About/conventions/listofconventions/pages/international-convention-on-the-control-of-harmful-anti-fouling-systems-on-ships-(afs).aspx)
423 [convention-on-the-control-of-harmful-anti-fouling-systems-on-ships-\(afs\).aspx](http://www.imo.org/en/About/conventions/listofconventions/pages/international-convention-on-the-control-of-harmful-anti-fouling-systems-on-ships-(afs).aspx) (accessed
424 Sep 28, 2016)
- 425 (24) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000
426 establishing a framework for Community action in the field of water policy.
427 <http://data.europa.eu/eli/dir/2000/60/oj> (accessed Sep 28, 2016)
- 428 (25) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008
429 establishing a framework for community action in the field of marine environmental
430 policy (Marine Strategy Framework Directive). <http://data.europa.eu/eli/dir/2008/56/oj>
431 (accessed Sep 28, 2016)
- 432 (26) UNEP. Regional Seas Programme (<http://www.unep.org/regionalseas/about/default.asp>)
433 (accessed Sep 28, 2016)
- 434 (27) US EPA. The Frank R. Lautenberg Chemical Safety for the 21st Century Act: First Year
435 Implementation Plan. [https://www.epa.gov/assessing-and-managing-chemicals-under-](https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/frank-r-lautenberg-chemical-safety-21st-century-act-2)
436 [tsca/frank-r-lautenberg-chemical-safety-21st-century-act-2](https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/frank-r-lautenberg-chemical-safety-21st-century-act-2) (accessed Sep 28, 2016)
- 437 (28) *Corrigendum to Regulation (EC) No 1907/2006 of the European Parliament and of the*
438 *Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and*
439 *Restriction of Chemicals (REACH), establishing a European Chemicals Agency; 2014*
440 (accessed Sep 28, 2016)
- 441 (29) UNEP. *Proposal to list pentadecafluorooctanoic acid (CAS No: 335-67-1, PFOA,*
442 *perfluorooctanoic acid), its salts and PFOA-related compounds in Annexes A, B and/or C*
443 *to the Stockholm Convention on Persistent Organic Pollutants; Geneva, Switzerland, 2015*
444 (accessed Sep 28, 2016)
- 445 (30) Weiss, J.; de Boer, J.; Berger, U.; Muir, D. C. G.; Ruan, T.; Torre, A.; Smedes, F.; Vrana,
446 B.; Clavien, F.; Fiedler, H. *PFAS analysis in water for the Global Monitoring Plan of the*
447 *Stockholm Convention. Set-up and guidelines for monitoring; Geneva, Switzerland, 2015.*
- 448 (31) Booij, K.; van Bommel, R.; van Aken, H. M.; van Haren, H.; Brummer, G.-J. A.;
449 Ridderinkhof, H. Passive sampling of nonpolar contaminants at three deep-ocean sites.

- 450 *Environ. Pollut.* **2014**, *195*, 101–108.
- 451 (32) Sun, C.; Soltwedel, T.; Bauerfeind, E.; Adelman, D. A.; Lohmann, R. Depth Profiles of
452 Persistent Organic Pollutants in the North and Tropical Atlantic Ocean. *Environ. Sci.*
453 *Technol.* **2016**, *50* (12), 6172–6179.
- 454 (33) Gilbert, D.; Witt, G.; Smedes, F.; Mayer, P. Polymers as Reference Partitioning Phase:
455 Polymer Calibration for an Analytically Operational Approach To Quantify Multimedia
456 Phase Partitioning. *Anal. Chem.* **2016**, *88* (11), 5818–5826.
- 457 (34) Reichenberg, F.; Mayer, P. Two complementary sides of bioavailability: Accessibility
458 and chemical activity of organic contaminants in sediments and soil. *Environ. Toxicol.*
459 *Chem.* **2006**, *25* (5), 1239–1245.
- 460 (35) Joyce, A. S.; Portis, L. M.; Burgess, R. M. Evaluating the Relationship between
461 Equilibrium Passive Sampler Uptake and Aquatic Organism Bioaccumulation. *Env. Sci*
462 *Technol* **2016**, *50* (21), 11437–11451.
- 463 (36) Smedes, F. Monitoring of chlorinated biphenyls and polycyclic aromatic hydrocarbons by
464 passive sampling in concert with deployed mussels. In *Passive sampling techniques in*
465 *environmental monitoring*; Greenwood, R.; Mills, G.A.; Vrana, B., E., Ed.; Elsevier:
466 Amsterdam, 2007; pp 407–448.
- 467 (37) Lohmann, R.; Burgess, R. M.; Cantwell, M. G.; Ryba, S. A.; MacFarlane, J. K.;
468 Gschwend, P. M. Dependency of polychlorinated biphenyl and polycyclic aromatic
469 hydrocarbon bioaccumulation in *Mya arenaria* on both water column and sediment bed
470 chemical activities. *Environ. Toxicol. Chem.* **2004**, *23* (11), 2551–2562.
- 471 (38) Jahnke, A.; MacLeod, M.; Wickstrom, H.; Mayer, P. Equilibrium sampling to determine
472 the thermodynamic potential for bioaccumulation of persistent organic pollutants from
473 sediment. *Environ. Sci. Technol.* **2014**, *48* (19), 11352–11359.
- 474 (39) Booij, K.; Smedes, F.; Crum, S. Laboratory performance study for passive sampling of
475 nonpolar chemicals in water. *Environ. Toxicol. Chem.* **2016**, DOI: 10.1002/etc.3657.
- 476 (40) Lohmann, R. Critical Review of Low-Density Polyethylene's Partitioning and Diffusion
477 Coefficients for Trace Organic Contaminants and Implications for Its Use As a Passive
478 Sampler. *Environ. Sci. Technol.* **2012**, *46* (2), 606–618.
- 479 (41) Rusina, T. P.; Smedes, F.; Klanova, J. Diffusion Coefficients of Polychlorinated
480 Biphenyls and Polycyclic Aromatic Hydrocarbons in Polydimethylsiloxane and Low-
481 Density Polyethylene Polymers. *J. Appl. Polym. Sci.* **2010**, *116* (3), 1803–1810.
- 482 (42) Smedes, F.; Geertsma, R. W.; Von der Zande, T.; Booij, K. Polymer - Water Partition
483 Coefficients of Hydrophobic Compounds for Passive Sampling : Application of Cosolvent
484 Models for Validation. *Environ. Sci. Technol.* **2009**, *43* (18), 7047–7054.
- 485 (43) Pintado-Herrera, M. G.; Lara-Martín, P. A.; González-Mazo, E.; Allan, I. J. Determination
486 of silicone rubber and low-density polyethylene diffusion and polymer/water partition
487 coefficients for emerging contaminants. *Environ. Toxicol. Chem.* **2016**, *35* (9), 2162–
488 2172.
- 489 (44) Huckins, J. N.; Petty, J. D.; Lebo, J. A.; Almeida, F. V.; Booij, K.; Alvarez, D. A.; Clark,
490 R. C.; Mogensen, B. B. Development of the Permeability/Performance Reference

- 491 Compound Approach for in situ Calibration of Semipermeable Membrane Devices.
492 *Environ. Sci. Technol.* **2002**, *36* (1), 85–91.
- 493 (45) Booij, K.; Robinson, C. D.; Burgess, R. M.; Mayer, P.; Roberts, C. A.; Ahrens, L.; Allan,
494 I. J.; Brant, J.; Jones, L.; Kraus, U. R.; et al. Passive Sampling in Regulatory Chemical
495 Monitoring of Nonpolar Organic Compounds in the Aquatic Environment. *Env. Sci*
496 *Technol* **2016**, *50* (1), 3–17.
- 497 (46) Rusina; T.P.; Smedes, F.; Klanova, J.; Booij, K.; Holoubek, I. Polymer selection for
498 passive sampling : A comparison of critical properties. *Chemosphere* **2007**, *68* (7), 1344–
499 1351.
- 500 (47) Carlson; J. C. ; Challis, J. K.; Hanson, M. L.; Wong, C. S. Stability of pharmaceuticals
501 and other polar organic compounds stored on polar organic chemical integrative samplers
502 and solid-phase extraction cartridges. *Environ. Toxicol. Chem.* **2013**, *32* (2), (334–337).
- 503 (48) Gewurtz, S. B.; Backus, S. M.; De Silva, A. O.; Ahrens, L.; Armellin, A.; Evans, M.;
504 Fraser, S.; Gledhill, M.; Guerra, P.; Harner, T.; et al. Perfluoroalkyl acids in the Canadian
505 environment: Multi-media assessment of current status and trends. *Environ. Int.* **2013**, *59*,
506 183–200.
- 507 (49) Kennedy, K.; Schroeder, T.; Shaw, M.; Haynes, D.; Lewis, S.; Bentley, C.; Paxman, C.;
508 Carter, S.; Brando, V.; Bartkow, M.; et al. Long-term monitoring of photosystem-II
509 herbicides on the Great Barrier Reef – trends and correlation to remotely sensed water
510 quality. *Mar. Pollut. Bull.* **2011**, *65* (4-9), 295–305.
- 511 (50) International Organization for Standardisation. *ISO 5667-23:2011(en) Water quality —*
512 *Sampling — Part 23: Guidance on passive sampling in surface waters*; 2011 (accessed
513 Sep 28, 2016)
- 514 (51) Huckins, J. N. ; Booij, K.; Petty. *Monitors of Organic Chemicals in the Environment*;
515 Springer-Verlag, 2006.
- 516 (52) Smedes, F.; van der Zande, A.; Roose, P.; Davies, I. ICES passive sampling trial survey
517 for water and sediment (PSTS) 2006-2007. Part 3: preliminary interpretation of field data.
518 Available from <http://www.ices.dk/sites/pub/CM Documents/CM-2007/J/J0407.pdf>
519 (accessed Oct 7, 2016).
- 520 (53) Kuhnert, P.; Liu, Y.; Henderson, B.; Dambacher, J.; Lawrence, E.; Kroon, F. *Review of the*
521 *Marine Monitoring Program (MMP)*;2015, CSIRO Digital Productivity Flagship, CSIRO
522 Land and Water Flagship. Report No. EP149350.
- 523 (54) Ruge, Z.; Muir, D.; Helm, P.; Lohmann, R. Concentrations, Trends, and Air – Water
524 Exchange of PAHs and PBDEs Derived from Passive Samplers in Lake Superior in 2011.
525 *Environ. Sci. Technol.* **2015**, *49* (23), 13777–13786.
- 526 (55) Liu, Y.; Wang, S.; Mcdonough, C. A.; Khairy, M.; Muir, D. C. G.; Helm, P. A.; Lohmann,
527 R. Gaseous and Freely-Dissolved PCBs in the Lower Great Lakes Based on Passive
528 Sampling: Spatial Trends and Air – Water Exchange. *Environ. Sci. Technol.* **2016**, *50*
529 (10), 4932–4939.
- 530 (56) Muir, D. C. G.; Fisk, A.; Lehnher, I.; Lohmann, R.; Amarualik, P. Community based
531 seawater monitoring for organic contaminants and mercury in the Canadian Arctic. In
532 *Synopsis of research conducted under the 2014-2015, Northern Contaminants Program*,

- 533 *Aboriginal Affairs and Northern Development Canada, Ottawa.*; Aboriginal Affairs and
534 Northern Development Canada: Ottawa, ON (Canada), 2015; pp 289–296.
- 535 (57) McDonough, C. A.; Puggioni, G.; Helm, P. A.; Muir, D.; Lohmann, R. Spatial
536 Distribution and Air – Water Exchange of Organic Flame Retardants in the Lower Great
537 Lakes. *Environ. Sci. Technol.* **2016**, *50* (17), 9133–9141.
- 538 (58) Morgan, E. J.; Lohmann, R. Detecting air– water and surface– deep water gradients of
539 PCBs using polyethylene passive samplers. *Environ. Sci. Technol.* **2008**, *42* (19), 7248–
540 7253.
- 541 (59) Morgan, E. J.; Lohmann, R. Dietary uptake from historically contaminated sediments as a
542 source of pcbs to migratory fish and invertebrates in an urban estuary. *Environ. Sci.*
543 *Technol.* **2010**, *44* (14), 5444–5449.
- 544 (60) Melwani, A. R.; Gregorio, D.; Jin, Y.; Stephenson, M.; Ichikawa, G.; Siegel, E.; Crane,
545 D.; Lauenstein, G.; Davis, J. A. Mussel watch update: Long-term trends in selected
546 contaminants from coastal California, 1977–2010. *Mar. Pollut. Bull.* **2014**, *81* (2), 291–
547 302.
- 548 (61) Hung, H.; Kallenborn, R.; Breivik, K.; Su, Y.; Brorstrom-Lunden, E.; Olafsdottir, K.;
549 Thorlacius, J. M.; Leppanen, S.; Bossi, R.; Skov, H.; et al. Atmospheric monitoring of
550 organic pollutants in the Arctic under the Arctic Monitoring and Assessment Programme
551 (AMAP): 1993-2006. *Sci. Total Environ.* **2010**, *408* (15), 2854–2873.
- 552 (62) Lohmann, R.; Klanova, J.; Kukucka, P.; Yonis, S.; Bollinger, K. PCBs and OCPs on a
553 east-to-west transect: The importance of major currents and net volatilization for PCBs in
554 the atlantic ocean. *Environ. Sci. Technol.* **2012**, *46* (19), 10471–10479.
- 555 (63) Allan, I. J.; Harman, C. Global Aquatic Passive Sampling : Maximizing Available
556 Resources Using a Novel Exposure Procedure. *Env. Sci Technol* **2011**, *45* (15), 6233–
557 6234
- 558

559 **FIGURE CAPTIONS**

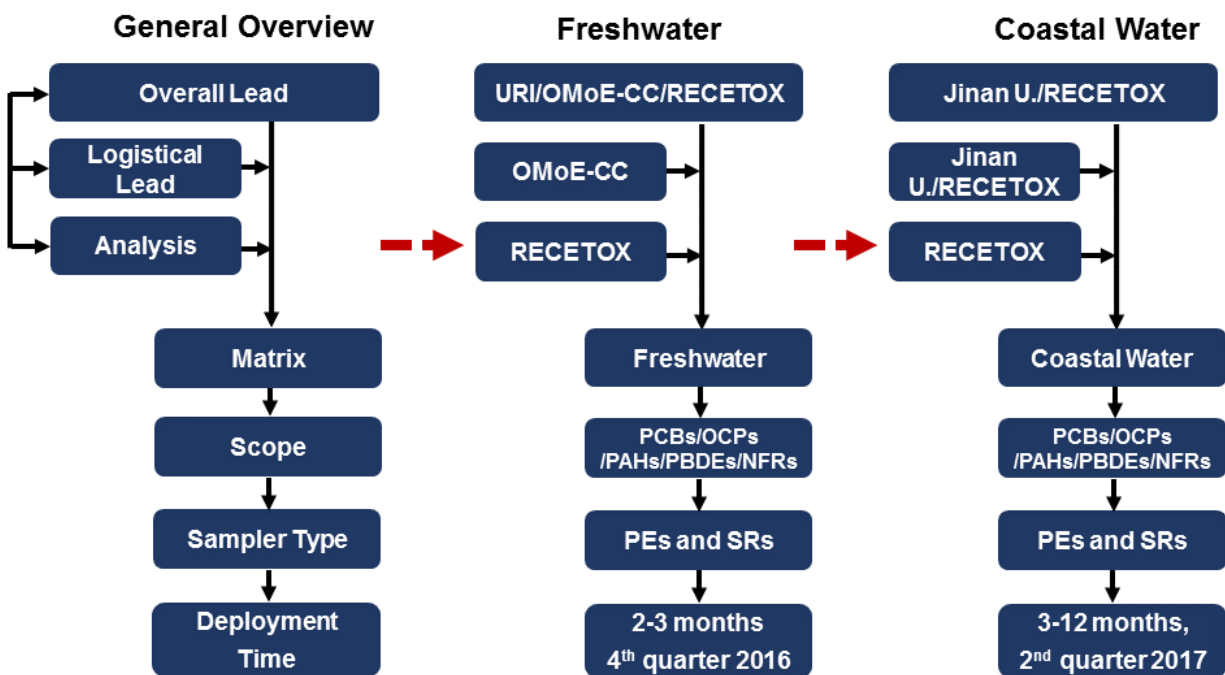
560 **Figure 1.** **General approach of an AQUA-GAPS campaign for dissolved organic**
561 **pollutants, with the proof-of-concept campaigns for a freshwater and a**
562 **coastal water deployments.** (OMoE-CC – Ontario Ministry of the Environment
563 and Climate Change; RECETOX – Research Center for Toxic Compounds in the
564 Environment, Masaryk University; Jinan U – Jinan University; PCBs –
565 polychlorinated biphenyls; OCPs – organochlorine pesticides; PAHs – polycyclic
566 aromatic hydrocarbons; PBDEs – polybrominated diphenylethers; NFRs – novel
567 flame retardants; PE – polyethylene; SR – silicone rubber).

568 **Figure 2.** Passive sampling holders to be deployed during AQUA-GAPS proof-of-concept
569 studies in freshwater (left) and coastal water (right) equipped with both
570 polyethylene and silicone rubber samplers.

571 **Figure 3.** Projected sites for freshwater and coastal water AQUA-GAPS proof-of-concept
572 deployments.

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Global Aquatic Passive Sampling (AQUA-GAPS) Flow Diagram



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Figure 1. General approach of an AQUA-GAPS campaign for dissolved

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organic pollutants, followed by details about the first two proof-of-concept

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campaigns for a freshwater and a coastal water deployments. (OMoE-CC –

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Ontario Ministry of the Environment and Climate Change; RECETOX – Research

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Center for Toxic Compounds in the Environment, Masaryk University; Jinan U –

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Jinan University; PCBs – polychlorinated biphenyls; OCPs – organochlorine

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pesticides; PAHs – polycyclic aromatic hydrocarbons; PBDEs – polybrominated

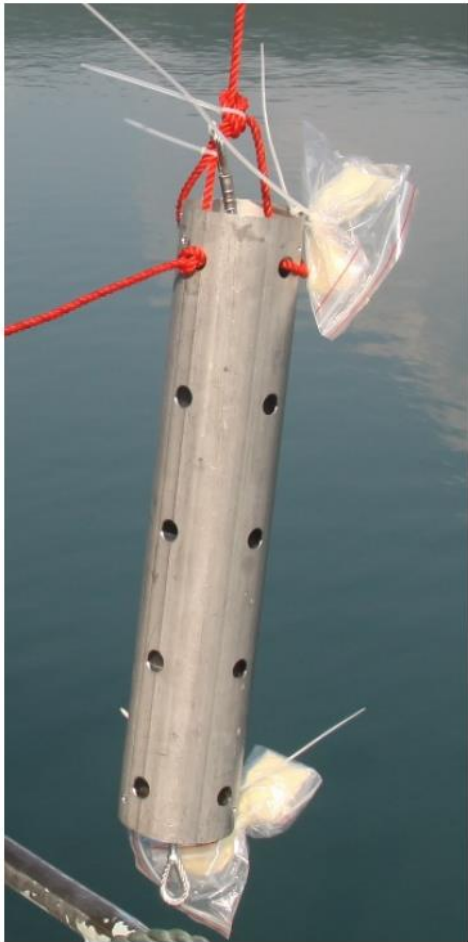
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diphenylethers; NFRs – novel flame retardants; PE – polyethylene; SR – silicone

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rubber).

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Freshwater Passive Sampler



Coastal Water Passive Sampler

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Figure 2. Passive sampling holders to be deployed during AQUA-GAPS proof-of-

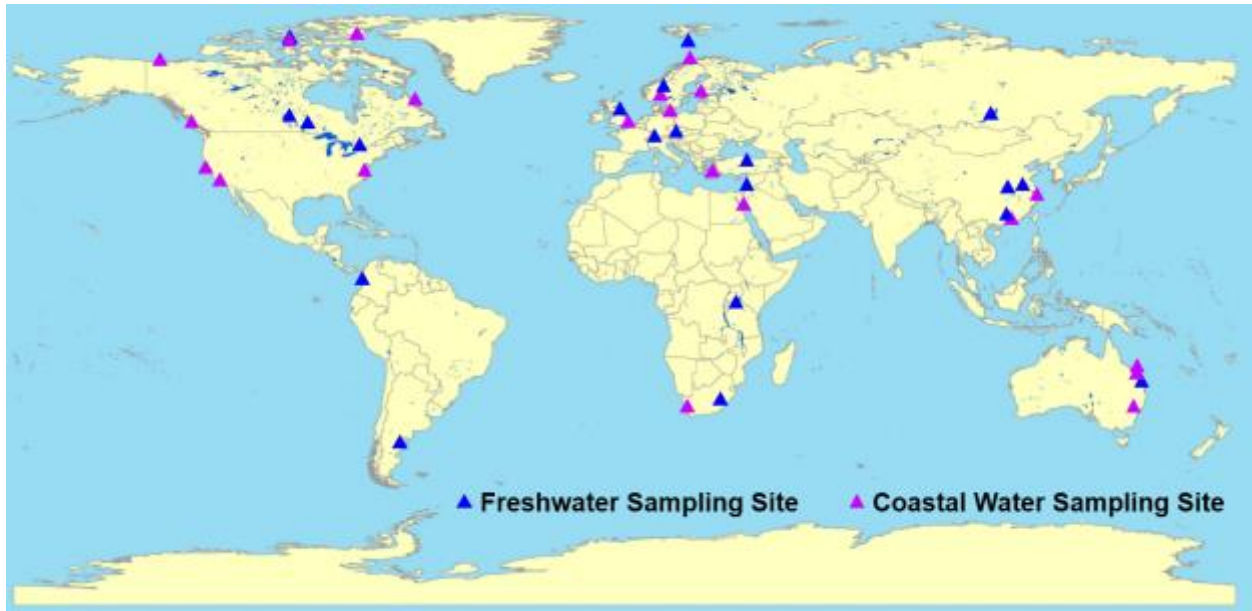
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concept studies in freshwater (left) and coastal water (right) equipped with

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both polyethylene and silicone rubber samplers.

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Figure 3. Projected sites for a freshwater and coastal water AQUA-GAPS proof-of-concept deployments. The map was created using ArcGIS 10.2.

Global Aquatic Passive Sampling (AQUA-GAPS)

The Network for Monitoring Organic Contaminants in the Aquatic Environment

