



Potential uses and constraints of emerging water quality monitoring tools: an operational perspective

Nina Graveline¹, Laure Maton¹, Helen Lückge², Josselin Rouillard³, Pierre Strosser³, Kristine Palkaniete³, Jean-Daniel Rinaudo¹, Didier Taverne⁴, Eduard Interwies²

¹ BRGM (French Geological Survey) Water department, 1039, rue de Pinville, 34000 Montpellier, France.

² InterSus - Sustainability Services - Chodowieckistr. 2 - 10405 Berlin, Germany

³ ACTeon, Le Chalimont, BP Ferme du Pré du Bois, 68370 Orbey, France

⁴ STS : centre de recherche Sciences, Territoires et Sociétés, Montpellier

Corresponding author Nina Graveline: email: n.graveline@brgm.fr; Tel : 00 33 4 67 15 79 83, Fax : 00 33 4 67 15 79 75

Abstract

The European Water Framework Directive adopted in 2000 requires Member States to adapt and strengthen their monitoring of aquatic ecosystems. New monitoring strategies and practices have to be designed to monitor all polluting substances discharged into the aquatic environment, including priority substances or emerging pollutants that might be present at low concentration. This implies adapting monitoring locations and density, and monitoring frequency. It might also imply adapting monitoring techniques by integrating alternative Screening Methods and Emerging Tools for water quality monitoring to complement existing monitoring. The paper presents the results of five European case studies that explored the potential uses of Screening Methods and Emerging Tools for responding to the new monitoring challenges of the Water Framework Directive under different hydrological and environmental conditions. Combining their technical characteristics with practical needs identify by monitoring experts and water stakeholders, potential applications and opportunities for operational and investigative monitoring were identified. Advantages of these methods include the rapid delivery of results on site, their low cost or their capacity to acquire a larger number of observations within a given (short) time frame.

Keywords: WFD, water quality monitoring, biological techniques, early warning, screening methods, monitoring networks

1. Introduction

The implementation of the European Water Framework Directive (WFD 2000/60/EC [1]) will significantly change the monitoring of aquatic ecosystems in many European Member States. The WFD requires establishing monitoring strategies that combine: 1) surveillance monitoring to assess the risk of non compliance with WFD environmental objectives for all water bodies; 2) operational monitoring to assess the effectiveness of measures for improving water status/quality; and, 3) investigative monitoring for identifying unknown causes of contamination and supporting the identification of remediation actions. As a result, existing monitoring networks will have to be adapted to new requirements. In the majority of cases, the location and density of monitoring points will need to be adapted to provide an adequate spatial coverage (surveillance monitoring) and capture the effect of individual (main) pressures (operational and investigative monitoring). Furthermore, a larger group of

49 substances have now to be monitored in a more systematic manner, in particular those
50 listed as priority substances, as specified by council directive 2008/105/EC [2].

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52 From a technical perspective, the main challenges will consist of establishing new
53 monitoring networks (selection of representative monitoring points), developing
54 information systems for managing an increasing volume of data coming from
55 different producers [3], developing new analytical methods and controlling
56 measurement uncertainty [4]. From an economic perspective, the challenge will be to
57 minimize monitoring cost. In some cases, organisational changes might also be
58 necessary, with possible redistribution of tasks and responsibilities within or between
59 organisations, be it private, public, national and/or regional actors. This changing
60 context may offer new opportunities for the development of techniques that differ
61 from the traditional spot (bottle or grab) sampling and laboratory analysis. The
62 Common Implementation Strategy (CIS) guidance document on surface water
63 chemical monitoring [5] identifies several new monitoring methods which are referred
64 to as Screening and Monitoring Emerging Tools (SMETs). This paper discusses the
65 potential uses and constraints of these SMETs.

66
67 The term “Screening and Monitoring Emerging Tools” (SMETs) is used here to
68 design tools that differ from classical spot sampling and laboratory analysis. They can
69 be used directly on-site or in-situ, and they often enable a quicker water quality
70 assessment than with classical lab analysis. Different types of SMETSs can measure
71 time weighted average concentrations of pollutants, provide rapid on-site or on-line
72 analysis or detect potentially harmful conditions through biological or chemical
73 detectors. The term SMETs encompasses a large variety of technologies including: (i)
74 equipment for measuring physico-chemical characteristics; (ii) biological assessment
75 techniques (e.g. biomarkers, bioassays/biosensors and biological early warning
76 systems); and, (iii) chemical analytical or sampling methods that can be used on- or in
77 site (e.g. sensors, passive sampling devices, test kits, immunoassays). A detailed
78 review of these tools can be found in Allan et al. [6] and Greenwood et al.[7].

79
80 The technical and economic potential offered by SMETs is likely to differ widely
81 across Europe to reflect the heterogeneity of existing monitoring networks,
82 organisation of actors (public / private), technology and labour cost structure,
83 monitoring culture (engineering-driven or not). This paper investigates their potential
84 uses from the perspective of water monitoring experts and stakeholders in charge of
85 implementing the Water Framework Directive and its monitoring requirements. It
86 describes both opportunities and constraints and give precious indication on the
87 potential integration of these innovative tools in the WFD monitoring programs. The
88 work is based on five European case studies conducted as part of the SWIFT-WFD
89 EU research project in the Czech Republic, France, Germany, Latvia and the United
90 Kingdom.

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92 The reminder of this paper is organised as follows. The following section presents a
93 typology of possible uses of SMETs. The third section presents how SMETs are
94 perceived by monitoring experts and practitioners. The fourth section then focuses on
95 constraints that may limit the use of SMETs. The paper concludes by discussing
96 possible options for removing these constraints.

97 **2. SMETs' technical characteristics from a user perspective**

98 Four main criteria can be used to classify SMETs from a user's perspective: Criteria
99 1: where the measurement is made – on site (including in situ measurements) or in a
100 laboratory, after sampling; Criteria 2: type of sampling protocol (spot sampling,
101 passive sampling, 24 hours average sample or no sampling (continuous
102 measurement)); Criteria 3: type and accuracy of the measurement (binary response if
103 the contaminant is present, quantification above a certain concentration) and its
104 specificity (does it detect a single substance, a group of substance or a total toxic
105 effect – for instance with biological early warning systems such as trout, that react
106 according their sensitivity to a general water quality); Criteria 4: sensitivity towards
107 contaminants (including detection limits).

108 Overall, there are different reasons why SMETs can change daily practices of
109 monitoring:

- 110 (i) A large number of SMETs can be used on site and be deployed quickly
111 (sensors, test kits), allowing the production of a large quantity of data in a
112 short period of time. This is relevant to screening purposes (in space or in
113 time), when the objective of the water quality survey is to detect the presence
114 of a contaminant over a large area (or with a high time resolution), without
115 necessarily quantifying its concentration.
- 116 (ii) Passive samplers or on-line sensors allow the monitoring of concentration over
117 time (cumulated weighted average or high time resolution) (even if passive
118 samplers are just a sampling tool and not a monitoring one as it needs further
119 lab analysis); their use can help assessing the total load carried by a stream
120 over a given period of time, an objective that is more difficult and expensive to
121 obtain with spot sampling.
- 122 (iii) Passive samplers can concentrate the presence of traces of contaminant (e.g.
123 pharmaceutical substances) which could not be detected with traditional
124 sampling.
- 125 (iv) Some SMETs (e.g. Biological Early Warning Systems - BEWS- like fishes)
126 can help assessing the overall toxicity of all contaminants, without identifying
127 the specific substance(s) causing the problem. This might help water managers
128 to rapidly detect problematic areas or time periods. Other BEWS can assess a
129 modification of the medium reacting to a sudden change of pH or of
130 temperature.

131 As illustrated above, SMETs are particularly useful when they provide a different type
132 of information than obtained with traditional spot sampling and laboratory analysis.

133 **3. Approach and methodology**

134 As a result of their technical characteristics, SMETs can deliver several functions
135 corresponding to some of the WFD monitoring requirements. Clearly, however, the
136 decision to integrate SMETs into existing monitoring strategies will account for the
137 demand and operational constraints faced by water monitoring experts.

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139 To capture the demand and perception of water monitoring experts vis-à-vis SMETs,
140 five river basins were selected throughout Europe for in-depth investigation. These
141 include: the Ribble in England; the Daugava in Latvia; the Aller in Germany; the
142 Orlice in Czech Republic; and, the French part of the Upper Rhine. Research activities
143 were carried out in these basins to investigate the potential integration of SMETs into

144 existing monitoring networks and campaigns. The case studies cover diverse
 145 environmental issues (agricultural, industrial and urban pollution) and water bodies
 146 (small and large rivers, aquifers, coastal and transboundary water bodies). In each of
 147 these basins, the demands, expectations and perceptions of potential users of SMETs
 148 were collated via individual interviews and collective meetings. For example, a total
 149 of 50 water monitoring experts or practitioners were met as part of the French Upper
 150 Rhine case study, representing staff from the environmental-water administration,
 151 communities in charge of local networks, health services (in charge of drinking water
 152 quality and monitoring), industries and private companies (in charge of monitoring or
 153 working with water quality data) and non governmental organisations.

154
 155 The methodology carried out was based on four main steps.

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 157 The first step built on a series of “face to face” interviews, based on a questionnaire
 158 that dealt with: (i) the profile of the expert interviewed and of its organisation; (ii) the
 159 description and evaluation of existing monitoring networks and water quality data (on
 160 technical, organisational and economic aspects); (iii) expected future changes in
 161 existing monitoring networks (in particular to respond to the WFD new requirements);
 162 and (iv) the potential for SMETs application for water quality surveys. A presentation
 163 of SMETs and of their general technical characteristics was included in the interview
 164 using a simple leaflet presenting the characteristics of the main SMETs (on-line
 165 systems, passive samplers, portative lab-instruments, electrochemical sensors, probes,
 166 bioassays, immunoassays and biological early warning systems...).

167 Based on the analysis of the results of the interviews and of existing documents
 168 dealing with water quality monitoring (study reports, national regulation, monitoring
 169 guidelines etc.), the second step identified specific potential uses for SMETs in each
 170 case study. This helps highlighting problems faced today for the collection of
 171 monitoring data, the organisation of data, their analysis and interpretation and their
 172 dissemination. Problems identified by producers, managers or users of data in current
 173 water quality monitoring systems were compared with the strengths of SMETs that
 174 could help solving these.

175 In parallel, real field testing of SMETs was carried out in each case study area (see [8]
 176 and [9]). An economic evaluation of the new information SMETs would deliver was
 177 also carried out (see [10]). And further experts feedbacks were collected to understand
 178 people’s perception and acceptance *vis-à-vis* SMETs.

179 The forth and final step aimed at presenting, sharing and debating results with a wider
 180 audience by organising European, national and basin scale workshops . This further
 181 helped refining the description of potential uses for SMETs in water quality
 182 monitoring and the identification of their main constraints and opportunities within
 183 the WFD implementation context. Reports on workshops results are available at
 184 internet website: www.swift-wfd.com.

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186 **4. Potential uses of SMETs**

187 Although experts’ consultation stressed today’s limited demand for alternative
 188 monitoring techniques, public organisations concerned with environment or health
 189 agreed that most existing monitoring networks would need to be redesigned to
 190 improve knowledge on water quality. Water monitoring experts highlighted the roles
 191 SMETs could play for developing an effective monitoring network.

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4.1. SMETs for designing monitoring networks

194 Before establishing new monitoring networks, SMETs can help capturing the spatial
195 and temporal variability of pollutant concentrations as pre-requisite to the selection of
196 representative monitoring stations. SMETs can be particularly interesting when it is
197 difficult to choose representative points such as in groundwater bodies. For example,
198 sensors and passive samplers could be used to assess concentration temporal
199 variability before optimising monitoring frequency. This application was suggested by
200 stakeholders consulted in the UK, the Czech Republic and Germany.

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4.2. Surveillance monitoring in future risk assessment and WFD cycles

203 When designing surveillance monitoring networks, choosing substances representing
204 a significant environmental risk, including emerging pollutants, remains a clear
205 challenge. “Emerging pollutants” are by definition not monitored today by current
206 surveillance networks. Surveys of a few months could be done with selective passive
207 sampling on integrative points (e.g. outlet of basins) to identify new pollutants to be
208 monitored in the future. Passive sampling enables to catch very low pollutant
209 concentrations. They can help detecting pollution at an “early stage”, for example for
210 pharmaceuticals and hormones discharged by wastewater treatment plants. The use of
211 SMETs in surveillance monitoring was seen as particularly relevant for the Latvian
212 case, where many water bodies lack monitoring. On the opposite, French, British and
213 Czech experts saw limited potential for SMETs in surveillance monitoring in their
214 countries. Other tools such as BEWS or online sensors could be used to assess long
215 term trends. However, their use could be restricted by the problem of dataset
216 continuity over long time series (historical data acquired with traditional techniques
217 are not comparable with new data collected with SMETs, explaining why experts may
218 prefer to stick to existing monitoring techniques).

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4.3. Operational monitoring

221 Old industrial sites often represent a risk that is poorly characterised, in particular
222 when pollution plumes are present in the soil or sub-soil. Monitoring the propagation
223 of pollution plumes in these sites, which are common in many parts of Europe, is
224 crucial to: (i) secure drinking water resources that might be threaten by pollution
225 propagation; and, (ii) to evaluate the efficiency of remediation measures that are, or
226 have been, implemented. The use of SMETs could increase the frequency of
227 monitoring at the border, and downstream, of contaminated sites. Sensors in wells and
228 passive samplers that could be installed and retrieved every month for instance, could
229 be used. This opportunity has been emphasized by experts consulted in France and
230 Latvia where many water bodies are significantly affected by industrial pollution for
231 which operational monitoring is mandatory.

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4.4. Investigative monitoring

234 In all five case studies, investigative monitoring is seen as having the greatest
235 potential for SMET applications. Where a recurrent pollution can be observed within
236 a natural network of rivers or a waste water collection network, specific field tools can
237 be applied to identify potential point emission sources. Easy to use, SMETs could be
238 applied on-site or in situ, for example sensors, biosensors, bioassays or immunoassays

239 (pesticides), providing the possibility to carry out a large number of measures in a
 240 single. To search for PCBs within a wastewater network is an example where the
 241 application of SMETs would help identifying the source of PCBs that currently
 242 deteriorates the quality of sludge, making it improper for manure spreading on
 243 agricultural fields. Similar investigations could also be proposed to identify the origin
 244 of mercury pollution that is currently unknown (probably an old industry) in the Thur
 245 River in Alsace.

246 SMETs could help revealing the existence of rare and sudden pollution peaks that can
 247 not be detected by existing monitoring systems but that can be responsible for
 248 ecological disorders (e.g. fish mortality, bioaccumulation of pollutants in fish flesh).
 249 Biological Early Warning Systems (BEWS) or on-line systems could monitor
 250 continuously indicator parameters (pH, conductivity, TOC) or more specific
 251 parameters such as pesticides (Fluotox for instance). This would help linking
 252 pesticides pollution “peaks” to practices of potentially polluting activities (green
 253 spaces treatment in cities or agricultural practices) and/or to climatic events
 254 (rainfalls).

255 SMETs could also help detecting sources and plumes of pollution in very large
 256 industrial sites characterised by the presence of numerous pollution sources,
 257 substances and plumes. In such sites, high spatial resolution mapping could be carried
 258 out with SMETs to identify the principal sources of pollution. It could, then, help fine-
 259 tuning remediation measures.

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4.5. ..and beyond the WFD

262 There are clear opportunities for using SMETs beyond the WFD, in some cases in
 263 areas where SMETs are already applied today. In particular:

264 (i) Alarm and continuous monitoring for strategic water resources such as a drinking
 265 water abstraction points can be proposed to reduce potential risks linked to the
 266 operation of large industrial sites or to urban discharges. Early detection of pollution
 267 would enable early remediation and prevention. Permanent Biological Early Warning
 268 Systems (BEWS) stations can be installed at the boarder between regions or countries,
 269 similar to the alarm station that already exists in Huningue (south of the Alsace
 270 region) at the Swiss-German-French border for protecting the (strategic) Alsace
 271 aquifer (used for drinking water) from accidental pollution. They are also used at the
 272 entry of wastewater treatment stations to protect their biological functioning from
 273 toxic discharges. Lastly, they can be used by industries with high water quality
 274 requirements.

275 (ii) Biological or very rapid tools can also confirm a “suspicion” in the case of an
 276 accident or of abnormal field observation data. In a regulatory context of discharge
 277 control, and when SMETs will be standardized, they could be used to check
 278 conformity with norms and pollutant concentrations fixed by legislation prior to
 279 embark on more detailed (and potentially expensive) analysis.

280 (iii) Continuous discharge monitoring can inform managers of the on-going
 281 functioning of their treatment plant. The detection of strong variation in effluents
 282 water quality can help identifying rapidly unstable processes. This early detection can
 283 help saving costs (avoiding damages and the payment of fines etc.). Water users might
 284 also use SMETs to obtain direct and continuous information on discharge quality and
 285 challenge the level of pollution tax they are paying.

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4.6. In summary

288 Overall, SMETs have four main advantages: (i) SMETs can help reducing the number
289 of spot samples and analyses; (ii) they can provide better information that reduces the
290 uncertainty of water quality measurements (for instance at risk or not to achieve good
291 status by 2015) and thus increases relevance of decisions taken to hamper
292 contamination; (iii) On site or in situ tools have the capability to deliver rapid results;
293 and, (iv), it ensures the quality of measurements for pollutants which concentration
294 degrades rapidly during shipping time.

295 5. Constraints and opportunities throughout Europe

296 Adapting monitoring strategies to comply with the WFD monitoring requirements
297 needs to account for: 1) available (human) resources and budgets; 2) the preference
298 given to existing monitoring and measurement techniques and to continuing past
299 practices to avoid discontinuity in time series data. In this context, limited attention is
300 given to innovations such as SMETs which advantages are rarely adequately
301 considered. To the opposite, many limitations of SMETs are called for to justify that
302 they are not really considered for WFD monitoring even if the technical report of the
303 European Commission on the implementation of water monitoring requirements
304 mentions their possible use [3]). These limitations can be summed up as follows:

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5.1. Regulatory constraints : SMETs lack normalisation

307 Whereas the majority of analytical and sampling methods are normalized, this is not
308 the case for SMETs. For many experts and countries, measurements and monitoring
309 procedures require normalized methods. This is crucial for government agencies using
310 the information to check compliance with regulation or to support court cases. In situ
311 or on site analysis makes it difficult to have reproducibility or traceability, as water
312 samples are not systematically taken back to lab for storage, although this could
313 represent a viable option.

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315

5.2. Technical constraints

316 For some SMETs, high limits of detection, low reliability (linked to regulatory
317 constraint) and lack of in situ robustness are important factors that constraint today's
318 application. Further, more technical information on the conditions of application of
319 SMETs and on the interpretation of their results should be made available by those
320 developing, distributing and selling these tools.

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5.3. Organisational constraints for users

323 Increased use of SMETS might require organisational changes for departments in
324 charge of monitoring and data analysis. Indeed the integration of SMETs in networks
325 and surveys would imply adaptation of information systems, changes in task
326 allocation and training needs. Continuous monitoring can in some cases require the
327 building of complex databanks. The example of the Netherland Aqualarm system
328 shows however the feasibility of such systems (see <http://www.aqualarm.nl/>).

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330 **5.4. Industry and market structuring**

331 Laboratories and monitoring departments that decide to use SMETs will need to rely
332 on new partners that develop and sell these SMETs. Many SMETs are developed by
333 small companies or universities subsidiaries that might not have today the capacity or
334 skills to market and disseminate their products. In some cases, necessary backup and
335 assistance for their use might also not be sufficiently developed.

336
337 **5.5. Socio-cultural constraints : acceptance towards innovation**

338 Water quality and laboratory experts (mainly chemists) might not consider the shift
339 from complex laboratory technologies to simple devices (a passive sampler is after all
340 only a piece of plastic including a membrane...) as progress and innovation. Cultural
341 habits might also lead to resistance from technicians that prefer to work in a secure
342 laboratory instead of undertaking in-situ measurements which require additional field
343 work.

344
345 **5.6. Economic constraints**

346 Public institutions recognise the limitations of their current monitoring networks. And
347 they are keen to improve the effectiveness of monitoring system to deliver “better
348 information” (i.e. information that better grasp the state of the aquatic environment).
349 Often, however, limited financial resources and frozen budgets are mentioned as
350 constraint to change. As a result, decisions that minimise change (and related potential
351 hidden costs) are favoured. This applies to SMETs when considered in addition to the
352 existing monitoring system and entailing higher costs. Assessments in the five
353 European case studies have also highlighted the impact of labour costs (from a high
354 40€/hour in Germany *versus* 4€/hour in Latvia) on the overall cost of using SMETs.
355 This turns SMETs to be more attractive from a financial & budgetary point of view in
356 low labour cost countries such as new European member states.

357
358 **5.7. Discussion: What to do for removing these barriers?**

359 As illustrated before, constraints to the wider use of SMETs are not limited to their
360 technical characteristics. They also include cultural and economic constraints, in
361 addition to classical reaction against innovation. Tackling existing constraints would
362 require a proactive development strategy by those involved in their development and
363 dissemination. To develop a standardisation protocol for the application of SMETs is
364 seen as the cornerstone of this approach. Concentrating on a limited number of
365 promising tools appears as essential to avoid potential end-users’ confusion, to
366 facilitate information and communication and to enhance trust. Training in the use of
367 SMETs and in the interpretation of their results is also an essential component of this
368 strategy.

369 Further work is also required to illustrate the potential impact of SMETs and their
370 economic relevance. Indeed, the impact of better information on the state of the
371 aquatic environment is often unknown and under-estimated. Integrating SMETs in
372 existing monitoring networks will enhance the effectiveness of these networks in
373 delivering adequate information. And better information can help targeting
374 remediation measures and propose a more cost-effective way to protect water
375 resources.

376 **6. Conclusion**

377 The consultation of experts and practitioners carried out in five European countries
378 confirms that SMETs are not perceived as substitute to standard analytical monitoring
379 practices. Instead, their potential is as complementary tools delivering better
380 information fast to achieve the objectives set by the WFD. While current large scale
381 surveillance and operational networks offer some opportunities for the development
382 of SMETs, their highest potential is in local surveys and investigations, e.g. (1) to
383 assess the extent of pollution with emerging contaminants, or (2) to assess the extent
384 and source of a groundwater pollution plume. The main strength of SMETs is clearly
385 their ability to conduct quick on-site or in situ measurements, saving time and
386 allowing the acquisition of a larger number of observations.

387 Extensive adoption of SMETs by water monitoring stakeholders is however not
388 expected to take place in a very short time period. The deployment of SMETs is likely
389 to generate additional costs resulting from training needs, adaptation of information
390 systems, etc., that few organisations are willing to bear today. And staff reluctance to
391 use methods providing results with high uncertainty that can not be compared to past
392 data, that cannot be validated and that are not accredited, needs to be overcome.
393 Private actors, to whom government agencies generally subcontract most of the
394 sampling and analysis work, are also not likely to adopt innovative monitoring
395 methods as they have often already invested time and money in high-tech instruments
396 and corresponding human skills.

397 In the medium-term, the WFD management cycles and the need to upgrade
398 monitoring systems will offer new windows of opportunity for integrating SMETs. It
399 is expected that the larger number of practical applications, reduced costs (as more of
400 them are used and produced) and efforts to develop and apply more systematically
401 validation protocols and accreditation, will then provide the right conditions for
402 SMETs to be given their due role in monitoring the state of the aquatic environment.

403
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