Moving Toward an Anthropogenic Metabolism-Based and Pressure-Oriented Approach to Water Management

Xingqiang Song, Ronald Wennersten and Björn Frostell

Abstract Effective and efficient water management systems require a comprehensive understanding of anthropogenic pressures on the water environment. Developing a broader systems perspective and extended information systems is therefore essential to systematically explore interlinks between anthropogenic activities and impaired waters at an appropriate scale. For this purpose, this paper identifies information dilemmas in contemporary water monitoring and management from an anthropogenic metabolic point of view. The European Drivers-Pressures-State of the Environment-Impacts-Responses (DPSIR) framework was used as a basis for classifying and discussing two approaches to water management, namely state/impacts-oriented and pressure-oriented. The results indicate that current water monitoring and management are mainly state/impacts-oriented, based on observed pollutants in environmental monitoring and/or on biodiversity changes in ecological monitoring. This approach often results in end-of-pipe solutions and reactive responses to combat water problems. To complement this traditional state/impacts-oriented approach, we suggest moving toward an anthropogenic metabolism-based and pressure-oriented (AM/PO) approach to aid in alleviating human-induced pressures on the water environment in a more proactive way. The AM/PO ideas can equally be applied to water-centric sustainable urbanization planning and evaluation in a broader context.

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1 Introduction

There is a growing consensus that it is essential to shift the focus from a single/sectoral approach to a more holistic approach to water management and planning. Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM), based on a systems approach to water management, have attracted wide international attention. One key principle of IWRM is to integrate both within and between the following two categories: the natural system (e.g., water availability and quality) and the human system (e.g., resource extraction, production, and waste management). Unfortunately, IWRM is not yet effectively implemented on a wider scale, for a number of reasons, but primarily due to the lack of systematic approaches to better address complex water resources systems (Castelletti and Soncini-Sessa 2007).

In recent years, there have been important advances in understanding causes of water problems from an interdisciplinary perspective. For example, the United Nations Educational, Scientific and Cultural Organization (UNESCO) called for thinking outside the conventional water box: for water issues to be linked to decisions on sustainable development and for drivers of water pressures to be handled in broader and interrelated contexts (WWAP 2009). The UNESCO call (re-) emphasizes the importance of achieving an improved understanding of causal relationships in considering both quantitative water degradation and qualitative water degradation. Another example is the "System of Environmental-Economic Accounting for Water (SEEA-Water)," published by the United Nations Statistics Division in 2012. In the SEEA-Water, an experimental water quality accounting approach is introduced. However, it addresses only the stocks of certain qualities at the beginning and the end of an accounting period, without further specification of the causes (UNSD 2012).

Moving toward improved water management depends on the availability of relevant, accurate, and up-to-date information, and decision makers often lack access to the critical information needed for effective decision making (Hooper 2005). To facilitate the early observation of water quality changes, for instance, the European Union approach has focused on the improvement of water quality monitoring systems and ecological outcomes (EC 2003). However, Destouni et al. (2008) reveal that waterborne loads of nitrogen, phosphorous, and organic pollutants traveling from land to the Baltic Sea might be larger from small, unmonitored areas than from the main rivers that are subjected to systematic environmental monitoring. Developing a broader systems perspective on water monitoring and accounting approach is therefore essential to systematically explore interlinks between anthropogenic activities and impaired waters at an appropriate scale.

To our knowledge, there has, as yet, been no systematic examination of cause–effect relationships between anthropogenic metabolism and water quality degradation, while alleviating human-induced pressures on waters at their sources. As two forerunners in the development of metabolic thinking, Baccini and Brunner (2012) provide concrete approaches to accounting society's physical metabolism. In fact, the real strength of a metabolic approach is that it does not discriminate between inflows of resources and outflows of emissions. Instead, it sees both phenomena as linked and thus represents an improved systems approach to ecological sustainability, which could be applied to water resources management.

This paper aims to identify dilemmas in contemporary water monitoring and management approaches from an anthropogenic metabolic point of view. For this purpose, the European Environment Agency (EEA's) so-called Drivers-Pressures-State of the Environment-Impacts-Responses (DPSIR) framework is used as a basis for the classification of water management approaches. Furthermore, the paper recommends moving toward an anthropogenic metabolism-based and pressure-oriented (AM/PO) water management approach, the necessity for which is discussed.

2 The DPSIR Framework and Classification of Water Management Approaches

2.1 The DPSIR Framework

The DPSIR framework (Fig. 1) in general intends to provide a basis for describing environmental problems by identifying the cause–effect relationships between the environment and anthropogenic activities. In terms of the DPSIR framework, socioeconomic development and sociocultural forces function as drivers (D) of human activities that increase or mitigate pressures (P) on the environment. Environmental pressures then change the state of the environment (S) and result in impacts (I) on human, ecosystems, and the economy. Those changes in environmental conditions and the corresponding impacts may lead to societal responses (R) via various mitigation, prevention, or adaptation measures in relation to the identified environmental problems (Smeets and Weterings 1999). In practice, the DPSIR framework has been widely employed as an environmental reporting approach, e.g., in the EEA's State of the Environment Reports.

Although the DPSIR framework has been frequently used to aid in addressing various environmental problems, it has received a lot of criticisms. From the perspective of researchers, for example, typical criticisms are that (i) it employs static indicators without considering system dynamics; (ii) it fails to clearly illustrate specific causal relationships of environmental problems under study; (iii) it suggests only linear causal chains for complex environmental issues; and (iv) it has shortcomings to establish good communication between researchers and stakeholders (Rekolainen et al. 2003; Svarstad et al. 2008). Moreover, Friberg (2010) claims that "the DPSIR framework is seldom used by applied scientists, who often use 'stress' and 'stressors' rather than 'pressure'." Typically, a stress-based approach in stream ecology focuses on how point source and diffuse pollution affect ecosystems at various levels of organization (Friberg 2010).

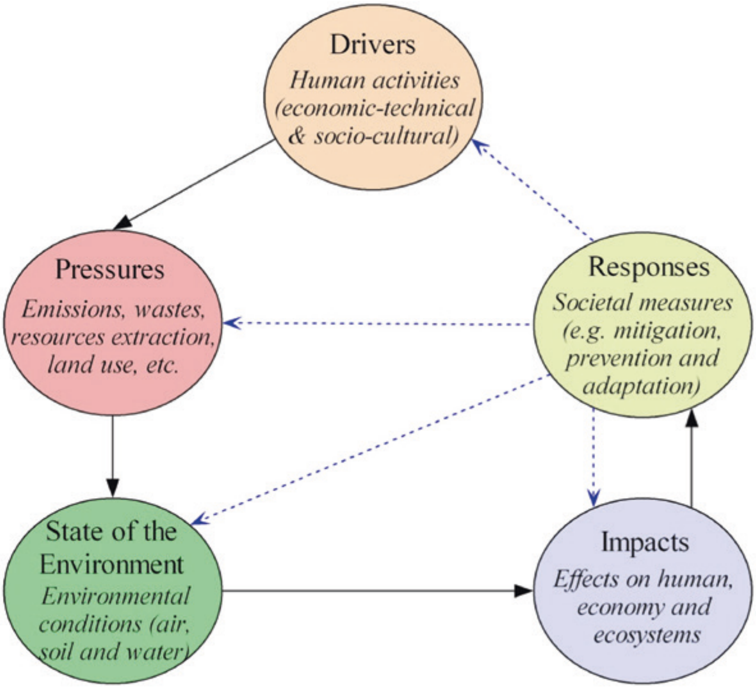

Fig. 1 The European DPSIR framework (after Gabrielsen and Bosch 2003)

On the other hand, Carr et al. (2007) hold the view that "DPSIR is not a model, but a means of categorizing and disseminating information related to particular environmental challenges." These authors further argued that the original goal of the framework is to identify appropriate indicators for framing particular environmental problems, rather than the elaboration of their cause–effect relationships, aiming to make appropriate responses. Referring to recent applications of the approach, Atkins et al. (2011) argue that "an expert-driven evidence-focused mode of use is giving way to the use of the framework as a heuristic device to facilitate engagement, communication and understanding between different stakeholders." In addition, Tscherning et al. (2012) highlight the usefulness of the application of DPSIR in research studies by providing policy makers with meaningful explanations of cause–effect relationships.

In this paper, the DPSIR framework is employed as a basis for identifying dilemmas in contemporary water monitoring and management systems. Furthermore, it is used to aid discussions about the necessity of moving from a state/impacts-oriented approach to an AM/PO approach to managing water resources.

2.2 The DPSIR-Based Classification of Water Management Approaches

Based on the European DPSIR framework, two classifications, namely state/impacts-oriented approach and pressure-oriented approach, are made for water management approaches and the derivation of information systems (Fig. 2). In simple terms, the state/impacts-oriented approach includes societal responses to changes in water environmental state and their impacts in terms of information from environmental and/or ecological monitoring networks. On the other hand, the pressure-oriented approach refers to management efforts focusing on drivers, pressures, and responses to anthropogenic metabolism.

The first classification, the state/impacts-oriented approach, requires pollutant-oriented environmental information and species-oriented ecological information. Its information systems focus on the ambient water environment and ecosystems. In a broader sense, the atmospheric system may also be referred to in relation to vapor flows and air pollutant concentrations. In other words, the main concern of a state/impacts-oriented approach is hydrophysical and biogeochemical changes in the water environment and the net effect is often reactive responses to combat water problems (because of late recognition of pollutant accumulation, for instance). Regarding water quality management, the main focus is usually on monitoring and controlling pollutants discharged to the natural recipient, e.g., by means of constructing monitoring networks and wastewater treatment methods (either natural, physical–chemical, and/or biological).

The second classification, the pressure-oriented approach, derived from a Drivers-Pressures-Responses (DPR) model, is based on the underlying principle that anthropogenic metabolism determines human-induced pressures on the water environment. According to Graedel and Klee (2002), metabolism of the anthroposphere "represents the metabolic processes of human-technological and

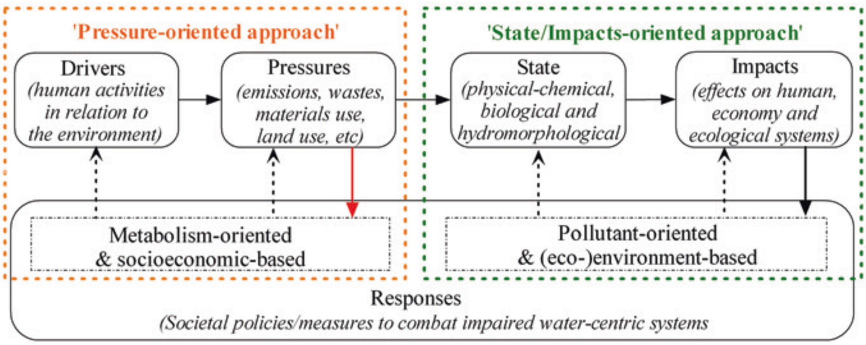

Fig. 2 The pressure-oriented and state/impacts-oriented approaches, where the *red arrow* shows the link emphasized in this paper to address the root causes of human-induced water problems (Song 2012)

human-social systems at all spatial scales, broadening the basic principles of urban metabolism to include all of the technical and social constructs that support the modern technologically-related human." In essence, the pressure-oriented approach includes the following: (i) an inventory analysis of water-related environmental loads (inflows of resources and outflows of emissions) of the system under investigation and (ii) assessing the water environmental consequences of the quantified environmental loads in the inventory analysis.

With respect to the pressure-oriented approach, accounting for the metabolism of the anthroposphere is necessary for identifying human-induced pressures on the water environment. Comprehensive water-related anthropogenic metabolic information system to a large extent could help optimize the allocation of limited resources in society for making proactive societal responses to water degradation. In this context, developing measures for combating environmental degradation would begin with investigating human-induced pressures exerted by production and consumption at their sources.

3 Dilemmas in Contemporary Water Monitoring and Management Systems

The following two examples are used as a basis for identifying dilemmas in demand for information in contemporary water management systems. However, a complete review of water monitoring techniques and indicators used in water management systems worldwide is beyond the scope of this study (it will be addressed in a follow-up study).

3.1 A Brief Conceptual Framework of Contemporary Water Quality Analysis

In recent decades, the focus of water quality management policy has gradually shifted from effluent-based (control of point pollution sources) to ambient-based (control of non-point pollution sources) water quality standards (National Research Council 2001). Generally speaking, water quality research is mainly driven by the following four needs: (i) toward scientific understanding of the aquatic environment; (ii) qualifying water for human uses; (iii) aiding in managing land, water, and biological resources; and (iv) identifying the fluxes of dissolved and particulate material through rivers and groundwater as well as from the land to the ocean (Meybeck et al. 2005).

According to Zhang et al. (2005), the current water quality approach "emphasizes the overall quality of water within a waterbody and provides a mechanism through which the amount of pollution entering a waterbody is controlled by the intrinsic conditions of that body and the standards set to protect it." This point is reflected in the two main streams of water quality management strategy: (i) setting water quality objectives (WQOs) and (ii) setting emission limit values (ELVs).

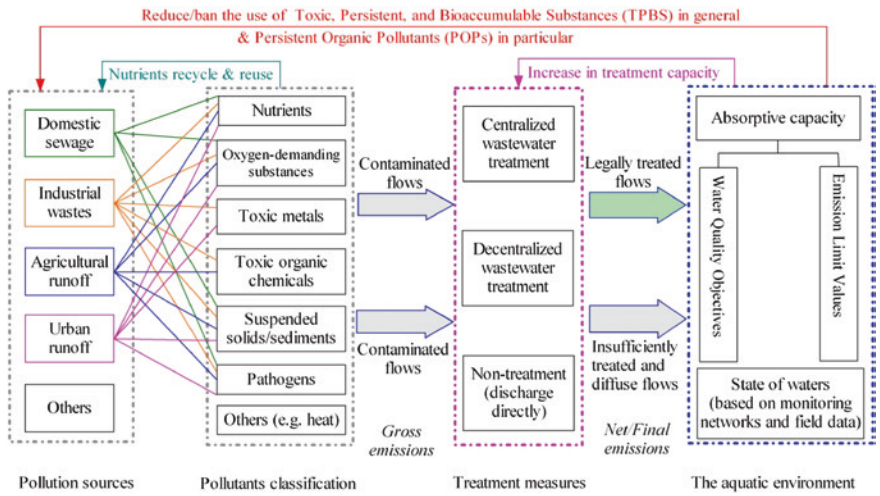

Fig. 3 A simplified conceptual framework of contemporary water quality research and management (after Song 2012)

In summary, Fig. 3 presents a simplified contextual framework showing some most frequently discussed issues in contemporary water quality research and management.

As shown in Fig. 3, discussions to date about causes of water quality degradation have mainly focused on substance and element fluxes (both point and non-point) from the anthroposphere to the environment. In fact, this point is also reflected in the two general objectives of water quality systems analysis (Karamouz 2003), i.e., to identify (i) major pollutant categories (e.g., nutrients, toxic metals/organic chemicals, pathogens, suspended solids, and heat) and (ii) principal sources of pollutants (e.g., domestic sewage, industrial waste, agricultural runoff, and urban runoff). Take, for example, the case of Helsinki Commission (HELCOM) Baltic Sea Action Plan (BSAP). The HELCOM BSAP, adopted in 2007, aims to restore good ecological status to the Baltic Marine Environment by 2021. One goal of the HELCOM BSAP is to have a Baltic Sea unaffected by eutrophication by means of cutting the nutrient (phosphorous and nitrogen) load from waterborne and airborne inputs (Backer et al. 2010).

3.2 *Information Demand of the EU WFD Regarding Analysis of Pressures and Impacts*

Regarded as a model framework for employing integrated approaches to water management, the European Water Framework Directive (WFD) came into force in December 2000 (EC 2000). To aid in the application of the WFD, the guidance document for pressures and impacts analysis (IMPRESS) was issued in 2003

(EC 2003). In the WFD, causal relationships are used to identify significant anthropogenic pressures and assess the impacts on the quantity and quality of surface water and groundwater (Article 5 and Annex II). In Annex VII of the WFD, significant pressures and impacts of human activities are presented as follows: (i) estimation of point source pollution; (ii) estimation of diffuse source pollution, including a summary of land use; (iii) estimation of pressures on the quantitative status of water including abstractions; and (iv) analysis of other impacts of human activity on the status of waters. Based on the IMPRESS, examples of cause–effect relationships are represented in Table 1.

The IMPRESS aims to evaluate the risk of failing to meet the objectives of the WFD by comparing the state of the aquatic environment with corresponding threshold values. In particular, the following four kinds of pressures are considered: (i) pollution pressures from point and diffuse sources, (ii) quantitative resource pressures, (iii) hydromorphological pressures, and (iv) biological pressures (EC 2003). In the IMPRESS, three prerequisites are identified for appropriately and successfully identifying pressures and assessing impacts, i.e.,

Table 1 Examples of driving forces, pressures, and impacts identified in the EU WFD (after EC 2003)

Type of pressures	Driving forces	Direct pressures	Possible impacts and change in environment
Diffuse source pollution	Agriculture	Nutrients (e.g., P and N) loss	Nutrients modify ecosystem
		Pesticide loss	Toxicity; water contamination
	Atmospheric deposition	Deposition of compounds of nitrogen and sulfur	Eutrophication; acidification of waters
Point source pollution	Industry	Effluent discharged to surface water and groundwater	Organic matter alters oxygen regime; increased concentration of suspended solids
	Thermal electricity production	Alteration to thermal regime of waters	Increased temperature; changes in biogeochemical process rates; reduced dissolved oxygen
Quantitative resource pressures	Agriculture and land use change	Modified vegetation water use	Altered groundwater recharge
	Water abstraction	Reduced flow or aquifer storage	Modified flow and ecological regimes; saltwater intrusion
Hydromorphological pressures	Physical barriers and channel modification	Variation in flow characteristics	Altered flow regime and habitat
Biological pressures	Fisheries	Fish stocking	Generic contamination of wild populations

(i) understanding of the objectives, (ii) knowledge of the water body and catchment, and (iii) use of a correct conceptual model. This strongly suggests that the proposed conceptual model for pressures and impacts analysis could describe both the quantitative nature and qualitative nature of the aquifer at a catchment scale and the likely consequences of pressures (EC 2003).

It is clear that the EU WFD focuses on discussing pressures of pollutants discharged into the water environment, in a form of either point or diffuse pollution. Indeed, the current water quality indicators—biological, physical–chemical, and hydromorphological—for determining the status of surface waters in the EU WFD are mainly state/impacts-oriented, while only water flow monitoring is partly pressure-oriented (Song and Frostell 2012).

Overall, the EU WFD and the above-mentioned HELCOM BSAP indicate the effort being made in Europe to improve the water environment. Although the main focus is on mapping and reducing emissions/wastes discharged to waters, they can be viewed as implementations of a semi-pressure-oriented approach. In fact, they show some promise of advancing toward an explicit pressure-oriented and proactive water management approach based on the metabolism of the anthroposphere.

4 Moving Toward an Anthropogenic Metabolism-Based and Pressure-Oriented Approach to Water Management

4.1 Facilitating a Broader Systems Perspective on Water Management

There is a growing consensus that a broader systems perspective is necessary for achieving improved environmental management in general and for improved water management specifically. This broader systems perspective could be regarded as a further clarification of the following opinion: "the former strategy of environmental management by controlling emission sources from industrial processes has to be replaced by a systematic approach that integrates all of the evaluations of environmental effects that can be assigned to a product" (Sonnemann et al. 2004). In the water domain, Biswas (2004) emphasizes that popular ways to address various national water problems "can no longer be resolved by the water professionals and/or water ministries alone." Moreover, Falkenmark (2007) claims that a shift in thinking about the focus of water management (like "blue" vs. "green" water) is needed because of past misinterpretations and conceptual deficiencies.

Here, we argue that a comprehensive understanding of the metabolism of the anthroposphere is essential for analysis and assessment of various water-related interactions between anthropogenic (human-made) systems and their environment(s) in a more integrated and proactive way. This often begins with using improved accounting for material and energy flows throughout the anthroposphere, followed by assessing the environmental impacts of resources used and waste/emission produced. Such a pressure-oriented approach aims to provide a basis for decisions and planning for more sustainable environmental performance, e.g., at an individual/household, company/industrial, or municipal/regional level.

Environmental changes and their pressures can only be properly understood if they are discussed in the context of the human activities or driving forces giving rise to them (EEA 2007). In particular, the root causes of human-induced water problems should be traced and analyzed from a metabolic point of view. Although WQOs and ELVs have been widely implemented for years, the traditional system of permits and enforcement is not leading to the required pollution abatement and is not effectively dealing with the sources of diffuse pollution (Van Ast et al. 2005). The traditional risk assessment-based approach does not fully capture the connections and interactions among individual existing environmental problems and drivers of environmental impacts (Bauer 2009).

Along with the suggested pressure-oriented approach, the DPR model (cf. the European DPSIR framework) should be promoted in order to effectively respond to emissions/wastes initially produced in the anthroposphere. A basic premise of the pressure-oriented approach to water management is that "the amount of resource flow into the economy determines the amount of all outputs to the environment including wastes and emissions" (EEA 2003). Here, it is worth emphasizing that the pressure-oriented approach includes, but is not limited to, input–output analysis. Theoretically, the pressure-oriented metabolic accounting approach could produce more pertinent water-related information with regard to the inputs of material/energy and the outputs of emission discharge including their interim transformation.

In principle, the metabolism-based pressure-oriented approach and the derivation of information systems could aid in effectively addressing water environmental degradation by means of avoiding/reducing various pressures exerted by human activities at all scales. The target information users include water researchers, water policy and decision makers, water-related socioeconomic decision makers, and other stakeholders involved in water-centric planning and decision making. In a broader sense, the AM/PO information could provide a basis for developing sustainable urban cycles (e.g., on water use, carbon flows, nutrient flows, and energy use) toward ecological sustainability.

4.2 Calling for a Transition to the Pressure-Oriented Approach

The state/impacts-oriented approach has now been employed not only in water planning and management, but also in environmental management. Very often, an accurate assessment of the state of the environment in relation to water, air, and soil is regarded as a prerequisite for policy makers and their scientific advisor committees to identify problems and take action for improvement (Kim and Platt 2008). In many cases, this holds true for indicator selection. Referring to the DPSIR framework, for instance, Bell and Morse (2008) emphasized that "impact and state sustainability indicators (SIs) are the primary measure applied to sustainability projects, but that drivers, pressure and response SIs may be developed at a later stage by the project team in order to help the team understand what the state SIs are describing—and thus to explain exactly what influences and drives the state and impact SIs." Here, according to Bell and Morse (2008), impact and state SIs (related to the state of a variable) should largely describe project impacts, while drivers, pressure, and response SIs (related to control, process, etc.) are more exploratory and analytical.

The current state/impacts-oriented approach is largely based on the concept of carrying capacity of environment and ecosystems. Under these circumstances, emissions and wastes would not be paid adequate attention until negative changes in water environment and ecosystems are monitored. As pointed out by Beder (2006), the implementation of environmental carrying capacity often "depends on value judgments about how much pollution a community is willing to put up with." In this context, societal measures often relate to pollution control, e.g., by means of increasing the extent of pollutant collection and treatment before being discharged into the ambient water environment. On the other hand, there is a time lag of about a decade, at a minimum, between nutrient concentration changes in a river basin and ecological and water quality response in waters (National Research Council 2009). In order to achieve better proactive water planning and decision making, the suggested pressure-oriented approach is one necessity in many ways.

Figure 4 briefly illustrates the state/impacts-oriented and pressure-oriented approaches, focusing on information flows. In contrast to the state/impacts-oriented approach, the pressure-oriented approach begins with exploring driving

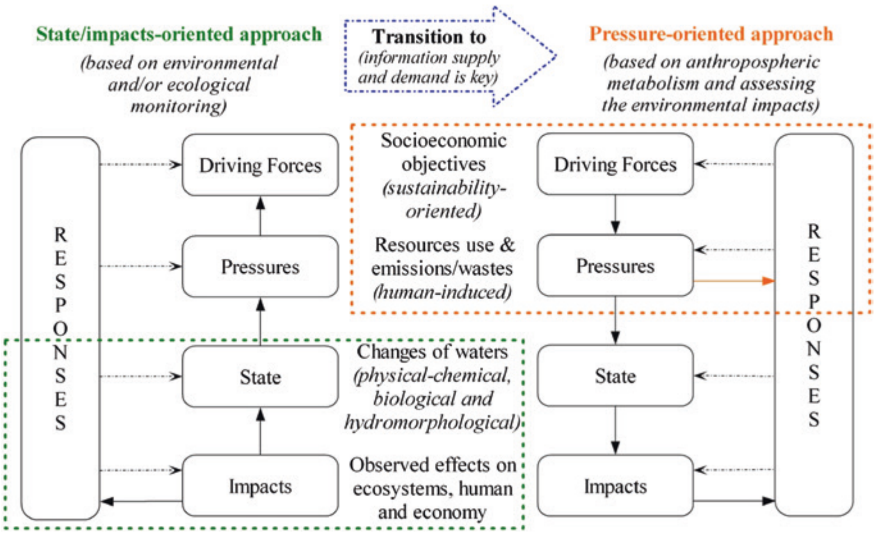

Fig. 4 Facilitating a transition from the state/impacts-oriented to the pressure-oriented water management approach (after Song 2012)

forces (various socioeconomic activities) and accounting for anthropogenic pressures (caused both by resource depletion and by pollution) on the environment. Thereafter, corresponding societal responses can be suggested, aiming to design an environmentally friendly anthropogenic metabolism in society at large. Most importantly, analysis of environmental pressures and impacts of socioeconomic development objectives could be comprehensively made beforehand by the use of the suggested pressure-oriented accounting approach as well as tools of integrated environmental assessment.

In order to trace the origins and pathways of pollutants in an area, one useful tool is material flow analysis (MFA), including substance flow analysis (SFA). MFA is a systematic assessment of flows and stocks of materials within a spatial or temporal system boundary by connecting the sources, the pathways, and the intermediate and final sinks of materials (Brunner and Rechberger 2003). When discussing the potential use of MFA for environmental monitoring, Brunner and Rechberger (2003) state that a well-established MFA of a region could replace traditional soil monitoring programs that are costly and limited in their forecasting capabilities by the use of statistics. On the other hand, Binder et al. (2009) argue that the efforts in MFA and SFA so far have been mainly academic and their actual impact on policy making is not clear. This is probably because most MFA studies are about material flows and stocks in a given area, while very few are accompanied by further discussion about their pressure-oriented contributions to environmental degradation at different scales from a broader systems perspective (Song 2012). In other words, facilitating the practice of the pressure-oriented approach largely depends on providing pertinent information by means of pressures and impacts analysis of anthropogenic metabolism.

In facilitating a transition to the pressure-oriented water management approach, it is essential to set an appropriate system boundary for monitoring, documenting, and reporting. The traditional socioeconomic statistics usually use an administrative boundary. In the water domain, a hydrological boundary has been suggested for IWRM at the scale of a river basin. In this context, alternative system boundaries suitable for pressure-oriented water systems analysis and management may be a hydrological boundary such as introduced in EU WFD, an administrative region, or a combination of these. In particular, an administrative approach on land (the socioeconomic system, e.g., companies, organizations, municipalities, provinces) should be used for data collection first, and then, the data are transformed to suit the hydrological system.

4.3 A Conceptual Framework for Accounting for Anthropogenic Pressures on Waters

Regarding water quality monitoring and management, a preliminary conceptual framework (Fig. 5) is developed as a brief demonstration of interlinks among the atmosphere, the natural water system, and the human-oriented system within an expanded systems boundary. Comprehensively identifying those links is a prerequisite to quantifying potential anthropogenic pressures on the water environment.

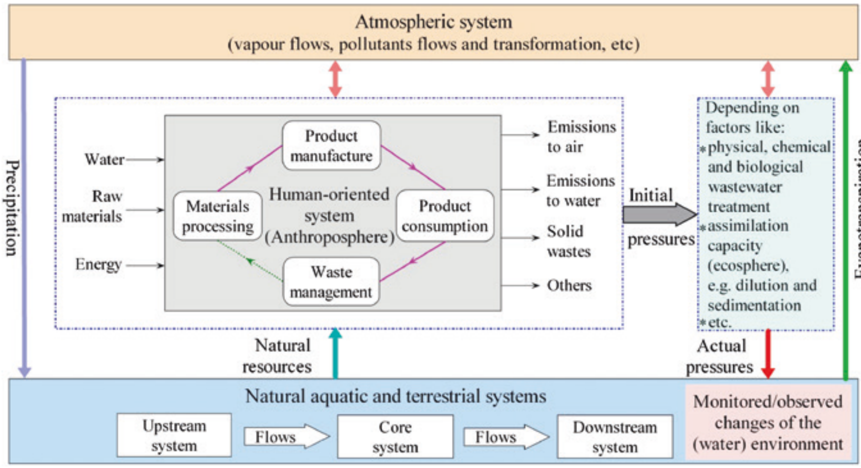

Fig. 5 A conceptual framework for a brief illustration of linkages between atmospheric, human-oriented, and natural water systems, which is a prerequisite to quantifying anthropogenic pressures on waters (after Song 2012)

In order to promote the use of a pressure-oriented water management approach in practice, a large amount of anthropogenic information needs to be produced by means of a metabolic approach. A metabolic approach also fosters different mass and energy balances, and thus, mass and energy accounting approaches are required to keep track of progress and deterioration of systems function. Same as any accounting approaches, the success of accounting for and analyzing anthropogenic pressures on the water environment depends on the extent of available information of relevant flows/stocks of materials and emissions throughout the human-oriented system (technosphere). A good documentation of this type of metabolic information is essential to effectively address the underlying drivers of both point source and non-point source of pollutants and human-induced water quantitative problems.

In principle, a comprehensive anthroposphere metabolic accounting process needs to be developed and implemented in order to systematically trace both input-related categories (e.g., resource depletion) and output-related categories (e.g., pollution) related to water degradation. Producing pressure-oriented metabolic information could complement the traditional water information systems and management by means of tracing the root causes of human-caused water problems back to the anthroposphere. To begin with, information on pressure-oriented water monitoring and accounting could theoretically (and later in practice) be achieved by the use of environmental systems analysis tools such as MFA/SFA, life cycle assessment (LCA), and environmental input–output analysis (IOA) over agreed system boundaries (Song 2012). Finally, the inventory results of emissions/wastes could be aggregated and assigned to different impact categories, such as eutrophication and toxicity. Then, the significant potential water quality/quantity pressures and their root sources could be determined.

The development and promotion of such a pressure-oriented approach could significantly assist proactive water policy and decision making (basically, planning practices). Compared with the state/impacts-oriented approach, the suggested pressure-oriented approach could account for metabolism of the material-based industrialized society as well as identify the most significant pressures on the water environment (e.g., the early recognition of metabolic factors contributing to water degradation). Moving toward sustainable water management systems, both the state/impacts-oriented and pressure-oriented approaches are necessary and complementary in many ways. Even so, facilitating the use of the AM/PO approach (based on the DPR model) could better allocate the majority of available scarce resources in society so as to aid in proactive water-centric planning and decision making in society.

5 Conclusions

Using the European DPSIR framework as a basis, this paper argues that the current water management approaches and associated information systems are mainly state/impacts-oriented, while very little is pressure-oriented. The state/impacts-oriented approach focuses mainly on physical and biogeochemical state changes in recipient waters, which often results in reactive responses to combat water problems (owing to the late recognition of contributing factors). To complement those traditional water management approaches, an AM/PO approach to water management is suggested at the conceptual level. The AM/PO approach is characterized in general by accounting for input of resources and output of wastes/emissions through the anthroposphere as contributing factors to water degradation. In principle, the produced metabolic information could help water-related planners and decision makers take proactive measures to address human-induced pressures on the water environment at their sources.

The suggested AM/PO approach, derived from a DPR model, shows a promising shortcut to effectively alleviating human-induced pressures (initially on land) with a focus on accounting for the anthropogenic metabolism. In order to cope with complex water problems in a more proactive way, it is not enough to focus only on water bodies (surface water and groundwater), e.g., either from the perspective of ecohydrology, biogeochemical monitoring and modeling, climate change, and/or adaptive water management. From a metabolic point of view, the root causes of human-induced water degradation are embedded in anthropogenic activities. A comprehensive understanding of the metabolism of the anthroposphere should be achieved and used as a basis for accounting for various pressures on waters and assessing their environmental impacts at their sources.

This paper only presents results of the first stage of this research at the conceptual level. Further studies will focus on developing pilot implementation projects. However, we hope that the preliminary results will stimulate interdisciplinary scientists and decision makers to rethink their individual preferred perceptions and approaches to environmental management in general and water management specifically. Concerns relate to, but are not limited to, guiding principles of water management (reactive vs. proactive), water-related data documentation (both socioeconomic and environmental), how to better use available scarce resources in water monitoring/accounting, and the water-centric planning process as well. In our opinion, regarding ecological sustainability in particular, the important issue is not only to make science-based decisions, but also to make decisions to address the "right" problems in an effective and efficient way. In a broader context, achieving a comprehensive understanding of human-induced pressures on the environment is essential to design or envision any "sustainable" society from a systems perspective.

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