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Original Research

Watershed Agricultural Non-Point Source Pollution Management

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Abstract

A growing focus on nutrient transfers from agricultural lands to watershed has served to accelerate our understanding of the environmental consequences of pollutants management in agriculture. A complete watershed-scale agricultural non-point source (ANPS) pollution management issue would include policy instruments, management practices, economic stimulation institutions, practice approach, and modeling simulation, as well as integrating management and technology programs. Considering the continued impact of ANPS pollution to watershed environment is necessary. The policy, practice, simulation and economic mix instruments are refined based on information obtained through the review of existing literatures and different district action processes. The recommended management scenario involved integrated BMP strategies and payments for agriculture services followed by an incentive program, and practical options for water quality management. More precautionary, positive and group optimizing management is needed to quantitatively assess ANPS pollution control processes feasibility.

Keywords: agricultural non-point source pollution, policy instruments, economic stimulation institutions, practical management

Introduction

NPS pollution is a significant source of water quality impairment in many countries [1], which is recognized as the single greatest threat to surface and subsurface sources of drinking water throughout the world. Agricultural non-point source (ANPS) pollution, common in water supply catchments worldwide, can have significant environmental and human health impacts [2].

Agriculture is an important source of nutriments (nitrogen and phosphorus) for the environment. Measures have been undertaken to reduce total N and P leakage from arable land, but their net influence on the large-scale transport of nutrients from the agricultural sector is low [3]. Existing regulations are complemented by a range of financial incentives for land stewardship such as auctions, payment schemes, subsidies, and rebates [4]. In addition, new policies, including catchment-based management-plans for farmers, have been suggested [5]. Various effective measures can be considered, such as regulatory standards, economic incentives, and suasive mechanisms. Policy instruments regarding water pollution control can be found within the legislative framework in most countries.

Effective management strategies of watershed ANPS pollution can widely depend on agronomic, sociologic, and hydrologic factors. The aim of pollutant management is to

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reduce and clean up environmental pollution as much as possible. Numerous government programs are available to help people design and pay for ANPS pollution management approaches to prevent and control ANPS pollution. For example, Scotland has carried out a series of management practices, including formulation of regulations, implementation of economic policies, and encouragement of farmers to reduce the impact of ANPS pollution [6]. We developed several management measure collective solutions based on their capacity to reduce water body pollutant concentration by considering the continued impact of agricultural pollution to the environment in the watershed (Fig. 1).

The literature reviewed has shown that establishing an ANPS pollutant management framework is, moreover, a demanding process of social and political construction, so the interrelations among different management institutions have been regulated at the watershed and regional levels. Inventive and payment principle are necessary, as they have the capacity to reduce transaction costs when allocating watershed environmental protection responsibility. The function of social organization relates to practice and policy instruments embedded in wider sets of integration management. This concerns the prevailing model simulation and best management practice, which have already established potential relations based on management components.

Policy Instruments

At present, the number of applications of policy instruments for environmental and natural resource management has grown. Policy instruments are tools that can be used to achieve objectives. ANPS pollution can be most effectively controlled by focusing policy instruments on these impediments and determinants of adoption of desired management practices [7]. To optimize target management interventions, information should be implemented based on best practice data acquisition and analysis [8].

ANPS Pollution Policy

Targeting of policy instruments is the need for a detailed understanding of the catchment-specific context of ANPS pollution management. There is a need to understand key determinants of adoption of water quality management and the careful selection and scheduling of policy instruments for addressing them for the effective mitigation of ANPS pollution [4]. By virtue of economic characteristics of policy instruments, policy instruments enhancing on-farm benefits could effectively increase the adoption of water quality management [9]. The utility of multi-criteria evaluation (MCE) could overcome a range of impediments to the efficient functioning for mitigating dryland salinity [10]. DMCE (deliberative multi-criteria evaluation) can assist policy design for enhancing adoption of on-farm water quality management. A policy of mitigating ANPS pollution impairment to watershed water quality should involve:

1) identify impediments of water quality management
2) specify policy scenarios for overcoming impediments
3) quantify the impact of policy scenarios
4) identify the preferred policy scenario
5) refine the preferred policy scenario

ANPS pollutant management policy mix harnesses the strengths of individual policy instruments while compensating for their weaknesses by the use of additional complementary instruments [11, 12]. Policy instruments may be operated or implemented on the ground to enable a comprehensive assessment of transaction costs of implementing policy instruments. In the review of various policy instruments, government policymakers are often multiple services oriented. In relation to this, the transaction cost is lower if communities are involved as opposed to individual landholders [13]. Transaction costs concerns both the setting up of the management system and the running of it. And the former is larger than the latter; there are reasons to believe that this depends much on the system [14, 15]. So the features of the selected ANPS pollution control policy must suit the watershed scale need. As a result, the nonpoint pollutant contributions can be implemented more effi-

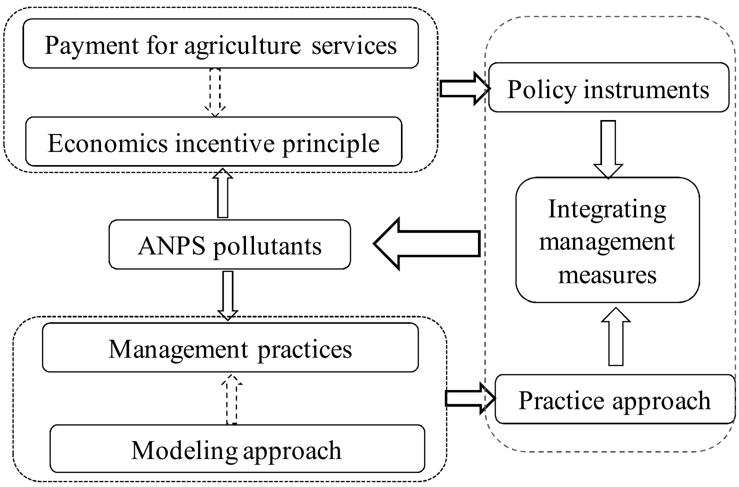

Fig. 1. ANPS pollution management methodology.

ciently, and the combined local knowledge of multiple farmers about potential pollutant contributions can be utilized [16].

ANPS Pollution Policy Instrument Implementation

ANPS pollution management policy instrument will be most effective when they form a coherent set of policies to address pollutant sources, migration, and attenuation. They are less likely to work well when other policy instruments aren't providing relative economic incentives or when water pollution legislation controlling allocation is inflexible. ANPS pollution control strategy will involve multiple policy instruments and approaches that will be complementary. The general rules of consideration include pollution control, water quality accession, supervision and water body self-restoration. The specific policies are depicted in Fig. 2.

Best Management Practices

Implementation of agricultural best management practices (BMPs) can have multiple benefits, such as simultaneous reductions in runoff of soils, nutrients and pesticides. Agriculture is the most widespread source of pollution in impaired rivers and lakes [17]. The potential for nutrients migrating to surface and groundwater is largely dependent on soil and site conditions. Understanding of the cumulative contributions of different land uses may be a vital ingredient for successful water management [18, 19]. Developing a comprehensive BMP management tool to control the temporal and spatial changes of pollution in small agricultural watersheds, which has been the effective measure to treat ANPS.

BMPs have been used to reduce or eliminate the losses of pollutants from diffuse sources into receiving water [20]. The Chesapeake Bay Region is suggested to develop and implement BMPs for controlling emissions of nitrogen and phosphorous in the basin [21]. A combination of BMPs is often the most cost-effective proposition. Selection of appropriate systems of BMPs for a particular condition is difficult, for the extent of pollution is related to uncontrollable climatic events as well as site-specific conditions such as soils, topography, and land use [22]. The effectiveness of BMPs at watershed-scale is not well identified. Most BMPs are used not alone, but in conjunction with complimentary BMPs. When appropriately selected and properly sited, BMP effectiveness can reach 95%, it may be highly effective to control soil erosion and nutrient loses and to increase water quality [23]. Emissions trading, taxes, and payments for environmental services are examples of policies that have been successfully utilized to address environmental pollution [24].

Implementation of BMPs is a conventional approach for controlling and mitigating pollution from diffuse sources. A large body of literature has explored the determinants of adoption of BMPs in agriculture (Table 1). In the future, the designer of BMPs of a specific region should consider financial incentives and cost-sharing availability to improve the effectiveness of BMP management. Management practices include:

1) control source contaminant discharge
2) interception, treatment, or reduction of contaminant delivery
3) river-reservoir system operation
4) pollutants natural abstraction and treatment management

The nutrient management plan is to minimize detrimental environmental effects and optimize farm profits [23]. The selection of BMP data is important for normal BMP performance. The database includes geometric information, runoff volumes, water quality data, and other general information [24]. The major data are categorized as illustrated in Fig. 3.

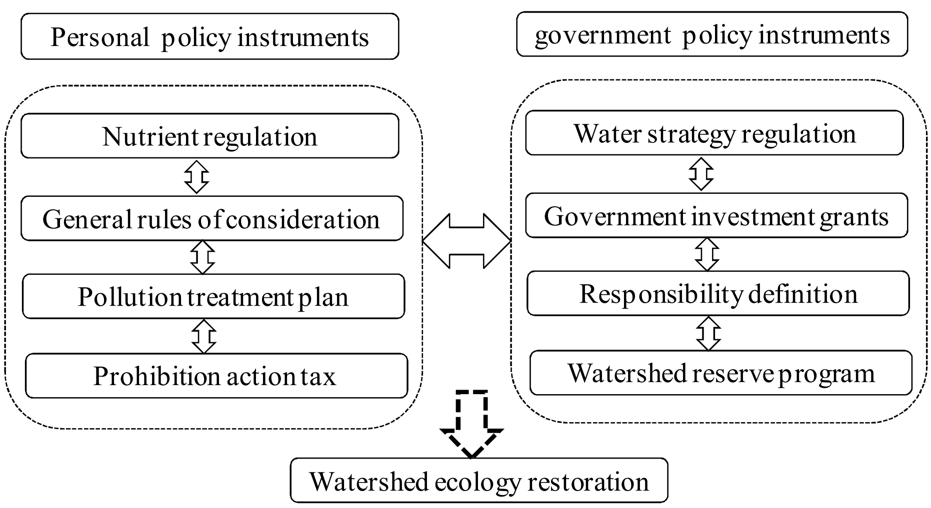

Fig. 2. ANPS pollutant management policy instruments.

Table 1. Integrated BMPs evaluated in previous studies.

Survey Item	Details	References
Approach	extensive land use management, grazing management practice, field buffer strip, and nutrient management plan	[25]
Regional practices	United States, Québec (Canada), U.S. government IPM, wetland basins BMP	[7, 26-28]
Management scope	environmental and economic harm contaminants; societal factors; chemical, biological, and physical variables	[29]
BMP effectiveness assessment	selecting the most appropriate BMP for ANPS pollution problem; estimating the benefits of BMP implementation; ranking alternative BMPs in terms of their cost effectiveness; determining an optimum BMP program based on program objectives	[30]
BMP applicability	temporally and spatially changing land use management practice in an agricultural watershed; interaction between surface and ground water over the entire system	

Economic Stimulation Institutions

Payments for Agricultural Services

Environmental economics literature provides a rich set of potential economic interventions that can be applied to overcome problems of external effects. Payments for agricultural services can help to decrease broad category ANPS pollution and to deal with sediment deposition in watershed systems to avoid the fuzzy risk of violating the water quality standards. Payments for agricultural service framework provides opportunities to think more widely and innovatively about the application of an integrated approach to catchment environmental management. For example, Vittel government launched a research program called "Agriculture-Environnement-Vittel" to understand the relationship between actual farming practices and the nitrate rate in the aquifer. Payments for agriculture services should form part of a package of instruments, especially those which reduce the opportunity costs of improving watershed environment. Payment funding has always been limited, which results in increasing environmental degradation and land use change with severe environmental impacts. To get enough money to remove ANPS pollutants, an efficient methodology for developing pollutant discharge permit trading is necessary.

During the on-farm management process, payment for agriculture services is a popular way to control agricultural chemicals reaching into the watershed using economic incentives. To express the management importance in reducing farm pollution, farmer groups' long-term viability under payment framework should be considered. Scientific and economic agricultural management is the basis of establishing compatibility between farmers' income and watershed water environmental protection objectives. Payments for agricultural services should:

1) understand the farming systems
2) analyze the conditions of changing farming behavior

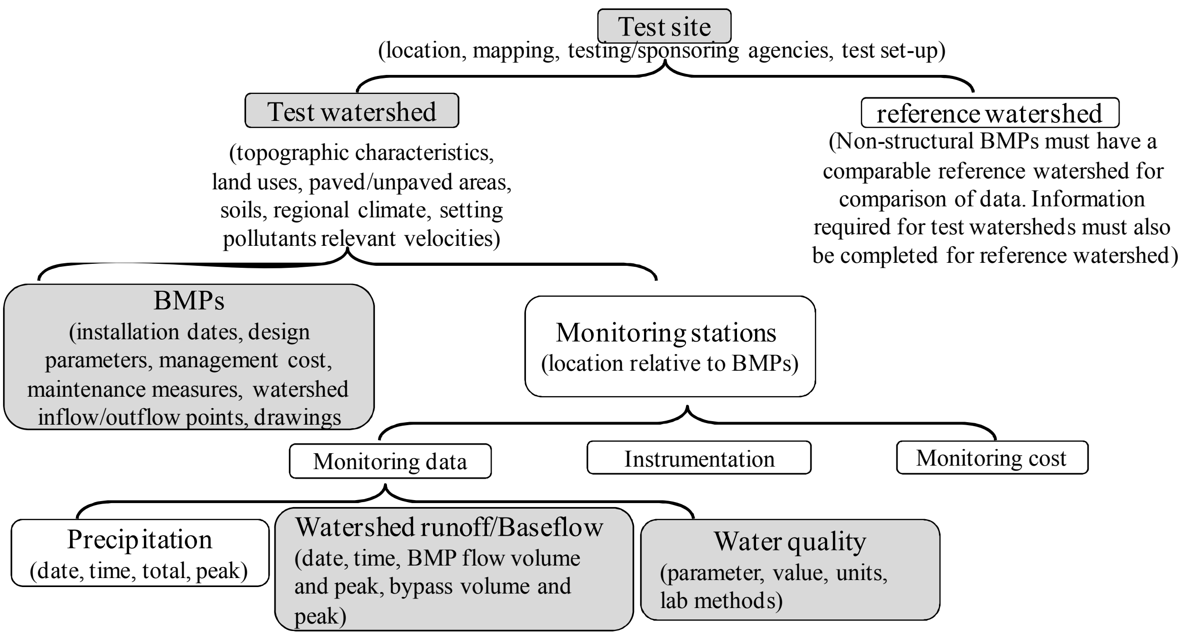

Fig. 3. ANPS pollution BMPs data categories.

Table 2. Practical options to minimize ANPS pollution of surface waters.

Soil nutrient loss status	Practical options to minimize ANPS pollution
Low	Soil testing: have soils tested for ANPS pollutants at least every 3 years to monitor loss or residual nutriments (N and P) in soil.
	Soil conservation: follow good soil conservation practices. Consider effects of changes in tillage practices or land use on potential for increased transport of pollutants from farmland.
	Nutrient management: consider effects of any major changes in agricultural BMPs on nutriment losses before implementing them on the farm. Examples include increasing the number of animal units on a farm or changing to crops with a high demand for fertilizer.
Medium	Soil testing: have soils tested for ANPS pollutants at least every 3 years to monitor loss or residual nutriments (N and P) in soil. Conduct a more comprehensive soil testing program in areas that have been identified by modern farming as being most sensitive to surface runoff, subsurface flow, and erosion.
	Soil conservation: implement practices to reduce fertilizer loss by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management).
	Nutrient management: any changes in agricultural practices may affect nutrient loss, so carefully consider the sensitivity of fields to fertilizer loss before implementing any activity that will increase soil P. Avoid broadcast applications of fertilizers and apply manures only to fields with lower absorption values.
High	Soil testing: a comprehensive soil testing program should be conducted on the entire farm to determine fields that are most suitable for further additions of crop planting area.
	Soil conservation: implement practices to reduce soil nutrient losses by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). Nutrient management: in most situations fertilizer, other than a small amount used in starter fertilizers, will not be needed. Manure may be in excess on the farm and should only be applied to fields where it is easily absorbed by crops. A long-term ANPS pollutant management plan should be considered.
Very high	Soil testing: a comprehensive soil testing program must be conducted on the entire farm to determine fields that are most suitable for further additions of crop planting area.
	Soil conservation: implement practices to reduce soil nutrient losses by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). Nutrient management: fertilizer and manure should not be applied for at least 3 years and perhaps longer. A comprehensive, long-term ANPS pollutant management plan must be developed and implemented.

3) identify, test, and validate the management practices necessary
4) provide financial and technical support to farmers

Once farmers have undertaken the transition, the farming system is sustainable [31].

Economic Incentive Mechanism

Setting of prices and charges are crucial to the success of ANPS pollutant management. If charges are too low, farmers may opt to pollute and to pay, whereas if charges are too high they may inhibit agricultural development. In the Virginia nutrient management program, the state offers a tax incentive to farmers to encourage them to purchase qualifying nutrient application equipment [32]. The application of nutrient management plans is expected to have a potentially expensive impact on farmers that generate or use animal manure [33]. So research findings about the success of programs to control agricultural non-point source pollution promote inexpensive changes in existing agricultural practices that are already familiar to the farmers, and on the tangibility of derived environmental benefits.

Although not to the exclusion of managerial or direct regulatory approaches, while great stress is placed on the cost-effectiveness of pollution control measures [34]. Economic instruments are known to be relatively cost-efficient in reducing ambient nitrate levels [35]. Economic incentives need to form the core policy instrument for enhancing the adoption of ANPS pollutant management measures. The aim of using incentives is to establish effective agricultural service payment schemes. Existing regulations are complemented by a range of financial incentives, such as auctions, payment schemes, subsidies, and rebates. Therefore, incentives may occur simultaneously with or follow the other management instruments. Integral economic incentive measures contain:

1) sign long-term environmental security contracts
2) abolition of debt during contract years
3) supply a number of subsidies for several years
4) government pay farm to cover the cost of all new environmentally friendly farm
5) free laborers to supply for compost use in farmers' fields
6) free technical assistance

Table 3. ANPS pollution modeling simulation characteristic.

Characteristic	Description
Components	hydrology, sediment yield, nutrients, pesticides, snowmelt, rainfall, irrigation, water conservancy facilities, crop growth, soil characteristics, and stream networks
Scale	long-term, daily, or sub-daily steps
Watershed representation	homogeneous land areas (cells), reaches, and impoundments/ Sub-basins grouping based hydrologic and meteorological conditions
Weather data	precipitation, maximum and minimum temperature, dewpoint temperature, relative humidity, wind speed and solar radiation
PET method	Penman/Penman-Monteith
Infiltration/runoff	Modified SCS CN2 [54]
Peak runoff rate	SCS TR-55 method [55]
Groundwater	subsurface flow or Interflow
Simulation	subsurface drainage /shallow (deep) aquifer or other water storage zone
Subsurface flow	Darcey equation/Hooghoudt equation/kinematic storage model/ empirical elations
Water routing/channel	Manning equation/Muskingum river routing method
Sediment yield-overland	loss equation based on farmland and watershed characteristics
Sediment yield-channel	equation for sediment transport, degradation capacity of flow
Chemical simulation	Soil moisture, nutrients(nitrogen and phosphorus), and pesticides are simulated combined with soil database, crop information and water body natural characteristic
BMPs evaluation:	impact of watershed management practices on runoff and sediment loss, nutrients, pesticides transport BMPs

Practical Simulation Management

Practice Approach

Agriculture has become the single greatest contributor of nonpoint source pollutants to soil and water resources [36]. The dynamic agricultural non-point source assessment tool (DANSAT) is used to simulate spatial and temporal impacts of BMPs on hydrology and water quality in small agricultural watersheds [37]. Codes of good agricultural practice can give guidance to farmers on how to prevent or reduce pollution of water bodies. Good agricultural practice is recognized as a means of minimizing the risk of water pollution and promoting the continuation of economic agricultural activity [38]. The agriculture practice of crop rotation has many economic and environmental benefits. We should identify impediments to the adoption of ANPS pollutant management practices to reduce agricultural chemicals and sediment from agricultural non-point pollution sources, alternative policy instruments for addressing the major impediments to adoption of water quality management [39]. Soil testing, soil conservation, and nutrient management practical factors influence the potential for fertilizer loss from agricultural land to watershed water body. Some studies have given the practical options to minimize ANPS pollution of surface waters in Table 2 [40].

Modeling Simulation

Many ANPS pollution studies have been based on modeling approaches. Modeling differentiates from different sources. A large number of NPS models have been developed, such as Ann AGNPS [41], ANSWERS-2000 [42], MIKE-SHE [43], HSPF [44], and SWAT [45], but only quantitative research and management agrochemical models are reviewed to control ANPS pollution. Simulating runoff and soil erosion components is the model basis for ANPS pollution management. USLE (universal soil loss equation) is considered to be a good method for estimating long-term average annual soil loss from homogeneous fields, but the model cannot simulate temporal and spatial variability required by an effective planning model [46]. GLEAMS (ground water loading effects of agricultural management systems) is a continuous simulation, field-scale mathematical model developed to evaluate the effects of agricultural management systems [47]. In order to consider pesticide registration, cropping practices, and agricultural management practices, PRZM (pesticide root zone model) is a one-dimensional, daily time scale, management model for predicting pesticide movement within an entire vadose zone. At present, RZWQM (root zone water quality model) is established to simulate hydrologic and chemical responses of agricultural management systems, as well as estimate the potential loadings of non-point source pollutants to the ground water [48]. To simulate water flow and different agricultural pollutants movement, Wagenet and Hutson [49] gave a highly physically-based, mechanistic, and finite difference research model-LEACHM (leaching estimation and chemistry model). Opus [50] is a comprehensive model developed to simulate the processes of sediment and nutrient cycles in soil microbial decay. Management models using capacity-based approach are considered as base models. ANSWERS-2000 is a process-oriented, distributed-parameter, and continuous-simulation model, which is selected as a base watershed-scale ANPS model. The dynamic agricultural non-point source assessment tool (DANSAT) is a newly developing model to evaluate the effectiveness of spatially and temporally changing BMPs. GRASS-AGNPS [51] are recommended to be appropriate for representing spatial distribution of topographics.

ANPS pollution modeling is an incentives approach of environmental protection, which is more efficiency than design policies to regulate watershed environmental externality. Morton [52] describes an institutional model within an individual's value system to encourage farmers to undertake the importance of water quality protection measures. Models can provide long-term simulations of various combinations of cropping systems and conservation practices, effects of best management practices, and assist in selection of appropriate conservation approaches for improved environmental benefits [53]. To improve model simulation precision of pollutant movement, the ANPS pollution modeling simulation characteristic is summarized in Table 3.

Integrating Management and Technology Programs

The assessment of water quality for management purposes requires the description and analysis of the sources (cause) and impacts (symptom) of water quality contamination [56]. Management measures should be tailored to match the level of economic and administrative capacity and capability, which should have an iterative and on-going process. To realize the environmental objectives of minimum river flow rates and reductions in nitrate pollution, a multi-farm catchment model combining management measures and economic instruments is developed [34]. The U.S. EPA and USDA have devised a joint strategy for sustainable nutrient management that could provide technical leadership in developing sound criteria [57]. To signal a commitment beyond measure of past promises, the EPA and other federal agencies proposed a Great Lakes Restoration Initiative action plan.

The influence of land use on water quality in streams is scale-dependent and varies in time and space [58]. With the increasing availability of geographic information systems and remote sensing techniques on river water quality and pollutant control at different scales, the integration of GIS and agricultural activities management decision support system can be developed to manage ANPS pollution at watershed scale. Although some studies have considered spatially untargeted land retirement to reduce non-point pollutants from agriculture [59], the literature has not considered the integration of direct regulation or managerial approaches.

Modeling will provide the link between the conceptual physical catchment characteristics and the empirical hydrological and water quality response. A variety of analysis techniques exist for water quality assessment, depending upon ANPS pollutant management focus, data availability, watershed temporal and spatial scale, contaminants constituents, and main transport mechanisms. Eric R.V. Dickenson et al. [60] presents a new approach that uses a suite of common trace organic chemicals as indicators to assess the degree of impact and attenuation of trace organic chemicals in receiving streams. On the basis of calculating the occurence probability, we can identify which management measure should be taken and treatment effectiveness (water quality and environment) in receiving streams.

Conclusions

ANPS pollutant managerial options can generate ancillary environmental benefits and sustain the multi-functionality of agriculture. Multiple-objective watershed ANPS pollution management seems likely to become more prevalent worldwide for the necessity of water quality assessment and management, as well as protect and maintain the ecological functioning of watershed water environment. This article provides a literature review of ANPS pollution management technical feasibility and scientific and validity, and the impacts of policy, practice, simulation, and economic incentive measures. However, due to key coordinated knowledge deficiencies, the current integrating ANPS pollution management measures are limited in their predictive capacities. The paper demonstrates that management institutions may be used to cooperate with scientific, economic, and practical relevant mechanisms, and the aim of controlling farmland non-point pollutant levels compatible with watershed water environmental restoration can be achieved. While existing policy and practice systems has a slight effect to ANPS pollution control and watershed contaminant reduction, management measures integration and operation still face major challenges.

1) ANPS pollutants precautionary principle. Until now the use of agricultural chemicals (fertilizer) and its release to the water environment has been widely accepted, unless scientific research has proven unambiguously a causal link between the substance and a well-defined environmental impact. The action to avoid potential ANPS pollution by hazardous substances should not be postponed on the grounds that scientific research has not proven fully a causal link between the substance and the potential damage [61].
2) ANPS pollutant management feasibility depends on the degree of regulatory strictness. Catchments with better agriculture development incentive policy and managerial regulation will effectively control impacts (symptom) of water quality contamination.

3) ANPS pollutant control is a group-optimizing behavior, so individual incentives to participate in management have not been particularly effective in solving the problem. During water quality management, individual action to decrease pollutant discharge has been limited due to high transaction costs, insufficient institutional structure, and difficulties in monitoring water quality improvements.

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