Potential of Artificial Wetlands for Removing Pesticides from Water in a Cost-effectiveness Framework

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1. Introduction

In the European Union, the water policy is mainly driven by the Water Framework Directive (WFD) of 2000. One of its main targets is to work toward an environmental quality illustrating the best trade-off between economic and ecological interests. One consequence is that member states look for economic instruments allowing to reach a pre-defined standard of water pollution at least cost. Wetlands play a crucial and growing role since they can constitute one of the cheapest means to be used, in combination with classical regulation instruments like charges on polluting inputs, in order to achieve environmental quality standards. For instance, in Sweden, one of the measures implemented by the Government to reduce the excessive nutrient that contributes to the eutrophication of the Baltic Sea was the establishment and restoration of wetlands.[1]

The point of departure of our paper is that the least cost means of improving water quality can involve the use of wetlands. But what are the implications in terms of water pollution regulation? The WFD also promotes the extensive use of economic incentives like input charges. This means that governments have to combine economic instruments consisting in giving incentives to reduce the use of polluting inputs and wetlands restoration. What will be the effect of using wetlands on the input charge and on the farmers' abatement effort? This is the main question that we want to investigate in this work. In order to answer, we propose to build a model underlying the main forces that are at work. We will keep this model as simple as possible in order to be able to illustrate it by using some "real" data in a joint effort with scientists from other disciplines.

We will present our model in section 2. In section 3, we will study the benchmark case in which the regulator does not construct an AW in order to reduce pollution. Section 4 will be devoted to the case in which it is constructed. In section 5, we will compare the two cases in order to investigate the implications on the charge that has to be implemented within such a framework, and thus on the effort of pollution abatement asked to the farmer. Finally, in section 6, we will develop a numerical illustration applied to a wine catchment area located in North-East of France. We will conclude this work in section 7.

2. The model

We consider a fixed number n of farmers and a regulator. The regulator wants to reduce pollution from pesticides used by farmers in order to reach a water quality target. We assume that there are two possible ways of reducing pollution:

- on the one hand, the farmers are supposed to be able to reduce the amount of pesticides used if the regulator gives them some economic incentives,
- on the other hand, the regulator can construct an AW that is able to remove pesticides molecules from water.

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[1] See Gren, Elofsson and Jannke (1997), for instance.

x_i denotes the amount of pesticides used by the farmer i ($i = 1, ..., n$). $\delta_i := \bar{x} - x_i$ is the pesticide use reduction operated by the farmer with respect to the one corresponding to one optimal running, $\overline{x}$. The pesticides use reduction δ_i has a cost[2], $\kappa(\delta_i)$, which reflects the change in the farmer's i profits resulting from this reduction. This cost is assumed to increase with the amount of pesticides removed, at an increasing rate (it is convex): $\kappa_{\delta_i} > 0$ and $\kappa_{\delta_i \delta_i} > 0$.[3] Furthermore, no reduction induces no cost, $\kappa(0) = 0$; small reductions are not very costly, $\lim\limits_{\delta_i \to 0} \kappa_{\delta_i} = 0$; but large ones are disheartening, $\lim\limits_{\delta_i \to \overline{x} - \underline{x}} \kappa_{\delta_i} = +\infty$. $\delta_i \to 0$ means that the amount of pesticides used is at its maximum, $\overline{x}$, and $\delta_i \to \overline{x} - \underline{x}$ that it is at its minimum one, $\underline{x}$.

We also assume that the mass of pollutant in water, M, is proportional to the total amount of pesticides used: $M := \alpha X$ where $X := \sum_{i=1}^{n} x_i$ is the global amount of pesticides used at the catchment level and $\alpha \in [0, 1]$ is the transfer coefficient of the pesticides used into the water; $1 - \alpha$ is usually called the natural assimilative capacity.

The regulator is assumed to own the land located downstream with respect to the farmers' fields. As a consequence, it can decide to construct on these lands an AW of size S, in order to eliminate some pesticides contained in water. We assume that the suitable land area that can be converted into an AW is such that the size can not be higher than $\overline{S}$, since the regulator does not hold infinite property rights on lands. The construction of an AW has a cost that is assumed to depend on the size converted: $c(S)$. It is increasing, $c_S > 0$, and convex, $c_{SS} > 0$, and there is no cost when no AW is constructed: $c(0) = 0$. Furthermore, small constructions are not very costly, $\lim\limits_{S \to 0} c_S = 0$, but large ones are disheartening, $\lim\limits_{S \to \overline{S}} c_S = +\infty$.

Concerning the physical process behind the reduction of the pollution with pesticides thanks to the construction of the AW, we are going to assume that the quantity, q, of pesticides assimilated by an AW of size S, depends both on the total mass of pesticides in water at the exit of the AW, M, and on this size: $q := q(S, M)$. We expect that q is increasing with the size of the AW (at a decreasing rate: $q_{SS} < 0$) and also with the mass of pollutant (q_M and $q_S > 0$). q_M can be interpreted as the efficiency of a pre-determined AW with respect to the pesticides assimilation; it is positive and we assume that the mass of pesticides assimilated by the AW increases less than one unit when the mass of pesticides entering into it increases in one unit: $1 > q_M > 0$. No molecule of pesticides induces no assimilation and neither does no AW construction: $q(0, M) = q(S, 0) = 0$. The total size of AW available, $\bar{S}$, is assumed so high that, next to this point, each additional unit of AW becomes inefficient, $\lim\limits_{S \to \overline{S}} q_S = 0 \ \forall X > 0$, and when no AW is constructed, the efficiency of constructing the first unit is assumed strictly positive, $\lim\limits_{S \to 0} q_S > 0 \ \forall X > 0$.[4]

To sum up,

- when the AW is not constructed, the mass of pesticide in water is proportional to the quantity

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[2] In order to keep the model easily tractable for a first numerical illustration, this cost function is assumed to be the same one for all farmers.

[3] Subscripts of functions indicate partial derivatives.

[4] All these assumptions were approved by some soil experts, members of the LIFE Environment ARTWET project.

applied by the farmers: αX,

- and when it is constructed, the mass of pesticide in water is equal to the previous one minus the assimilation of pesticides by the AW: $\alpha X - q(S, \alpha X)$.

The targeted mass of pesticide is denoted $\overline{TM}$. The pollution induced by the minimum mass of pesticides use is assumed always lower than the targeted mass: $\overline{TM} > \alpha \underline{X}$ where $\underline{X} := n\underline{x}$. Furthermore, the AW is assumed to be unable to assimilate the amount of pesticides corresponding to the farmers' maximum profits up to the targeted mass: $\alpha\overline{X} - q(S, \alpha\overline{X}) > \overline{TM}\ \forall S > 0$ where $\overline{X} := n\overline{x}$. As a consequence, the pollution induced by the maximum mass of pesticides use is always higher than the targeted mass: $\alpha\overline{X} > \overline{TM}$.[5] This assumption, combined with the symmetrical one, is in phase with the WFD setting since the targeted mass, $\overline{TM}$, is negotiated between farmers and environmental protection associations. The assumption on the targeted mass without AW construction also implies that: $\alpha\underline{X} - q(S, \alpha\underline{X}) < \overline{TM}\ \forall S$.

Remark 1. *Our assumptions on* $\kappa(\delta_i)$ *insures that the minimum of this function is reached at* $x_i = \overline{x}$.

Remark 1 tells us that when no regulation is implemented, the farmers aiming at minimizing the costs of their pesticides use reduction will choose to use the amount of pesticides maximizing their profits. Since we assumed that $\alpha\overline{X} > \overline{TM}$, the targeted mass can not be reached without some form of regulation of water pollution like a charge on pesticides used. Within our framework, it is the regulator that will pursue this aim. In the benchmark case, this regulator will only implement such a fiscal scheme. We will then consider another case in which an AW can be constructed in order to reduce the mass of pesticides in water. In this latter case, since we assumed that the total AW size can not be sufficient in order to reach the target ($\alpha\overline{X} - q(S, \alpha\overline{X}) > \overline{TM}\ \forall S > 0$), the regulator will also have to implement a new fiscal scheme. We make these assumptions in order to concentrate on the impact of an AW construction on the proportional fiscal scheme in more details. From the best of our knowledge, no paper concentrates on this aspect.

3. The benchmark case: artificial wetlands are not constructed

In order to better underline the implications of AW construction, we propose to build a very basic model consisting in three steps. But since these steps reflect a decision process, they can be considered so closed in time that it is possible to ignore discounting effects.

- In the first step, the regulator chooses the proportional charge on pesticides use, τ, that minimizes the sum of the farmers' costs needed in order to achieve the targeted mass.

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[5] This assumption doesn't work for pesticides with very low adverse effects in aquatic ecosystems where the pollution corresponding to farmers' maximum profit could be below the targeted mass. A a consequence, our results won't fit to such uncommon kind of pesticides.

- In the second step, the farmers choose the amount of pesticides that minimizes their costs, which then include the level of money levied through this proportional charge. In this work, we don't enter into the description of the decision process behind the pesticides use reduction.
- In the third step, the regulator balances its budget through transferring the amount of money collected in the previous step as a lump-sum transfer back to the farmers who are assumed myopic, i.e. they do not anticipate the exact value of this lump-sum transfer. We justify the requirement of a balanced budget with respect to charge/lump sum payments for water pollution by a "water pays water" principle. Furthermore, this will allow us to lead a complete cost-effectiveness analysis.

We are going to solve this model backward.

In the **third step** and once the targeted mass had been reached, the total amount of money collected with the charge on pesticides use is redistributed, in an equal way, as a lump-sum transfer, $\widetilde{LS} = \frac{\tau X}{n}$, to each farmer. The regulator is assumed to be a public agency that does not want to make profits; it is why it redistributes the money collected to the agents that we have in our model: the farmers. We assume all along this paper that there are no regulation costs.

The lump-sum transfer could induce a strategic behavior of the farmers consisting in not reducing the amount of pesticides used. But we assumed that they are myopic and thus unable to anticipate the amount of the transfer, i.e. the lump-sum appears as a constant in the objective function of the polluter. What about the European "polluter pays" principle? It is still at work since even if the charge collected in order to reduce pesticides used is given back to the farmer, he has to support the costs of reducing his pesticides use up to the level allowing to reach the target $\overline{TM}$.

In the **second step**, each farmer takes the charge rate as given since it is fixed by the regulator. Furthermore, since the farmers are assumed myopic, they are unable to anticipate the exact value of the lump-sum transfer. The program that each farmer solves is thus the basic following one:

$$\min_{x_i} \kappa(\delta_i(x_i)) + \tau x_i - \widetilde{LS}$$

where $\delta_i(x_i) = \overline{x} - x_i$.

Remark 2. *The objective function is strictly convex since* $\left(-\kappa_{\delta_i} + \tau\right)_{x_i} = \kappa_{\delta_i \delta_i} > 0$.

The solution x_i^* of this program, where the superscript $*$ denotes the solution of the benchmark case, satisfies a classical first order condition according to which marginal cost of abatement equal the charge on pesticides:

$$\kappa^*_{\delta_i} = \tau \tag{3.1}$$

Lemma 3.1. *(i) The total amount of pesticides used in the catchment area decreases with the charge rate.*
(ii) When the charge rate is zero, the amount of pesticides used in the catchment area is maximum and when the charge is very high, it goes to its minimum.

It directly follows from this lemma that $X^*(\tau) \in [\underline{X}, \overline{X}]$.

Finally, in the **first step**, the regulator chooses the proportional fiscal scheme τ such that the targeted mass is reached:

$$\alpha X^*(\tau) = \overline{TM}$$

We assumed that it has got a perfect and complete information but no profits maximization objective. As a consequence, it is perfectly able to anticipate the best reply of the farmers to this charge, $X^*(\tau)$.

Furthermore, our assumptions on the targeted mass, $\alpha\overline{X} > \overline{TM} > \alpha\underline{X}$, insure that $X^*(\tau) \in]\underline{X}, \overline{X}[$ and the interiority of the charge rate, i.e. $\tau^* \in]0, +\infty[$, then directly comes from Lemma 3.1.

Proposition 3.2. *At the solution of the benchmark case* (X^*, τ^*),
(i) $\frac{\sum_{i=1}^{n} \kappa^*_{\delta_i}}{\alpha}$ *denotes the marginal cost of removing one unit of pesticide from water.*
(ii) The global amount of pesticides used in the catchment area is decreasing with the transfer coefficient of pesticides into water and increasing with the targeted mass.
(iii) The cost-effective charge on pesticides is increasing with the transfer coefficient and decreasing with the targeted mass.

We now turn to the study of the solution of the same problem in which we add the AW construction.

4. The new condition of cost-effectiveness when an artificial wetland is constructed

As we explained in the introduction, there is some empirical evidence in favour of the construction of AW in order to clean up water from the pesticides that it contains. When the regulator is taken this possibility into account, it is mainly the first and the third steps of the model previously studied that are changed. As before, the model is going to be solved backward.

In the **third step**, as in the previous case, a lump-sum transfer is redistributed to the farmers. It now includes the AW construction costs and becomes the following one: $\widehat{LS} = \frac{\tau X - c(S)}{n}$. With such a formulation, the AW construction costs are supported by the farmers; the "polluter pays" principle is thus checked and, contrary to the benchmark case, the lump-sum transfer can either be positive or negative, according to the size of the AW.

In the **second step**, the objective function of each farmer is the same one as when the regulator does not construct an AW except that the lump-sum transfer has got a quite different value. But this has no effect on the marginal values and the solution shares the same properties as in the case where the AW is not constructed.

In the **first step**, the regulator chooses the proportional charge on pesticides, τ, that minimizes the costs needed in order to achieve the targeted mass, i.e. the sum of the costs of reducing the amount of pesticides used and of AW construction. We remind here that we assumed that AW construction can only be implemented by the regulator. The optimization program to be solved by the regulator is thus the following one:

$$\begin{aligned} &\min_{\tau,S} \sum_{i=1}^{n} \kappa(\overline{x} - x_i^{\circledast}(\tau)) + c(S) \\ s.t. \quad : \quad &\alpha X^{\circledast}(\tau) - q\left(S, \alpha X^{\circledast}(\tau)\right) = \overline{TM} \end{aligned}$$

where $X^{\circledast}(\tau)$ shares the same properties as $X^*(\tau)$ and the superscript $\circledast$ denotes the solution of the model with AW construction.

Proposition 4.1. *When the regulator considers the possibility of constructing an AW in order to reduce the mass of pesticides in water, the solution of the model,* $\left(X^{\circledast}, S^{\circledast}, \lambda^{\circledast}, \tau^{\circledast}\right)$, *is such that the marginal cost of removing one unit of pesticide from water located after the AW is the same one if an AW is constructed and if the pesticides uses are reduced, i.e. they are equal for all measures:*

$$\frac{c_S^{\circledast}}{q_S^{\circledast}} = \frac{\sum_{i=1}^{n} \kappa_{\delta_i}^{\circledast}}{\alpha\left[1 - q_M^{\circledast}\right]}$$

We now want to investigate the implications of the regulator construction of AW in order to clean up the water pollution with pesticides.

5. The implications of constructing an artificial wetland

We are going to compare the results obtained in both the versions of our model (denoted by the superscripts * and $^{\circledast}$).

First of all, if the targeted mass is reached in both cases, the effort asked to the farmer in order to do so is quite different. Indeed, since we showed that $X^{\circledast} \in]\underline{X}, \overline{X}[$ and $S^{\circledast} \in]0, \bar{S}[$, we know from our assumptions that $q^{\circledast} > 0$. It directly follows that the total amount of pesticides used by the farmers in the benchmark case is lower than the one occurring when the regulator constructs an AW:

$$X^{\circledast} > X^* \Leftrightarrow \sum_{i=1}^{n} x_i^{\circledast} > \sum_{i=1}^{n} x_i^*$$

As a consequence, AW construction reduces the total effort $\Delta := \sum_{i=1}^{n} \delta_i$ that is asked to the farmers of the catchment in terms of pesticides use reduction in order to reach the targeted mass:

$$\Delta^* := \sum_{i=1}^{n} \delta_i^* > \Delta^{\circledast} := \sum_{i=1}^{n} \delta_i^{\circledast}$$

What about the cost-effectiveness of reaching the targeted mass thanks to AW construction if some interiority assumptions (ensuring that $S \neq 0$) are relaxed? Up to this point, it seems that, when all farmers are assumed identical ($\delta_i = \delta \forall i$), the construction of an AW by the regulator generates a gain, $\Gamma := n\kappa(\delta^*) - n\kappa\left(\delta^{\circledast}\right)$, which accrues to the farmers since the use of a higher amount of pesticides reduces the cost, κ, of the deviation from the point maximizing their profits, $\overline{X}$:

$$\kappa_{\delta_i} > 0 \text{ and } n\delta^* > n\delta^{\circledast} \Rightarrow n\kappa\left(\delta^*\right) > n\kappa\left(\delta^{\circledast}\right) \text{ and } \Gamma > 0$$

But in order to fully compare the cost-effectiveness of the two cases, we also have to enter into the picture the global fiscal scheme (the proportional charge, τ, but also the lump-sum transfer, LS) implemented by the regulator. As a consequence, we compare the global cost function of the farmers evaluated at the solution of each of our cases: $n\kappa(\delta^*)$ for the benchmark case and $n\kappa\left(\delta^{\circledast}\right) + c(S^{\circledast})$ for the case with AW since the fiscal schemes are respectively $(\tau^*, \widetilde{LS})$ and $(\tau^{\circledast}, \widehat{LS})$. According to the difference between the gains accruing to the farmers thanks to an AW construction and the costs induced, we can distinguish between two cases:

(i) if $\Gamma > c(S^{\circledast})$, constructing an AW in addition to a fiscal scheme is more cost-effective than not,

(ii) if $\Gamma < c(S^{\circledast})$, constructing an AW is not cost-effective.

Finally, we can simply deduce from $\kappa_{\delta\delta} > 0$ and $\kappa\left(\delta^*\right) > \kappa\left(\delta^{\circledast}\right)$ a property of the charge levied on each unit of pesticides used according to which it is higher in the benchmark case than in the case with AW construction:

$$\tau^* > \tau^{\circledast}$$

Proposition 5.1. *The proportional charge that has to be implemented in order to reduce pollution with pesticides to the targeted mass is lower than if no AW had been constructed:* $\tau^* > \tau^{\circledast}$. *When the AW is constructed, the total effort that is asked to the farmers in order to reach the targeted mass in water is reduced:* $\Delta^* > \Delta^{\circledast}$.

This result can seem quite uncommon since when AW are constructed, the farmer is allowed to pollute more, i.e. this type of water pollution regulation increases the amount of pesticides use allowed. But the reader must keep in mind that the targeted mass is still reached. Furthermore, if we now imagine that no fiscal scheme is implemented, we know from our assumptions that the farmer will use the maximum amount of pesticides, $\overline{X}$, and that the targeted mass won't be reached, neither in the case without AW, nor in the one with it. Nevertheless it remains that AW allows to reduce the ambient amount of pesticides contained in water since we have:

$$\alpha\overline{X} > \alpha\overline{X} - q\left(S, \alpha\overline{X}\right) \forall S > 0$$

As a consequence, our results abet the possibility of more stringent water quality when AW can be constructed by the regulator.

6. A numerical illustration: a wine catchment area in Rouffach (North-East of France)

To illustrate the theoretical model, we further propose a numerical illustration. For this illustration, we focus on fungicide pollution from viticulture. For the ease of exposition we propose to name the assimilation of pesticides by the AW the "downstream treatment" and the abatement by the farmers the "upstream treatment".

6.1. Downstream treatment

In the framework of the LIFE Environment ARTWET project, Grégoire (Grégoire et al., 2009) and Imfeld (Imfeld et al., 2009) completed some experiments in a small catchment in Alsace (France) to simulate the credibility of an AW for removing pesticides from water.

In this catchment of 28.9 *ha*, about 20 *kg* of fungicides are applied upstream by 28 wine-growers each year, and each year about 20 *g* streams to the AW after rain events. The residues are assimilated or stocked upstream, and a part can be found on the groundwater in the long term. In this illustration we are only interested in the short term effect namely the fungicides that reach the AW.

In the theoretical model the treatment rises when the size S of the AW increases. Here, this effect is reproduced by increasing the size of the gravel filter. Increasing the gravel filter causes an increase of the hydraulic retention time and, therefore the removal of pesticides. Nevertheless, above a certain threshold, increasing the gravel filter more is useless.

From the observation of 12 rain events from April 2009 to July 2009, we have estimated the treatment function q according to the volume of the filter S and the mass of pollutant M as following:

$$q(S,M) = 10^{-4}\left(-0.45S^2 + 126S\right)M$$

The functional form selected fit to the main assumptions of the theoretical model since: $q_S = 10^{-4}\left(-0.9S + 126\right)M$ and $q_M = 10^{-4}\left(-0.45S^2 + 126S\right)$. We have calibrated the natural assimilative capacity (without AW) as $\alpha = 6.10^{-3}$.

The gravel filter consists in quaternary gravels from the local Alsatian quaternary floodplain and a gabion barrier in front of the filter to block the gravel mass. We used data provided by the LIFE Environment ARTWET project: the gabion barrier has a unit cost of 5000 € and the price of the gravel is about 15 € per m^3:[6]

$$C(S) = 15S + 5000$$

6.2. Upstream treatment

Leroy and Soler, within the Framework of a French project (see Bazoche et al., 2009), estimated the reduction of the mean yield when the wine-growers use less fungicides. In calibrating this

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[6] Let us remind that we assumed that the regulator already owns lands bordering some farmers' fields.

information with economic data of this catchment, we estimated the following function:

$$\kappa(\delta_i) = 0.0224\delta_i^2 + 2\delta_i$$

with: $\kappa_{\delta_i} = 0.0224\delta_i + 2$.

The abatement cost is estimated as an opportunity cost (profit loss) when the fungicides used decreases. In such a case, a part of the production is lost, because of diseases increase.

6.3. Results of the simulations

First, the reader certainly noticed that all our theoretical assumptions are not exactly checked, specially the one ensuring the uniqueness of the solution. We obtained a unique solution by not considering solutions with a complex part.

Without any regulation, the maximum quantity of fungicides spread upstream, $\bar{X}$, is equal to $24,620$ g.

One per 1000 reaches the AW zone, which treats again 40% of pesticides when there is no AW ($S = 0$). Then with $X = 24,620$ and $S = 0$, it remains $14,769$ mg of fungicides in the downstream of the AW.

If we want to divide this mass of pesticides by 10 without increasing S, we have to reduce X from $24,620$ g to $2,462$ g. The total abatement cost is then $436,929$ € and the charge rate is 37.4 € by gram.

Nevertheless another solution would consist in a combination of upstream and downstream effort. By this way, we can reach the same target of $1,476.9$ mg with a total cost of $25,885$ € in increasing S to 139.88 (downstream cost $C(S) = 7,098$ €) and reducing X to $20,860$ g (upstream cost $K(\Delta) = 18,786$ €). The charge rate for the farmers is 8 € by gram of fungicides rejected and the difference between the charge paid and the cost of the AW construction, LS, is $159,937$ €.

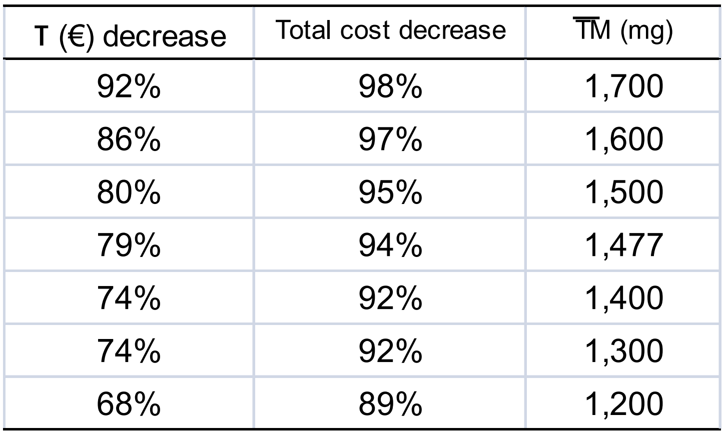
Then, with the AW the percentage reduction of the total cost is 94%, and the reduction of the charge rate is about 78.5%.

A sensibility study around this target, gave us the following Figure 1.

We can see on Figure 1 that the savings with the AW are very important. The magnitude of these savings seems to depend on the target.

7. Conclusion

In this paper, we proposed to consider an original method of water pollution with pesticides abatement: AW construction. The assimilative capacity of an AW differs here from the basic natural one by the fact that it strongly depends on the size of the filter that can be adjusted by the regulator with a limited amount of land. The main difference of our paper with respect to the existing literature is that we studied the impact of considering AW construction on the fiscal scheme implemented by a regulator in order to reduce water pollution with pesticides to a targeted mass. We



T (€) decrease	Total cost decrease	$\overline{TM}$ (mg)
92%	98%	1,700
86%	97%	1,600
80%	95%	1,500
79%	94%	1,477
74%	92%	1,400
74%	92%	1,300
68%	89%	1,200

Figure 6.1: Savings with AW construction

also studied its impact on the effort that is asked to a farmer in order to reduce pesticides found in water bodies.

More particularly, we showed that the consideration of AW construction in order to reach a pre-determined targeted mass of pollution in water can reduce both the effort that is asked to the farmers and the charge on pesticides that has to be implemented. We checked this theoretical result on a numerical example. It remains true as long as the costs of constructing an AW are lower than the gains accruing to the farmers thanks to the AW construction. As a consequence, our framework is able to take into account the trade-offs that can occur between different land-uses.

Policy implications are of two natures. Firstly, our results abets the possibility for more stringent water quality standards at the national level since regulators can construct AW in order to reduce the amount of pesticides contained in water. Secondly, we know that in the real life input charges are below their optimal level for lobbying reasons. When considering the possibility of constructing an AW in addition to classical regulation tools such as environmental taxation, our results show that the input charge implemented in practice by policy-makers could come closer to the optimal input charge needed in such a situation.

Our model is so generic that it could be applied to any measure with a similar assimilative capacity and cost function. And as a consequence such a measure would result in the same conclusion with regards to efficiency of the input charge under its presence.

Nevertheless, this work contains some limits. Firstly, we need to investigate empirically the costs functions in order to lead a more robust empirical analysis and, in the line of Shibata and Winrich (1983), to see how results could be changed according to the assumptions made on this function. But in order to carry out a careful econometric analysis, we need more data related to the wine-growers production function and to the AW costs. Secondly, we did not enter into the picture the fact that AW can provide a lot of other services, in particular ecological one. Considering them induces that AW construction can even more be of major importance, assuming that these services are higher than the one induced by an input charge that would also have to be taken into account within such a framework. Indeed, the benefits induced by an input charge must include the effect on health of pesticide use reduction in agricultural production. But in the real world, the ecological services of wetlands and the effects of pesticides use reduction on health are very difficult to evaluate and, from the best of our knowledge, no economic work concentrates on the AW services. It is why we limited our work to a cost effectiveness framework. Finally, it would be of interest to include some dynamic effects in the assimilation process of wetlands. But such an extension needs a strong help of scientists of other disciplines and it is why it is left for future works.

References

[1] Bazoche P., Cartolaro P., Deliere L., Del'Homme B., Hernandez F., Goutouly J.-P., Léger B., Leroy P., Naud O., Soler L. G., Steffe J., Ugaglia A. 2009. Vin et environnement : comment réduire les quantités de pesticides utilisés en viticulture ?, Synthèse du projet *ANR Agriculture et Développement Durable* (2005-2008)

[2] Bel F., G. Drouet d'Aubigny, A. Lacroix, A. Mollard. 2004. Efficacité et limites d'une chargee sur les engrais azotés: éléments d'analyse à partir de 16 pays européens, Economie et Prévision, 5(166), 99-113

[3] Grégoire C., Elsaesser D., Huguenot D., Lange J., Lebeau T., Merli A., Mose R., Passeport E., Payraudeau S., Schütz T., Schulz R., Tapia-Padilla G., Tournebize J., Trevisan M., Wanko A. 2009. Mitigation of agricultural nonpoint-source pesticides pollution in artificial wetland ecosystems, *Environmental Chemistry Letter* 7(3),.205-231

[4] Gren I.M., K. Elofsson, P. Jannke. 1997. Cost-Effective Nutrient Reductions to the Baltic Sea, *Environmental and Resource Economics* 10, 341–362

[5] Imfeld G., Braeckevelt M., Kuschk P., Richnow H. H. 2009. Monitoring and assessing processes of organic chemicals removal in constructed wetlands, *Chemosphere* 74, 349-362

[6] Shibata H., Winrich J.S. 1983. Control of pollution when the offended defend themselves, *Economica* 50, 425-437