Annexes

The place given to aquatic environments in the action plans of the French National Biodiversity Strategy (SNB)

We have only taken account of the action plans that related to aquatic environments and whose objectives have been reinforced since 2008. These plans are at different stages of development.

Natural heritage action plan

The objectives of this plan are to maintain biodiversity and ecosystem functioning, improve the ecological corridor and populate follow-up indicators. The intervention tools used by this plan are the same ones that form the building blocks of the territorial nature conservation policy: the Natura 2000 network, the creation of protected areas, the green and blue corridors and the wildlife preservation policy. Regarding these conservation priorities, the question of governance is a central concern, in terms of fiscal/economic/incentive tools and of knowledge and participation.
Concerning water and aquatic environments, the large natural infrastructures relating to water are taken into account from the point of view of their ecological value and contribution to human well-being as detailed by the MA. These are estuaries, rivers, river valleys, aquatic migration corridors, wetlands, bocages (wooded farmland), coral reefs and their associated ecosystems. The natural heritage plan sheds light on the links between the water policy and the nature protection policy. Aquatic environments (like wetlands) and watersheds are becoming concentration areas for State intervention tools.

It should be noted that most actions do not have a set timeframe. Only the start date of the sub-actions is given (from 2009 and 2010 for example).

Priorities	Number of actions (2009-2010)	Actions relating to aquatic environments	Sub-actions relating to aquatic environments
Maintain the good ecological quality of the territory	4 actions and 30 sub-actions	Develop specific plans for natural infrastructure	Draw up guidelines for the green and blue corridors and support their implementation at regional level.
			Rivers and aquatic environments: application of the WFD (review of river basins, setup of the surveillance programme, definition of management plans and programmes of measures, implementation of the water law)
			Wetlands: Continue and resume implementation of the national wetlands plan. Designate wetlands of international importance for the Ramsar List.
			Acquisition of 20,000 ha of wetlands to counter destruction: encourage purchases by Water agencies.
			Grassy banks and planted buffer zones at least 5 metres wide along rivers and water bodies listed in urban-planning documents.
			Extension of grassy banks along all rivers in vulnerable areas in 2009 (4th action programme 2009-2013 pursuant to the "Nitrates" Directive).
			Restore continuity for freshwater ecosystems: elimination of hydroelectric concession dams should operation not be renewed under a general agreement on sustainable hydroelectricity in keeping with the restoration of aquatic environments (blue corridor).
			Coastline: measures by the coast Interministerial Committee for Land Planning and Development (CIADT); long-term strategy of the French Conservatory of the Coast.
			Increase the means of the French Initiative for Coral Reefs (IFRECOR) for a sustained action in favour of coral reefs and their associated ecosystems.
Support concerted natural heritage management as it picks up pace		Save endangered wild species	Setup of national action plans for endangered species in mainland France and in its overseas départements.
Continue to renew rights and economic tools		Tackle invasive species	Draw up a terrestrial and marine invasive species plan
	3 actions and 14 sub-actions	Consolidate expertise and management	Provide for marine and coastal ecosystem reconstitution and restoration measures in management plans (revised SDAGE) and programmes of measures that will be decided on at the scale of a river basin.
	3 actions and 10 sub-actions	Renew and extend legal provisions	Continuity of freshwater ecosystems: possibility of intervening on private sites with the owner's agreement.
		Increase the effectiveness of nature policing	Give official form to the administration doctrine on water, fishing and nature policing. Set up a nature policing unit in départements/forge closer ties between the water police and hunting police.Boost the human resources for nature policing by the public institutions working in overseas départements (national parks, ONF, ONCFS and ONEMA) to ensure the regulations are implemented effectively.

Agriculture action plan

The agriculture plan has endeavoured to demonstrate the value/contribution of ecological services of biological diversity for rural and agricultural areas, whilst casting a pragmatic eye over the possible room for improving the farming profession in terms of maintaining or restoring some ecological infrastructure (riparian vegetation, hedges, small ponds, etc.) and reducing plant protection product use (Ecophyto 2018 plan) by up to half. The green and blue corridors facilitate implementation of contractual tools, particularly for the setup of planted banks and drafting of good practice guides for protecting remarkable biodiversity. Agro-environmental measures help to protect wetlands.

Priorities	Number of actions (2009-2010))	Actions relating to aquatic environments	Actions relating to aquatic environments	Status
Territories	5		Help to implement the green and blue corridors (GBCs) to restore ecological continuities	The contractual tools for the green corridor are currently being defined. GBC implementation to be determined with local partners.
Agricultural practices	12	1	Encourage through support for establishing environmental leasing contracts	To be initiated (develop information on this tool and describe the current content of environmental leasing contracts)
		3	List and promote the studies on agroecological infrastructure for the GBC	To be carried out
			Publish a brochure on the buffer zones and biodiversity	To be carried out
Ecophyto	4		Develop input-saving agricultural pathways and trial run on 3,000 farms	Underway with an INRA study
		4	Promote input-saving systems	A guide to designing economical systems is currently being written
			Develop and fit out agroenvironmental measures (AEMs) for reducing plant protection product use	The treatment frequency indicator (IFT) has been set up.Underway: monitor individual commitments and propose adjustments
			Set up monitoring of the unintentional effects of plant protection products	To be initiated: set up of biodiversity impact indicators; create a pesticide residue observatory and surveillance network for pests and unintentional effects
Genetic resources	6	0		
Monitoring (observatory on changing biodiversity in connection with agricultural practices)	11	1	Develop the AEM contractual procedure in Natura 2000 sites and keep track of how they are progressing	Underway

Action plan on land-based transport and infrastructure

The requirements concerning biodiversity impact and incidence studies make the strongest link to aquatic environments. But the plan does not go far enough and needs to clarify the notions of compensation further in particular. The green corridor and water is a major driver in this action plan. The 2008-2010 phase is devoted to writing guides, raising awareness and training.

Priorities	Number of actions (2009-2010)	Actions relating to aquatic environments
Raising awareness, information and training	4 actions	Improve service training of project owners, managers and infrastructure operators (SNCF, RFF, VNF, dealers, etc.) on biodiversity preservation, particularly the setup of the green and blue corridor, and on landscaping and ecological engineering work; for the State, initial and continuing education institutions and schools are especially concerned
Development of partnerships and expertise	6 actions	Forge scientific partnerships with research and expertise organisations (French National Museum of Natural History [MNHN], Onema, French National Office for Hunting and Wildlife [ONCFS], etc.)
		Encourage businesses in the public works sector to undertake proactive initiatives in favour of biodiversity
Knowledge of biodiversity, scientific research and observation	6 actions	Take account of how the green and blue corridors are progressing
Preservation and restoration of ecological continuity and habitats.	4 actions	Avoid areas where there is much at stake regarding ecology and the landscape from the stages upstream of project design, and if this isn't possible, plan suitable mitigation and/or compensation measures
Preservation and non-disruption of species		Assess the effect of current biodiversity practices to adapt them if necessary and promote practices in favour of biodiversity. This involves encouraging "environmental management" type initiatives; adapt upkeep and operating methods for more effective preservation of habitats (references: MNHN "cahiers d'habitats", rounding off the interpretation manual of European Union habitats for France) and species in areas where there is much at stake ecologically speaking; improve the ecological transparency of infrastructures managed by project owners (crossings for large and small wildlife, mixed crossings, treatment of surrounding areas, wildlife enclosures that aren't working properly), in liaison with all managers of areas with no particular regulatory protection, in keeping with the green and blue corridors

Sea action plan (2009-2010)

The main strategies of this plan are broken down into several themes:
- better consideration of biodiversity in sea policy;
- coordination of public policies;
- management of the land-sea interface;
- improvement of knowledge;
- development of protected areas.

Town planning action plan

The regional development and planning tools must be compatible with the tools applied for the water policy (SDAGE, SAGE). This is very significant with regard to assessing the ecosystem services in question, reducing stress and combating degradation of areas and the landscape.

The green and blue corridors are central to integrating biodiversity. The blue corridor, in particular, aims to ensure the ecological continuity and restoration of rivers as well as maintain water's ability to self-purify through the action of microorganisms and plants which absorb nutrients.

SNB and WFD indicators

	SNB indicators	Water and aquatic environment link	2004 results	2008 results (halfway point)
Genetic diversity	Number of plant varieties and animal breeds, recorded and certified for marketing purposes, in the main categories of cultivated plants and livestock			
Specific diversity	Common bird indicator			
	Specific wealth of fish	X	76 species represented, 24 of which have been introduced, 2 have vanished and 17 are "endangered" or "vulnerable"	7 out of 34 amphibian species are endangered
	River fish indicator	X	N/A	Between 2006-2007, between 50 and 60% of populations were of good or very good status and 20% of poor status
	Statuses of national red list species	X	The red lists of freshwater fish in mainland France. No mention on the amphibian lists.	See the red lists on fish and amphibians
Habitat diversity	Conservation status of habitats of European interest in Natura 2000 sites. The number (and surface area) of protected areas	X	Wetlands (account for between 1.5 and 1.7 million ha, i.e. 3% of the territory.Fresh water (management of hydrosys-tems and water resources)	The Caribbean reefs overseas are t he most affected (20-30% of coral deaths by bleaching). Between 2003 and 2008, protected areas have increased overall. Water expanses and aquatic environments represent 8 and 5% respectively of biotope decrees, 1° and 8% of national nature reserves, 2 and 1% of regional natural parks and 10 and 16% of Conservatoire du littoral sites. Major breakthroughs concerning the sea
Ecological corridor	Diversity map of the types of land cover with low degradation at local level	X	This will contain the indicators for wetlands and water surface areas	Between 2000-2006, regression of wetlands
	Dominance in the landscape of environments with low degradation			Degraded net surface areas annually between 2000-2006 in favour of water surfaces due to the transformation of aggregate extraction areas into lakes once operations are complete.
Functioning of ecosystems	Defoliation of trees			
	Standardised global biological indicators for rivers	x	Indicator of the status of water bodies according to the WFD	"Water quality" indicator supplied since 2007 under the WFD (42.5% of water bodies are of good status) + for pesticides and plant protection products, water bodies of average and poor status are 37% and 48%

Points being discussed by economists on the distinction between services and functions

De Groot *et al.* (2002) suggest defining the functions of ecosystems as a "subset of ecological processes and ecosystem structure [that] provide the goods and services that are valued by humans". In this regard, they present a list of 32 functions, grouped into four primary groups corresponding to our fundamental needs (regulatory, habitat, production and information). We can see that most of these function headings have been subsequently termed as "services" by the MA – hence the criticism already mentioned of this classification. To distinguish functions from services, Wallace (2007) suggests an "ontological" distinction between "ends" (services) and "means" (functions and processes): "It is essential to clearly separate means (processes) and ends (services)".

The merits of introducing this notion of function are nevertheless questioned by other economists for several reasons:

- the distinction between ecological processes and functions is weak and the ability of economists to define the "subset" mentioned by De Groot is far from certain. Wallace (2007) therefore considers the two notions to be synonymous and only proposes to use the term processes, for "parsimony of terms generally leads to greater clarity";
- even if we reserve the term "service" to designate the "end products" of ecosystems, we note that, in some contexts, functions can become services, and vice versa. For example, if someone were to collect insects from the wild that are useful for protecting crops, with a view to selling them to amateur gardeners, the "function" of protecting crops would become a "service" under Boyde's definition. Vice versa, if we were to decide to list a forest as an integral biological reserve, the service of wood production would, at the local level, become a function that supports tourist or educational activities;
- it will always be the case that, in some contexts, there are functions that are not end products but are subject to market trade. Take, for example, the hiring of hives for the pollination of orchards or the Vittel water company's support for "agricultural production functions" that protect the quality of spring water (see CAS report p. 322).

Wallace's ontological distinction therefore appears to be very contingent. Costanza (2008) particularly considers, by recalling the MA's general diagram, that all services are means as "the end or goal is sustainable well-being". He therefore believes it more suitable to distinguish end services and intermediate services only, and defines the MA's broad definition as "a good, appropriately broad and appropriately vague definition". (This apology for the "vagueness" somewhat irritates Wallace, who retorted in 2008: "I was uncomfortable with Costanza's acceptance of an 'appropriately vague definition'. (…) Should science accept vagueness?"

Fisher and Turner (2008) make the same analysis as Costanza, but reassert the need to distinguish services and benefits – a viewpoint that we have defended above.

Classification of wetland goods and services

Classification de Brander *et al.*, 2006

Ecological function	Economic goods and services	Value type	Commonly used valuation method(s)a
Flood and flow control	Flood protection	Indirect use	Replacement cost Market prices Opportunity cost
Storm buffering	Storm protection	Indirect use	Replacement cost Production function
Sediment retention	Storm protection	Indirect use	Replacement cost Production function
Groundwater recharge/discharge	Water supply	Indirect use	Production function, NFI Replacement cost
Water quality maintenance/nutrient	Improved water quality	Indirect use	CVM
Retention	Waste disposal	Direct use	Replacement cost
Habitat and nursery for plant and animal	Commercial fishing and hunting	Direct use	Market prices, NFI
Species	Recreational fishing and hunting Harvesting of natural materials Energy resources	Direct use Direct use	TCM, CVM Market prices Market prices
Biological diversity	Appreciation of species existence	Non-use	CVM
Micro-climatestabilization	Climate stabilization	Indirect use	Production function
Carbon sequestration	Reduced global warming	Indirect use	Replacement cost
Natural environment	Amenity Recreational activities Appreciation of uniqueness to culture/ heritage	Direct use Direct use Direct use	HP, CVM CVM, TCM CVM

Classification proposed by Morardet (2009)

Provisioning services	
Food	Production of fish, wild game, fruit and seeds
Fresh water	Storage and retention of water for domestic, industrial and agricultural uses
Fibre and fuel	Production of logs, firewood, peat, fodder and materials used for arts & crafts
Biochemicals	Extraction of biochemicals for producing medicinal products, biocides, food additives, etc.
Genetic resources	genetic material used for animal and plant reproduction and biotechnologies(e.g.: resistance of pathogens to plants, ornamental plants, etc.)
Regulating services	
Climate regulation	Springs and wells for greenhouse gases; local and regional influence on temperatures, rainfall and other climate processes Storage and retention of water for domestic, industrial and agricultural uses
Hydrological regulation	Filling and emptying of aquifers, storage of rainfall and run-off
Water purification and wastewater treatment	Retention, restoration and elimination of excess nutrients and pollutants
Erosion regulation	Retention of soils and sediments
Regulation of natural risks	flooding control and storm protection
Pollination	Habitat for pollinators
Cultural services	
Spiritual and inspiration	Source of inspiration; many religious attach spiritual and religious values to certain aspects of wetlands
Recreation	Possibilities of countless recreational activities
Aesthetic	Many people attach aesthetic value to certain aspects of wetlands
Education	Possibilities of formal and informal training
Supporting services	
Soil formation	Retention of sediments and buildup of organic matter
Nutrient cycling	Storage, recycling, transformation and acquisition of nutrients
Habitat for animal species	Habitats for numerous species - particularly migratory birds
Primary production	Assimilation and accumulation of energy and nutrients by living organisms
Photosynthesis	Production of oxygen necessary for most living organisms
Water cycle	Circulation of water essential for living organisms

List of hydrosystem services according to MA France

	Quantified services
Provisioning services	Supply of water for domestic use
	Production of bottled water (mineral and spring)
	Supply of water for agricultural use
	Supply of water for industrial use
	Supply of water for energy production
Regulating services	Flood prevention and rising water levels
	Mitigation of the effect of drought
	Waste treatment and purification (self-purification of water)
	Pest regulation
Social services	Landscapes
	Value of biodiversity and heritage
	Recreational fishing (sea and fresh water)
	Nature leisure and tourism
	Development of educational knowledge

Services provided by rivers, lakes, aquifers and wetlands according to EcoWhat-ACTéon (2009a)

Water supply
Supply of water for domestic use
Wastewater, hydroelectricity and other industrial uses
Irrigation of crops, parks, golf courses, etc.
Aquaculture
Goods other than water
Fish
Waterfowl
Shellfish
Pelts and fur
Goods other than water (that do not comprise sampling from the resource)
Flood regulation
Transport
Recreational uses (bathing, etc.)
Dilution of pollution and protection of water quality
Hydroelectricity
Habitat for wildlife
Soil fertilisation
Increase in real estate value
So-called "non-use" values (aesthetic, etc.)

Formalisation de l'approche coût-efficacité

A simple illustration of the cost-effectiveness approach is as follows. Let's assume that the hydrosystem is composed of I management units indicated by i, $i = \{1, ... I\}$. To each unit we intend to apply a measure, understood as a complex M_i of possible measures for the unit i. To simplify the presentation, let's suppose that a continuous gradient of measures and therefore the complex of possible measures M_i can be compared to a standard interval $[\underline{m}_i, \overline{m}_i)$. Note $C_i(m_i)$ as the cost associated to the measure m_i if it is applied to unit i.

The same measure does not necessarily have the same cost in the different areas due to their specific ecological features. Without loss of generality, let's organise the measures in M_i such that $C_i(m_i)$ is defined as an increasing function of m_i in M. In other words, $\underline{m}_i$ refers to the least expensive measure and $\overline{m}_i$ the most expensive measure when they are applied to unit i. This results in the marginal cost defined as the cost derivative in relation to the measure being positive, $dC_i(m_i)/dm_i > 0$. Note e_i as the ecological status of the management unit i, e_i^0 as its intial status before the programme of measures is implemented and $\overline{e_i}$ as the good status that must be achieved for the unit. The initial status may or may not be satisfactory. It is also possible that the implementation of a measure on a given site has knock-on effects on other sites due to their ecological solidarities. Note $A_i(m)$, where $m=(m_1,m_2,...,m_i,...m_I)$ designates a programme of measures applied to all of the ecological management units making up the hydrosystem, the impact on the ecological status of the unit i of the entire programme of measures. This illustration captures the existence of knock-on effects from a measure applied on one site on any other site. The impact is measured in terms of ecological status and, here again, to simplify the presentation, we shall assume that the status is measured according to a continuous gradient. Such that $A_i(m_k)/\partial m_k$ refers to the marginal impact on the ecological status of zone i of the measure m_k applied to zone k. Moreover, it has not been ruled out in theory that this knock-on effect is negative on certain sites – even if it is probably positive on the zone to which the measure is applied.

The purpose of the cost-effectiveness approach is to determine the programme of measures to take so as to achieve good status on all sites at the least cost. Formally, this involves resolving the following problem:

$$
\begin{array}{lll}
Min & \displaystyle\sum_{i=1}^{I} C_i(m_i) & \\
s.c. & e_k^0 + A_k(m) \geq \overline{e}_k & k \in \{1,...,I\} \\
 & \underline{m}_i \leq m_i \leq \overline{m}_i & i \in \{1,...,I\}
\end{array}
$$

The Lagrangian associated with this programme is as follows:

$$L = -\sum_{i=1}^{I} C_i(m_i) + \sum_{k=1}^{I} \lambda_k \{A_k(m_1, m_2, ..., m_i, ..., m_I) + e_k^0 - \overline{e}_k\} + \sum_{i=1}^{I} \{\alpha_i(m_i - \underline{m}_i) + \beta_i(\overline{m}_i - m_i)\}$$

Where λ_k designates the Lagrange multiplier associated with the requirement of reaching good ecological status on unit k while α_i and $ß_i$ designate the Lagrange multipliers associated with the technical feasibility requirements of the measures in each zone i. A cost-effective programme of measures satisfies:

$$
\begin{array}{lll}
\dfrac{dC_i(m_i)}{dm_i} = \displaystyle\sum_{k=1}^{I} \lambda_k \frac{\partial A_k(m)}{\partial m_i} + \alpha_i - \beta_i & & i \in \{1,...,I\} \\
\lambda_i(A_i(m) + e_i^0 - \overline{e}_i) = 0 & \lambda_i \geq 0 & i \in \{1,...,I\} \\
\alpha_i(m_i - \underline{m}_i) ; \alpha_i \geq 0 & \beta_i(\overline{m}_i - m_i) = 0 , \beta_i \geq 0 & i \in \{1,...,I\}
\end{array}
$$

For simplicity's sake, let's overlook the technical feasibility requirements by supposing that they have been met – i.e. that the measures making up the solution programme do not touch on the end boundaries of the possible measures. In this case the corresponding multipliers are all nil.

The multipliers λ_k can be interpreted as the monetary equivalent (i.e. the "value" in the economic sense) of meeting the good status requirement on site k. The second line of conditions precedent shows us that, in the event that the programme of measures improves the ecological status of the site beyond what the good status requires, the value of this even better status would be nil. It would only be positive for sites only just achieving good status. Since the objective is good status, taking costly measures to improve this status would constitute waste with regard to the objective and therefore be worthless. The first line indicates that the best measure for zone i is the one that will bring the marginal cost into line with the sum on all the sites of the value of status improvements it allows.

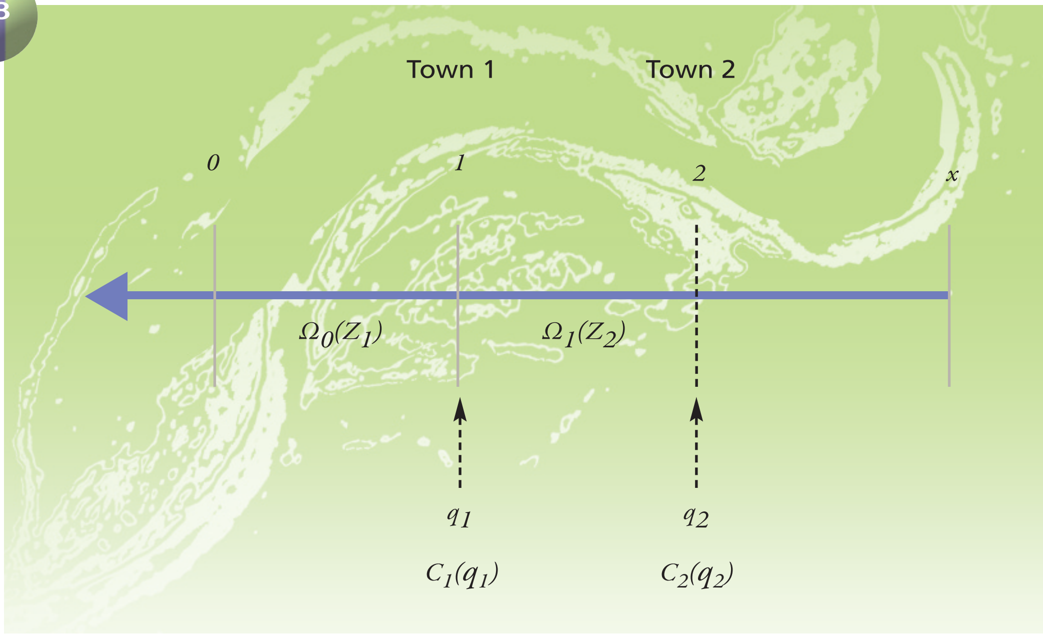
We can see the relevance of measuring the monetary values of multipliers by numerical programming λ_k. By only considering the cost of a measure on a site, we cannot know what the economic value of this measure is in terms of effectiveness in achieving good status for all of the sites that might be impacted by the measure. This is what makes it possible to identify the calculation of multipliers zone by zone. These multipliers are sometimes called marginal opportunity benefits of the improvement of zone k. In fact, the method for calculating the cost-effective programme that we have just described briefly is an illustration of the opportunity cost methods described previously – but applied here to the establishment and assessment of the economic value of a programme of measures on the basis of its cost-effectiveness results.

Measuring the value of environmental purification

Let's consider that pollutants are being discharged into a river. To give us a clearer idea, the river can be compared to an oriented line with two intermediate release points – one downstream which is, by convention, point 0, and one upstream, X, the water flows from point X to point 0. Two urban areas are located at points 1 and 2 – it is their waste that is polluting the river. We note q_x as the volume of waste discharged into the river at point x, $C_x(q_x)$ as the purification cost resulting from net discharge into the river of an amount q_x and $c(q_x)$ the marginal cost function where $c(q_x)$ is negative and growing. Indeed, the more the effort to reduce discharged waste increases, the more the marginal cost should increase – which implies that, as a net function of the discharged pollution, the marginal cost should decrease.

We note Z_x as an indicator of river pollution measured at point x. The Agency's objective is to ensure compliance with a maximum pollution standard, $\overline{Z}$ all along the river. For simplicity's sake, we assume that there is no pollution coming upstream of point 2, such that: $Z_2=q_2$ the river pollution measured at point 2 is simply the waste of the urban area located at this point. Pollution tends to build up when we go from upstream to downstream, but the natural environment is able to eliminate a fraction of this pollution. Note $\Omega_x(Z_{x+1})$ as the amount of pollutant eliminated by the environment along stretch $[x,x+1)$ as a function of the biological and morphological characteristics of the stretch and the volume of pollutant from upstream passing through this stretch (Figure 88).

Figure 88



Main elements of the simple model under study

The spatial dynamics of pollution are consequently given by:

$$z_x = q_x - \Omega_x(z_{x+1}) + z_{x+1}$$

The Agency's objective is to set up a release policy for achieving standard $\overline{Z}$ at minimum cost. We are therefore thinking in terms of a cost-effectiveness programme in the sense defined in the third section: the environmental objective is set and we are looking for the least expensive means to meet it.
must be less than $\Omega_x(Z_{x+1}) < Z_{x+1}$. As a result, the level of pollution at best stays the same from one release point to another, or increases as we move downstream. We conclude from all this that, for the standard to be met at any point along the river, it simply has to be met downstream, i.e. at point 0. All the points located upstream will do better than the standard. The problem can therefore be presented in writing as follows:

$$\begin{array}{ll} Min & C_1(q_1) + C_2(q_2) \\ s.c & z_x = q_x - \Omega_x(z_{x+1}) + z_{x+1} \quad x = 0,1 \\ & z_0 \leq \overline{z} \end{array}$$

To resolve this problem, we have to apply the principle of the discrete maximum. If we remember that $Min\, f(x) = - Max\, f(x)$ and rewrite the spatial dynamics of pollution as follows: $Z_{x+1} - Z_x = -q_x + \Omega_x(Z_{x+1})$, the Hamiltonian associated with this programme will be written as follows:

$$H_x = -C_x(q_x) - C_2(q_2) + \lambda_{x+1}(-q_x + \Omega_x(z_{x+1}))$$

With the initial condition: $Z_0 = \overline{Z}$, there's no economic point to outdoing the standard downstream. The optimality conditions are therefore as follows:

$$-c_x(q_x) = \lambda_{x+1}$$

$$\lambda_{x+1} - \lambda_x = -\lambda_{x+1}\frac{d\Omega_x(z_{x+1})}{dz_{x+1}}$$

To grasp the economic implications of these formulae, it would be best to study specific cases. We will look at two cases in turn:

1. The environment does not clean up the pollution: $\Omega_x(Z_{x+1}) = 0$

This case is primarily useful as a starting point. We deduce from the first-order condition that the following must be true: $\lambda_0 = \lambda_1 = \lambda_2 = \lambda$ and thus that the marginal abatement costs must be equal at any release point. To clarify things, let's suppose that the function of the cost for cleaning up communities' discharged waste is the same at any point and that the gross (raw) pollution to be treated is also the same (the towns are the same size). To be more exact, let's postulate that this function is expressed as follows:

$$C(q) = \frac{c}{2}(\overline{q} - q)^2$$

Where $\overline{q}$ measures the level of gross release before purification, supposedly the same for both urban areas. It can be deduced that the marginal cost is simply: $c(q) = -c(\overline{q} - q) = cq - c\overline{q} < 0$ since, by construction, the net release is less than the gross release: $q<q$. Consequently, the first optimality condition is:

$$\lambda = c\overline{q} - cq_1 = c\overline{q} - cq_2 \quad \Rightarrow \quad q_1 = q_2 = q$$

It is clear that, since the towns are meant to be identical, they should carry out the same extent of purification and therefore discharge the same amount of net release. But since $Z_0 = q_1+q_2 = 2q = \overline{Z}$ in the absence of purification by the environment, we can see that the net release must be equal to $\overline{Z}/2$ et donc que $\lambda = c(\overline{q} - \overline{z}/2)$

λ can be interpreted as the contribution to the objective function of the programme of a slight improvement in the pollution present in the environment. It is therefore in an equivalent way the marginal opportunity cost of the standard in the sense that this extent measures the increase in charges in terms of purification costs that the urban areas should bear if the river water quality standard were to be tightened. With no natural purification, the problem boils down to sharing the burden of maintaining the standard equally between the two towns, since they have been presented as being identical in size and purification performances. The environment's purification ability will completely shake up this way of thinking. This is what we will look at now.

2. Natural purification in proportion to the incoming pollution

The natural purification is proportional to the incoming pollution: $\Omega_x (Z_{x+1}) = \partial_x Z_{x+1}$ with $\partial_x < 1$ measuring the abatement coefficient along the stretch $[x, x+1)$, not necessarily the same from one stretch to another, to express the fact that environments can be heterogeneous – something we have stressed at length in the main body of this publication. The problem of this formulation is that it supposes that the environment purifies better the more polluted it is – which hardly makes biological sense.

The equation defining the spatial dynamics of the quality standard value is therefore: $\lambda_{x+1} - \lambda_x = -\lambda_{x+1}\delta_x$

where it turns out that: $\lambda_x = (1+\delta_x)\lambda_{x+1}$

$$\lambda_0 = (1+\delta_0)\lambda_1 = (1+\delta_0)(1+\delta_1)\lambda_2$$

And therefore, at present: $\lambda_0 > \lambda_1 > \lambda_2$

Because of natural purification, it is no longer possible to talk about an opportunity cost being associated with the quality requirement having to be applied to the whole river. Although the maximum pollution standard is uniform along the river and therefore independent of the location, its "value" in the sense of the opportunity cost of the standard varies all the way along the river depending on the natural purification processes by the aquatic environment. In the case in question, we get the highest result when, independently of environmental heterogeneity, the opportunity cost increases the further downstream you go.

This is how we can interpret this result. Let's consider the marginal impact of a pollution increase. If this increase occurs very far upstream, it will benefit the entire natural purification chain all the way downstream. But if this increase occurs downstream, it will only benefit a shorter purification chain. All other things being equal, this means that an increase in pollution very far upstream is less serious than one further downstream – which explains a lower opportunity cost of pollution upstream than downstream and therefore the growth in opportunity cost as we move downstream.

In the case of identical towns looked at above, we can now see that town 1 must make more purification efforts than town 2, i.e. bear higher purification costs such that $q_1<q_2$. Let's expand on the spatial recurrence of pollution:

$$\begin{aligned} \overline{z} &= z_0 = (1-\delta_0)z_1 \\ &= (1-\delta_0)(q_1 + (1-\delta_1)z_2) \\ &= (1-\delta_0)(q_1 + (1-\delta_1)q_2) \end{aligned}$$

The rule of sharing the efforts, at present, means that: $q_1 = (1-\partial) q_2$. Town 2 has an advantage in terms of natural purification along the stretch of river joining the two urban areas.

By comparing the opportunity cost in the model without purification to the opportunity costs relating to the stretches, we establish the marginal value of the purification service provided by the natural environments. Let's note some important points. Even if the biophysical characteristics of the environments were the same, there is no reason for the service value thus calculated to be the same over different stretches of the river. This is because it obviously depends on the pollution discharged in the environment, which varies. Secondly, even if the pollution discharged is the same at each release point and that the environments are uniform, there is no reason for the service value to be the same. Indeed, the environments are linked by the river and therefore their spatial position in the pollution purification chain along the river influences the value of the service they provide. In the simple example we have presented, note that the value of the opportunity cost goes up in a multiplicative manner along the river, while the contaminant mass transfer process is additive in nature. This is a consequence of the proportionality hypothesis. As a result, adding up the costs for each stretch to work out a sort of "aggregate" value applicable to the entire river is generally pointless.