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CHAPTER 10. POLICY RESPONSES

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Water pollution from agriculture is complex and multidimensional, and managing it effectively requires a range of responses. Such responses need to act on the key drivers of agricultural expansion and intensification, such as unsustainable dietary shifts. They also need to limit the export of pollutants from farms, protect water bodies from agricultural pollution loads and help restore affected water ecosystems. Influencing both farm- and landscape-scale practices may require regulation, the use of economic instruments, education and awareness-raising, cooperative agreements, and research and innovation.

Recent analyses suggest that a combination of approaches (regulations, economic incentives and information) works better than regulations alone (OECD, 2012; OECD, 2017). This chapter focuses on a broad set of policy solutions, which can provide the enabling environment for the adoption of effective on-farm and off-farm practices and technologies (discussed in Chapter 11) and thus prevent and mitigate pollution in practice.

10.1 Prevention vs remediation

The most effective way to mitigate pressure on aquatic ecosystems, and on rural ecologies more generally, is to limit the export of pollutants at the source, or intercept them before they reach vulnerable ecosystems. Once in the system, the costs of remediation progressively increase (Hardisty and Özdemiroglu, 2005). A recent assessment of the environmental performance of agriculture in OECD countries concluded that the economic costs of treating drinking water to remove nutrients and pesticides are already substantial. In the United Kingdom, for example, the cost of water pollution from agriculture amounted to €345 million in 2003/04. The eutrophication of marine waters also imposes high economic costs on commercial fisheries in some other countries (e.g. Korea, the United States of America) (OECD, 2008).

Broadly speaking, the contamination of groundwater is much harder to remediate than surface water and is consequently more expensive. The remediation of contaminated groundwater is a long-term undertaking (Rivett *et al.*, 2002; Rivett *et al.*, 2008) and may, in some cases, not even be feasible. Similarly, coastal hypoxia leads to serious and worsening social, economic and ecological costs, as has been experienced by some OECD countries. It may require 10-30 years to return hypoxic zones to acceptable conditions, although improvements usually manifest after the first few years of reclamation efforts (Kemp *et al.*, 2009).

Since remediation is expensive and not always effective, it is preferable to start by acting on pollution drivers (e.g. diets) and to manage and minimize the emission of pollutants at source with sustainable agricultural practices. Water quality modelling (see Chapter 9) can play a key role in identifying and quantifying the sources of diffuse pollution and understanding their dynamic behaviour to be able to anticipate the expected impacts and act in advance to prevent them.

10.2 Acting on drivers: sustainable diets and reduced food waste

Different diets have different environmental footprints. An increase in demand for food with large environmental footprints, such as meat from industrial farms, is contributing to unsustainable agricultural intensification and water quality degradation. However, this can be changed. The right policies and incentives can encourage people to adopt diets that are more sustainable and healthy and thereby moderate increases in the demand for food with a large footprint. For example, financial incentives, such as taxes and subsidies on food and coupons for consumers, have been shown to positively influence dietary behaviour (Purnell *et al.*, 2014). However, with the possible exception of organic labelling (see Box 10.1), there is little evidence that environmental food labelling plays a major role in the food choices of consumers. The approach would need to be combined with broader environmental awareness campaigns to turn an increasing concern among consumers about sustainability into a change in food purchasing habits (Grunert *et al.*, 2014; UNEP, 2005).

Another key issue relates to food supply and how food systems will respond to the projected growth in food demand. Food losses and waste should be reduced as much as possible to bring food production closer to actual demand and to minimize the waste of resources and

BOX 10.1 Organic labeling

Organic produce accounts for about 15% of market value (less in terms of product volume) in OECD countries, but it is rising in importance, as wealthier consumers make more informed choices about the way their food is produced. Organic labelling has benefitted from consumer demand in the USA and Europe and has been supported by clearly defined standards, a strong certification system and a system of enforcement (OECD, 2003).

In other countries, such as China, there has been a sudden rise in consumer interest in organic produce. The volume of 'organic produce' quadrupled (from an initially low level) between 2003 and 2005, with a change from export to local focus. Since then, there have been a number of campaigns to improve consumer safety with regard to pesticide residues on fruit and vegetables. The campaigns were initiated by local and international NGOs, but have been taken up more broadly with programmes on the internet and TV. Three 'environmental' labels are now used in food certification: organic, green and pesticide-free. The policing of organic certification is growing tougher. According to one recent China Daily report, about ten percent of the organic food sampled in Beijing was counterfeit (Yang *et al.*, 2007).

associated environmental impacts. About one-quarter of produced food is lost along the food supply chain. Producing this lost and wasted food accounts for 24 percent of the freshwater resources used in food crop production, 23 percent of total global cropland area and 23 percent of total global fertilizer use (Kummu *et al.*, 2012). Nitrogen pollution has a major impact on water quality. Grizzetti *et al.* (2013) calculated that the nitrogen pollution associated with global food waste was 6.3 teragrams per year, and that, in the European Union, 12 percent of water pollution from using nitrogen in agriculture is linked to food waste. FAO has extensively reviewed options for reducing food loss and waste (e.g. FAO, 2013a; FAO, 2015).

10.3 Regulatory instruments

Typical regulatory instruments include water quality standards; pollution discharge permits; mandatory best environmental practices; restrictions on agricultural practices or the location of farms; and limits on the marketing and sale of dangerous products. Some agricultural activities may be restricted without an environmental impact assessment or specific protective measures, such as the creation of buffer zones adjacent to water courses. Many regulatory approaches require inspection or self-reporting to ensure compliance, with violations subject to penalties such as fines and compensation payments. Enforcement remains a challenge, however.

Well-known principles for reducing pollution, such as ‘polluter pays,’ are hard to apply to non-point agricultural pollution because identifying the actual polluters is neither easy nor cheap (OECD, 2017). Assessing compliance and the effectiveness of regulations, (e.g. the adoption of best practices to manage diffuse pollution) is also difficult as it requires multiple steps, such as nutrient management plans; bookkeeping for fertilizers, pesticide and manure management on farms; nutrient accounting; and soil analysis. Therefore, regulations alone are typically not cost-effective for diffuse sources, although they have worked reasonably well with wastewater treatment plants, industry and intensive livestock units (UN-Water, 2015).

Regulations to protect water quality need to be enforceable. Water quality targets also need to be realistic and time-bound, and they need to balance the costs of adopting a solution and the benefits resulting from higher water quality. In addition, water quality targets need to take into account time lags between the introduction of a given practice and measurable outcomes (this is particularly relevant for the restoration of aquifer water quality). Once a target is set, planners need to find the most cost-effective combination of policy instruments (UNU-EHS/UNEP, 2016; OECD, 2017). As noted above, pollution prevention will typically be cheaper than the restoration of affected aquatic ecosystems.

BOX 10.2 | Regulations to control point source effluents from intensive livestock in USA

Pollution from factories and sewage treatment plants has been dramatically reduced in the United States of America over the past 40 years, but runoff from agricultural activities, including animal feeding operations (AFOs), continues to degrade the environment and puts drinking water at risk. To address this, and after intense debate, the US Environmental Protection Agency (US EPA) issued in 2003 the *national pollutant discharge elimination system permit regulation and effluent limitations guidelines and standards for concentrated animal feeding operations* (US EPA, 2003). As per these rules, a farm that meets certain size criteria and/or has the capacity to pollute is defined as a Confined Animal Feeding Operation (CAFO) and is subject to legislation associated with point source pollution, namely the National Pollutant Discharge Elimination System (NPDES) permits under the authority of the Clean Water Act. CAFOs must have certified animal waste management plans, including a nutrient management plan; a waste utilization plan that includes a 30 metre quarantine zone between surface waters and manured areas; and a standardized recordkeeping and reporting system. While this regulation will assist in reducing the impairment of United States of America waters, the actual effectives of such regulations are still debated and have not been well assessed (Burkholder *et al.*, 2007).

BOX 10.3 Pesticides are needed as is their regulation: examples from France and India

France, the major user of pesticides in the European Union(EU), enacted the Loi Grenelle in 2009 with the intention of making significant reductions in the use of pesticides of all types, by implementing a range of activities. One target is to increase the certified organic area of the country from 2% to 20% by 2020. A secondary thrust is to certify 50% of farms as "nature-friendly" through compliance with set standards and norms. A third component is the Ecophyto programme, which has 8 gears: 1) Assessing progress with pesticide use reduction; 2) Identifying and prioritizing agricultural systems for pesticide use reduction; 3) Encouraging innovation in design development of low pesticide input practices and cropping systems; 4) Better training in safe use; 5) Better surveillance and monitoring; 6) Meeting pesticide residue requirements in foreign markets; 7) Reduction in use of pesticides in non-agricultural settings (gardens); and 8) Overseeing the plan at national and regional levels and managing stakeholder involvement and consultation. This program is expected to withdraw 40 pesticides, targeting a 50% reduction in pesticide use for plant production by 2018 (Crosskey, 2016).

Many developing countries are lagging behind in the design and implementation of effective pesticides regulations. Some have old statutes on the books relating to pesticides and many provisions are honored in the breach. Nevertheless, some countries are now seeking to update legislation and to find better means of ensuring implementation. For example, the Government of India has drafted the Pesticides Management Bill (GoI, 2017), which will replace the Insecticides Act, 1968, providing a more effective regulatory framework for the country. The new act will regulate the import, manufacture, export, storage, sale, transport, distribution, quality and use of pesticides. It also codifies harsher punishments for manufacturers of spurious pesticides in order to prevent risk to human beings, animals or the environment.

Increasingly policy-makers are interested in regulating pollution outputs, rather than the use of farm inputs. This requires reaching a consensus on the maximum tolerable concentration of a given pollutant in a waterbody so that, with models, maximum pollution loads (caps) can be calculated. Subsequently, pollution caps can be allocated to individual landowners. Land managers can use innovative farm practices that minimize pollution without necessarily restricting the inputs they use. However, the allocation of caps to farmlands in a cost-effective and equitable manner remains challenging (OECD, 2017). Additionally, there are some limitations on the use of models related to the uncertainly of data or model components, and these require continuous efforts on data collection and model accuracy (see Chapter 9).

Nevertheless, the implementation of pollution caps is an emerging reality. On the east coast of the United States of America, a total maximum daily load (TMDL) programme is used to reduce nitrogen, phosphorus and sediment loading to the Chesapeake Bay (Batiuk *et al.*, 2013). Korea is also adopting a TMDL management system, which aims to control both point and diffuse pollution with a permitting system and the support of water quality models (Kim *et al.*, 2016, NIER, 2014).

10.4 Economic instruments

Economic instruments are increasingly employed to improve or replace simple legal provisions or regulations. They include taxes, 'set-asides' (the conversion of agricultural land to natural uses) and payments to limit production or the intensity of land use.

Taxes include polluter payments, dedicated environmental taxes and taxes on technologies, products and inputs that have adverse ecological consequences (e.g. pesticides), according to the level of hazard.

Incentives encompass tax breaks for the adoption of practices that minimize farm export of nutrients and pesticides; revolving funds for upgrades to water treatment plants such as the US EPA Clean Water State Revolving Fund with $5 billion on account; and reverse auctions – for example, the sale of irrigation water to a private or state buyer for environmental use. Some European countries make substantial payments to farmers for 'landscape maintenance', and the Conservation Reserve Program in the United States of America pays farmers to take land out of production for specified periods.

Agri-environmental payments (AEPs) have been widely used to encourage farmers to adopt more ecologically-friendly practices. In the postwar era, subsidies were provided to farmers in Europe and North America to improve the quantity and quality of food, at ever-cheaper prices to the consumer. This resulted in overproduction and in no small measure contributed to the high use of fertilizer and pesticide in increasingly intensive agriculture. Support payments under the Common Agricultural Policy (CAP) were designed to protect small traditional farmers from the economic 'efficiency' of larger, more industrial producers. With continued overproduction, the burden of support payments, a better understanding of the externalities of intensive agriculture, and the limited success of production quotas, the CAP eventually morphed support payments, first into set-asides and later into payments for specific environmental outcomes on-farm.

More complex economic instruments are emerging. One that took its lead from carbon trading (climate change mitigation) is nutrient credit trading (Corcoran *et al.*, 2010). The opportunity for nutrient trading exists because of substantial price variations between markets for different nutrients, although it is not clear that the environmental cost of the nutrients actually varies from place to place. If a farmer removes more nitrate or phosphate loading from a watershed than is required by law, these credits can be traded. Since it is difficult to monitor the actual export of nutrients, farm credits require proxies such as changed fertilizer rates, production practices and crop patterns or the retirement of land from cultivation. Water quality trading initiatives have started in Australia, Canada, New Zealand and the United States of America. Water quality trading in Australia is not a market activity – the Salt Credit Scheme (1994) is designed to limit the total salt contribution to the Murray River from each riparian state. Each state has, in effect, a quota and in order to manage rising salinity in one area, it must mitigate the salinity in another part of its territory. This has provided a flexible framework for investment to prioritize and manage salinity across each state and across the basin. In the long term, the salt credit available (measured as the median concentration at Morgan, in South Australia) to each state is intended to decline.

10.5 Education and awareness

Policies to change farmer behaviour and incentivize the adoption of good practices are critical to preventing pollution at the source. Such policies need to include (free) advisory services and training for farmers. Demonstrating the economic benefits of adopting good practices has also been shown to be effective. Benchmarking can promote behavioural change among farmers by showing them how they perform as compared with their peers (without identifying the best and worst performers). Benchmarking can be applied to the application of fertilizers, manure and slurries, and pesticides. A subtler form of persuasion is the incorporation of environmental modules into school curricula and motivating students to raise environmental issues in their communities.

Information can be provided directly through training and extension, radio and TV broadcasts and voluntary codes of practice. Farmer awareness of high water tables and incipient salinity has been raised through a community programme in Australia, known as Water Table Watch, which involves schools in monitoring water levels in their community. Similar initiatives have been undertaken to monitor flora, fauna (birds) and habitat.

10.6 Cooperative agreements

There is increasing interest in cooperative and voluntary agreements – typically between farmers, water suppliers and authorities – as a means to implement better environmental practices in agriculture. In some cases, private water suppliers have signed agreements with farmers to limit practices (e.g. nitrogen use) that may compromise water quality (and therefore their products), with the costs paid by the water supplier and ultimately borne by consumers (FAO, 2013b). In other cases, specific areas in river catchments may have been identified as major contributors of sediment (and sediment-borne pollutants) to important ecosystems. To address this, cooperative agreements can be developed between landowners and relevant authorities to reduce erosion, potentially incentivized by policies in favour of agro-environmental payments.

One of the best-known examples is the agreement between Vittel, a well-known producer of bottled natural spring water in the Vosges Mountains in France, and local farmers and pastoralists (FAO, 2013b). Vittel has signed agreements to limit nitrogen use (to zero in some cases) and other farm management practices that may compromise the quality of their product. Recently, specific areas of river catchments feeding into the Great Barrier Reef in Queensland, Australia have been identified as major contributors of sediment and sediment-borne pollutants. Cooperative agreements have been developed between land owners and the state to reduce erosion by a number of means requiring investment and payments (Queensland government, 2018).

10.7 Corporate social responsibility and GAPs

One of the most significant trends in the private sector is the rapid growth in activities related to corporate social responsibility (CSR). Although there is not a standard and commonly accepted definition of CSR, the term typically refers to actions taken by corporations, beyond their legal duties, in support of their employees, broader communities and the environment. Although debates are still ongoing as to whether a good CSR performance contributes to a firm's success, social benefits and environmental improvement (Hatanaka, 2005; Kong, 2012), the reputational and economic risks for companies with deficient social responsibility are unquestionable.

In the food industry, CSR approaches are increasingly shifting from the single firm level to supply chains and networks. Accordingly, agricultural producers are being required by their buyers to provide documentation about their production practices to ensure that good agricultural practices (GAPs) are use. Producers who are unable to provide these assurances to their buyers may find that they will have less opportunity to sell their products. The adoption of GAPs may be important for downstream firms seeking to project the image of a good corporate citizen. This becomes an economic incentive if a good public image encourages buyer loyalty or shareholder investment (FAO, 2003).

While GAPs can be seen as attempts to improve the sustainability of agriculture and can bring reputational benefits to the different companies along the value chain, concerns have also been raised regarding their potential effect on smallholders in developing countries (FAO, 2003). It is critical that the adoption of too stringent GAPs do not marginalize small producers, by cutting off access to export markets or imposing disproportionately higher production costs on the given the investments that may be needed to adopt good practices.

10.8 Broader policy frameworks

Policies addressing water pollution in agriculture should be part of an overarching water policy framework at the national or river-basin scale, with all pollutants and polluters considered together.

International conventions and declarations play a role in raising awareness and political profile. For example, the Nanjing Declaration on Nitrogen Management was signed in China on October 16, 2004 (Nanjing Declaration, 2004). The declaration, while acknowledging the vital role that nitrogen plays in the production of food and fibre, commits its signatories to optimizing nitrogen management in food and energy production. The declaration was motivated by the increasing recognition of non-point source nutrient export from farms, which is already a serious concern in many regions around the world (Clothier, 2008). This international commitment needs to translate into specific activities in individual countries.

Nevertheless, few countries have national policies and standards to control water pollution from agriculture. There are notorious exceptions, however. For example, both Australia and Sweden have had water quality strategies that consider non-point source pollution for more than 15 years. Broader water quality frameworks, such as the Nitrates Directive (Council of European Communities, 1991[8]) and the Water Framework Directive (European Parliament and Council of the European Union, 2000) in the European Union (discussed in more detailed in Box 10.4), and the Clean Water Act in the United States of America (US EPA, 2017) combine point and diffuse pollutant standards for industrial and agricultural compounds.

National policies need to be coherent. Interventions aimed at increasing food production and farm income on the one hand and at mitigating pollution on the other should be mutually supportive – or at least not in conflict, although this may be hard (politically) to achieve in practice. For example, the subsidies that are often in place for

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[8] Amended by the European Commission in 2003 and 2008.

agrochemicals do not act as an incentive for efficient use, and they encourage farming on more fragile lands. Effective inter-ministerial cooperation mechanisms are required to increase policy coherence.

BOX 10.4 Selected policy frameworks for water pollution control in Europe

The European environmental policy is based on three main principles: the precautionary principle; the principal of preventive action; and the polluter pays principle. The actions that should be taken to tackle environmental problems are based on five pillars:

- enhanced implementation of the existing environmental policy;
- integration of environmental concerns in all other policy areas;
- close cooperation with trade, industry and consumers;
- enhancement of the quality and accessibility of environmental information to the public; and
- development of a more environmentally-minded attitude towards spatial planning.

(European Commission, 2002)

Two overarching water quality policy instruments set requirements on ecological health for member countries of the European Union: the Nitrates Directive and the Water Framework Directive. The directives require individual countries to establish policies and supporting actions in line with their legislative and governance frameworks.

The objective of the Nitrates Directive (Council of European Communities, 1991) is to reduce water pollution caused or induced by nitrates from agricultural sources in order to protect human health, living resources and aquatic ecosystems. The directive includes rules for using animal manure and mineral fertilizers. The core of the directive is that a balance should be reached between N supply to soils (including mineral and organic fertilizers) and the nutrient demands of the crop being grown. Member states are required to guarantee that the annual farm application of N, as animal manure, does not exceed 170 kg per hectare. This is equivalent to a stocking rate of about one dairy cow per hectare. In European regions with relatively intensive dairy farming, stocking rates are often much higher and reducing them is a significant challenge.

The implementation of the Nitrate Directive proceeds in five steps:

1. designate ‘nitrate vulnerable zones’ (NVZ): agricultural land that makes a significant contribution to nitrate pollution in a susceptible area;

2. develop codes of good agricultural practice for farmers. These are voluntary at the national level and compulsory in NVZs;
3. develop action programmes for NVZs;
4. reduce nitrate leaching, monitor programme effectiveness; and
5. undertake national management of nitrate concentrations and eutrophication.

NVZs cover about 47% of the total EU area (European Commission, 2013), largely due to the importance of groundwater in the drinking water supply, with a legal upper limit 50mg/l of nitrate:

The action programmes specify:

- periods when the land application of certain types of fertilizers is prohibited;
- the capacity of storage vessels for livestock manure; and
- limits to the quantity, timing and mode of fertilizer application, consistent with good agricultural practice and the characteristics of the vulnerable zone.

The **Water Framework Directive** came into effect in 2000 and set a goal for all the EU member states to protect all waters and have them in a good condition by 2015 (European Parliament and Council of the European Union, 2000). Three phases were agreed, with preparatory work lasting until 2002, followed by testing of river basin management guidelines in pilot basins between 2002 and 2004 and the finalization of the guidelines and an outline action programme by the end of 2005. The Water Framework Directive has been implemented in steps, such that it was first incorporated into each member state's national law in 2003 with the identification of river basins and their management bodies. By 2006, each member state was required to have an operational system in place for monitoring the ecological and (chemical) water quality status of surface waters. River basin management plans had to be developed by 2009, which specified measures to control point source discharges and non-point pollution; to prevent or limit leakage from point sources (e.g. feedlots, dairies, processing plants); and to promote sustainable and efficient water use.

The river basin plans were required to classify all subcatchments, and define water quality status. Measures to address diffuse pollution in each basin had to be in place by the end of 2012 and ecological health targets had to be achieved (and verified) by 2015.

10.9 Research and data

There are many knowledge gaps around water pollution caused by agriculture. For example, the contribution of crops, livestock and aquaculture to water pollution are frequently not well assessed, particularly in developing countries. Box 10. 5 illustrates – with an example from the Ganges Basin – what is a common reality in many other low and middle-income countries.

Quantifying the relative contribution of agriculture to water quality problems is essential if national governments are to develop meaningful and cost-effective responses. The polluter pays principle cannot be applied if the source of the pollution is unclear. A sustained research and modelling effort, supported by water quality monitoring, is needed to better understand pollutant pathways and the links between the causes and effects of pollution.

The pathways of, and the health and environmental risks posed by, emerging agricultural pollutants, such as animal hormones, antibiotics and other pharmaceuticals, are growing areas of research that require more attention. For example, greater understanding is needed on the contributions of animal medicines to the increasing problem of antimicrobial resistance among pathogens.

There are opportunities for greater innovation in practices and technologies to diminish the use of nutrients and pesticides on farms and reduce the movement of pollutants from farms to sensitive aquatic ecosystems. Research is needed to evaluate policies and instruments for reducing source loads and minimizing pollution along flow paths to the sea. More work is also required to quantify the effectiveness of different approaches to reducing the economic impacts of water pollution on agriculture.

There is scattered evidence of the costs associated with diffuse pollution of water in general and agricultural pollution in particular. While existing studies suggest that the global costs of water pollution from agriculture could exceed billions of US dollars (OECD 2017), there is a need for a more systematic assessment of such costs as a key tool for awareness raising and influencing political will.

Research results need to be used and applied if they are to be effective in reducing pollution in agriculture in practice. It is crucial to establish information systems for transferring new knowledge and technologies to support farmers, water managers and policy-makers. Research projects need to consider, from the conceptual stage, the

BOX 10.5 **Key knowledge gaps around water quality in the Ganges basin (Mateo-Sagasta and Tare, 2016)**

Despite efforts to clean the Ganges River, the main stream still directly receives at least 2.7 billion litres of sewage from medium and large cities every day, of which at least 74% is untreated. Industrial effluents are in the range of 10-20% of the total volume of wastewater directly reaching the Ganga. Although this is a relatively low proportion, it is a cause for major concern because the effluents are often toxic and non-biodegradable.

The Ganga is also impacted by non-point source pollution, but the actual contribution of agriculture, livestock and aquaculture to water quality degradation is not known. Trends in agrochemical use as well as the density of livestock suggest that these pressures could be important in the river basin. To understand the extent of the problem, a sustained research and modelling effort would be needed to track the pathways and loads of nutrients and organic matter from their sources to water bodies. Similarly, the contribution of other non-point-sources of pollution, such as faecal sludge or open defecation, to the degradation of the Ganga is not well understood and will need further research.

The hydrological links between groundwater and surface water in the Ganga basin have not been properly assessed and modelled, therefore it is not possible to estimate the contribution that groundwater pollution may have made to the Ganga and tributaries, and vice versa. Understanding this is particularly important in the case of pollutants such as nitrate, pesticides and salinity.

A comprehensive water quality model at the basin scale, which allows researchers to simulate solutions, will be critical for planning and assessment. Rejuvenating the Ganga will require a massive investment. From the government perspective, it will be crucial to select the most cost-effective combination of solutions to meeting water quality standards and improving river health. These solutions need to include reducing pollution from different sources, restoring appropriate water flows and, ideally, a combination of both. Understanding how these solutions might translate into reduced pollution loads, enhanced water flows and, consequently, improved water quality along the river will require complex water quality modelling, an exercise that has not been done comprehensively in the Ganga basin.

Any water quality assessment and modelling effort will require good quality data. The current water quality monitoring network along the Ganga and its tributaries is very poor and will need to be strengthened with substantially more stations, which will need to monitor more parameters and with a greater frequency. ➤

➤ Finally, a better understanding of how pollution translates into health and environmental impacts, and the costs of such impacts, will help to raise awareness on the size of the problem and will help justify the massive investments that the river needs if it is to be restored.

specific needs of users and engage them in the process, from knowledge generation to environmental and health outcomes.

Research cannot be conducted without data. We need better data to understand the process by which specific waterbodies become polluted and the pressure that this puts on aquatic systems. Because many indicators are subject to temporal and spatial variability, adequate monitoring programmes with appropriate sampling rates and density are key (but expensive) priorities for improvement.

Monitoring data help to determine the state or condition of a waterbody and to quantify the amount of polluting material that is reaching aquatic systems. Data is also needed to understand long-term trends in the state of global water bodies and to better understand the pressures and drivers behind them.

Impacts can be measured directly, but require modelling to predict future behaviour and severity. Modelling ecological impacts often demands intensive calibration and data. Research is needed to evaluate which policies and instruments will work best to reduce source load and minimize pollution along the flow path to the sea. Similarly, work is required on the cost-effectiveness of different technological and economic solutions.

Load and concentration data need to be gathered at key points in the landscape, and this can be done at places where flows are already measured for other purposes: e.g. for flood warning and control, irrigation diversion, etc. Monitoring and characterization does not have to be costly. For example indicators of soil health and nutrient use efficiency can be collected by farmers, and biodiversity can be surveyed on a long-term basis as part of school science activities. Data aggregation and analysis can be facilitated by GIS, which can also assist in the development of cost-effective sampling strategies.

It is relatively straightforward to measure concentrations and loads at the point of discharge from a wastewater treatment plant or feedlot that flows directly into surface water. It is more difficult to measure the net flux to groundwater below fields that receive heavy applications of manure and slurry. It is even harder (and costlier) to measure the surface and subsurface fluxes from individual fields and farms, although it is possible to monitor when and how much agricultural chemicals are applied.

Typically, monitoring requires sampling representative conditions that differ in time and space. For example, the pesticide contents in a lake should be sampled at a range of depths and locations that enable a good estimate of the average condition of the whole lake. They should be sampled frequently enough so that major changes are not missed. Sediment (and thus phosphate) loads will be highest during storm events that may last one or two days. Gauging stations normally record sample flows at fixed time intervals, perhaps once or twice per day. If recordings are done manually, dangerous weather conditions could make it difficult to collect any data at all.

Both concentration and load provide important information: when concentrations in any flow reach a certain level, they may be directly toxic to some organisms (e.g. pesticides) or they may trigger conditions that commence a harmful algal bloom (e.g. nutrients, dissolved oxygen). In general, the impacts of concentration are of greater concern in low flows. Although the concentration of pollutants in solution are often lower at high flows, sediment-borne concentrations may be greater. The average condition of receiving waters depends more on the load received over the course of time. Load is determined by flow rate and concentration, integrated over time. Thus, both adequate sampling frequency and combined measurement of flow and concentration to determine load are very important. Four types of sediment monitoring are being conducted under the EU’s Water Framework Directive: risk assessment, trend monitoring, spatial monitoring and compliance monitoring, with a focus on the type and level of industrial contaminant transported by sediment.

Although watershed boundaries can be clearly determined from topographic maps or by using sophisticated remote sensing data to create digital elevation models, the delineation of groundwater zones and their connectivity may require intensive hydrogeological sampling. Determining the connectivity between surface and groundwater often requires another level of investigation, and is mostly confined to research at the moment.

Ecological monitoring is an emerging science and, as a result, it is rare to find a strong historical data set that allows a clear depiction of trends in ecological health. An interesting approach has been developed in Victoria, Australia, to rapidly survey the ‘ecological assets’ in a river reach to define their health (using condition scoring) and then prioritize where the best returns to conservation and remediation are likely to be (DPI Victoria, 2006). The inventory of ecological assets provides a framework for further routine monitoring.

BOX 10.6 | Monitoring using remote sensing

Successful techniques in remote sensing analysis tend to find rapid application and, when costs are prohibitive, there is often quick adaptation of the techniques to other more affordable sensors. This has been the case with MERIS (Medium Resolution Imaging Spectrometer), one of the main instruments used on board the European Space Agency (ESA)'s Envisat platform, which gathers data on large inland and coastal waterbodies. The application of remote sensing techniques to smaller water bodies, wetlands and rivers remains expensive and is likely to be done on a research, or one-off diagnostic basis, although as the pace of sensor development and the associated analysis remains high, it is likely that there will be continued and widespread application to environmental monitoring, including water quality issues.

At present, the focus of the effort around water quality lies in monitoring the extent and dynamics of harmful impacts, notably harmful algal blooms in freshwaters, coastal zones and in the open ocean. The indicators of inland and coastal eutrophication include:

- chlorophyll-A content (Chl-a), which is a measure of phytoplankton concentration;
- phycocyanin (PC), which is an indicator of cyano-bacterial concentration; and
- sediment concentration (TSS) in surface layers.

Chloropyll-A provides a good measure of phytoplankton growth, and can be correlated to the chemical and biological oxygen demands of organic pollutants (CEARAC, 2007). It is a proxy for eutrophication, but high levels of phytoplankton growth do not necessarily indicate eutrophic conditions. The emergence of harmful cyanobacterial algae is a better indication of eutrophication, but at present anoxia cannot be detected. The hazards of toxic cyanobacterial blooms call for frequent and rapid monitoring of waterbodies. Suspended solids can be estimated from turbidity. Estimates of both can be retrieved from water colour. In practice, the estimates of Chl-A and turbidity can confound each other, and other colourations, such as yellow pigmentation from dissolved organic matter (CDOM) can introduce further variability n accuracy. Analysis is based on three categories: inland waters; open ocean waters and coastal waters.

At the farm level, better methods are needed for assessing nutrient and pesticide needs, as are techniques for managing fertilizer applications to minimize accumulation and export. This ranges from soil and plant testing, which are relatively inexpensive, to soil zoning (GIS and precision farming).

Better understanding of the chemistry of organisms and soils may lead to better targeted, more discriminating, shorter-lived and species-specific pesticides. An improved understanding of the same fundamentals can help us to understand and prevent the loss of key ecosystem components, which undermines the health of the trophic chain and hence the whole ecosystem.

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