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AGRICULTURE AND WATER QUALITY: MONETARY COSTS AND BENEFITS ACROSS OECD COUNTRIES

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NOTE BY THE SECRETARIAT

Following the discussion at the 10-12 October 2011 Joint Working Party on Agriculture and the Environment (JWPAE) the attached report is the FINAL version of *Agriculture and Water Quality: Monetary Costs and Benefits across OECD Countries*, prepared by the consultant Andrew Moxey, Pareto Consulting, Edinburgh, Scotland, United Kingdom.

Following agreement to the declassification of this report under the written procedure at the October 2011 JWPAE, the FINAL report includes written comments received from Delegations and the points raised during the meeting (please find a version in tracked changes mode on the OECD Delegates' Corner).

Publication of this consultant report, together with the accompanying Main Report – *Sustainable Management of Water Quality in Agriculture (COM/TAD/CA/ENV/EPOC(2010)42/FINAL)* – will be timed to coincide with the OECD's Secretary-General's visit to the World Water Forum, Marseille, France, 12-17 March 2012.

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EXECUTIVE SUMMARY

1. Agricultural activities influence water quality. Depending on production patterns and baseline conditions, this can be a negative or a positive effect. For example, sedimentation, nutrient and chemical run-off can all be increased or decreased through adjusting management practices. Equally, abstraction for livestock or irrigation can affect the volume and flow of water and thus alter the concentration (i.e. dilution) of contaminants. However, although policy responses may be in place, such effects are often mis-priced or un-priced externalities. Accounting for them more explicitly would result in improved resource allocations.

2. Changes in water quality have a variety of economic impacts, including upon human health, ecosystem health, agricultural and fisheries productivity, and recreational and amenity uses. Although some of these effects are tangible, many are not and their monetary quantification entails non-market valuation techniques. Valuation also requires some prior underpinning scientific monitoring and understanding of complex biophysical relationships. For example, to differentiate between agricultural and non-agricultural sources of pollution or to trace the passage of diffuse pollution through complex hydrological systems. The latter point is important since the separation of cause-and-effect by both physical distance and by time-lags adds complexity to the measurement and comparison of monetary values.

3. A search for information across OECD member countries confirmed the existence of agricultural impacts on water quality in all cases. In most cases, reported effects were negative. This does not deny the potential for beneficial mitigation activities, merely that current production patterns and management practices are generally polluting in nature. An important exception is paddy fields, where mimicking natural wetlands can contribute to improvements in water quality. Achieving mitigation in other production systems may incur more of a trade-off with commodity production.

4. Explicit valuation studies are rarer than biophysical reports of impacts, are often not related specifically to agriculture and do not encompass all categories of economic impact. Moreover, they are often conducted at a regional rather than national level and deploy a variety of methodological approaches, including in relation to whether reporting marginal, average or total costs. As such, results are difficult to interpret out-of-context and cross-country or cross-study comparisons can be misleading. Nevertheless, valuation estimates were identified for most OECD members and serve to illustrate the existence of externalities and a need to adjust agricultural water usage and other management practices to reduce negative impacts.

5. However, the fragmented, incomplete and variable quality of valuation figures suggests various themes for further research. These include improvements to the underpinning science, continued refinement of non-market valuation techniques and more routine inclusion of water quality in environmental accounts. In addition, given that not all categories of impact are addressed equally, there are gaps to be filled at both the national and regional level.

6. Whilst detailed discussions of policy issues are beyond the scope of this paper, as are more detailed discussions of the technical aspects of improving valuation figures, the externality effects identified and the reported illustrative valuations for them across OECD countries are hopefully indicative of the nature and scale of the issues remaining to be addressed.

**AGRICULTURE AND WATER QUALITY:
MONETARY COSTS AND BENEFITS ACROSS OECD COUNTRIES**

by

Andrew Moxey¹

1. Introduction

7. As an economic activity, agriculture generates a number of marketed goods such as grain, milk and meat. However, the process of agricultural production also generates a number of effects felt externally to any market. Some, such as attractive landscapes, are beneficial to society. Others, such as pollution, are costly to society. In either case, failing to account for such non-market goods and services means that the allocation of resources to and within agriculture is sub-optimal from society's perspective. This short paper reviews agriculture's (but not the broader food sector's) externality impacts on water quality and collates illustrative valuations of these impacts reported across OECD countries. Some supporting literature is offered in Annexes A and B.

8. Identifying and estimating the significance of agriculture's impact on water quality is of relevance to policy makers seeking to promote sustainable agricultural and wider economic development. A failure to account correctly for externality effects leads to a misallocation of resources, to an inappropriate mix of land uses and inappropriate management of individual parcels of land. For example, too much arable land relative to grazing land or to livestock densities and fertilizer applications that are too high. Such misallocations result in a loss of economic efficiency that lowers the overall gains to society and should be considered alongside other agricultural policy issues. Beyond the immediate agricultural policy interest, quantification of externalities is also relevant to improving the treatment of natural capital and environmental degradation in systems of national economic accounting as a guide to the sustainability of resource usage.

9. Globally, despite more rapid growth in other sectors' usage, agriculture dominates the usage of freshwater. Although some of this water remains within final crop and livestock products, much of it is returned to rivers, lakes and groundwater stores. As it flows across fields as surface runoff or percolates down through the soil, this water can pick-up a number of contaminants from farmland. For example, sediments from eroded soil, salts from irrigation, nutrients from organic and mineral fertilisers, pathogens from livestock, and chemicals from pesticides and farm machinery.

10. The level of contamination varies considerably and can be influenced by a number of local factors. For example, the timing and intensity of management activities, the slope and soil in a field, and whether weather conditions are wet or dry. Importantly, agricultural use of water can also influence the concentration level of contaminants by altering the volume and rate of flow of water entering rivers and lakes (i.e. affecting the diluting effect of water). For example, via abstraction for watering livestock or for irrigation of crops. Land management practices can also improve as well as degrade water quality. For

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example, unfertilized and ungrazed buffer strips alongside watercourses can absorb and disperse pollutants. The same is true of paddy fields and of wetlands created on farms.

11. The impacts of contamination also vary depending on the types of pollutant and how they impact on other uses of water. For example, sensitivity to pollution in drinking water is higher than in water used for industrial cooling, visible pollution may matter more to tourists looking at a river or lake than invisible chemical pollution. The costs of some of these effects are revealed through expenditure on protective or avertive measures, others may be inferred through estimated lost output.² The latter includes tangibles such as lower crop yields or fish catches but also intangibles such as recreational enjoyment, meaning that non-market valuation techniques are required. From an economic perspective, information on total or average costs is of less policy relevance than information on how they vary with changes in water quality and management – the costs and benefits of marginal changes. Whether mitigation practices are interpreted as delivering environmental performance that is expected by society with or without reward depends upon how reference levels and property rights are perceived. For example, on whether pollution levels are compared to a pristine environment without any agricultural activity or to existing agricultural production patterns and management practices and on whether mitigation is viewed as voluntary and meriting reward under the “provider-gets-principle” or as obligatory under the “polluter-pays-principle”.

12. Assessing the economic significance of agriculture’s influence on water quality thus requires some understanding both of how farming practices influence water quality and also of how and why changes in water quality matter and can be achieved. The next two sections outline a framework to aid such understanding by identifying various categories of impact and then outlining the information needed to quantify them.

2. Categories of impacts

13. As a key component of life on Earth, water is clearly central to economic activities linked directly to biological health and productivity but freshwater and saltwater are also used directly or indirectly in a variety of other ways too. Although sensitivity to water quality varies across these different uses, some more important categories may be relatively easily identified and are described briefly below. As with most such categorizations, some categories may overlap to a certain extent and there is scope for further refinement. Nevertheless, it is hopefully sufficient to help frame subsequent analysis and discussion.

Human health

14. Given the essential nature of drinking water to human survival, degraded water quality has implications for human health whether from pathogens or chemicals. Extreme contamination can render water physically undrinkable, posing an immediate health risk and/or recourse to expensive short-term alternative provision (e.g. bottled water). More typically, contamination poses a potential longer-term risk and is addressed through routine treatment of drinking water to remove pollutants (e.g. pathogens, nitrates, pesticides) that can cause immediate illness and/or longer term diseases. However, such treatment is not costless and represents an additional burden on water companies and thus consumers. The more degraded water is, the more costly it is to treat. Additional water treatment may incur not only significant capital costs, but also an increase in energy and chemical costs. There may also be secondary pollution issues regarding how extracted contaminants are then subsequently disposed of.

² Typically, there is some scope for substitution between these different responses although protective expenditure is often driven by regulatory requirements (e.g. treatment of drinking water) and does not necessarily relate precisely to avoided damage costs.

Ecosystem health

14. The presence of pollutants in water can alter ecosystems, changing habitat characteristics and wildlife species composition. For example, chemicals such as pesticides or oils can directly kill plants and animals in-stream whilst nutrient enrichment (eutrophication) can indirectly alter the relative prevalence of different species. Such impacts extend beyond rivers and lakes into the marine environment, particularly around coasts or in enclosed seas with relatively shallower water and/or weaker currents where pollutants can accumulate and persist. For example, sediment loadings can cause river mouths to silt-up and nutrient loadings can lead to coastal eutrophication and algal blooms. In some cases, the species affected are of extractive commercial interest (i.e. for fishing), in others they are not – but may still have economic value through contributions to wildlife tourism (e.g. whale watching) or the background maintenance of ecosystem services which implicitly underpin many economic activities.

Agriculture

15. Agriculture can be both a source of water pollution and a victim. For example, water courses contaminated with pathogens, chemicals or salts can pose a health risk to both livestock and crops and leading to lower the productivity. In some cases, such effects may be felt on farms causing them but more often will spill-over onto other farms leading to lower yields and/or higher expenditure on counter-measures elsewhere.

Fishing

16. Commercial and recreational fishing activities can be directly affected by water quality issues. For example, toxic contaminants can directly or indirectly, through bio-accumulation of contaminants, kill target species or they can simply render species unfit for human consumption – in both cases reducing catch volumes and values. Such problems have been encountered in relation to both free-swimming species and shellfish, with both being highly susceptible to eutrophication effects.

Recreational/amenity activities

17. Not all uses of water are consumptive in the sense of extracting water or something tangible from water. For example, swimming in, canoeing on or looking at a river, lake or sea. Yet such activities may be also limited by the presence of pollutants, either because they pose an actual health risk and/or merely reduce potential enjoyment, but also in some cases pollution can lower riparian property and land values. For example, some algal blooms associated with eutrophication are toxic and thus preclude recreational contact activities but can also impair the visual appeal of a water body, as can murky, sediment-carrying or smelly water. Such changes can impair values for visitors and residents alike, leading to, for example, less tourism or lower waterfront property values. In addition, in some cases, particular bodies of water may have specific local cultural significance and visually apparent quality degradation may reduce spiritual value. Less easily detectable pollutants, such as some chemicals or pathogens, may degrade habitats and affect ecosystems without altering the appearance of water bodies, highlighting how different water users may be affected in different ways. This is sometimes expressed as a “ladder” of water use, with progressively higher quality water permitting more uses.

Other uses

18. Other industries can also be affected by water quality issues. For example, over time, sedimentation of navigable waterways can disrupt water-based transportation networks and/or incur additional (dredging) maintenance costs. Equally, sediment, chemical and salt loadings can increase cleaning and corrosion maintenance requirements where water is used for industrial cooling (e.g. power

generation). Similarly, as with drinking water, treatment of water used in bottled mineral water, food processing or textile manufacturing may be necessary to avoid contamination of final consumer products.

3. Information needs

19. Although it may be possible to identify categories of agriculture's impact on water quality, translating these into quantitative estimates of their economic significance requires more detailed information on their physical scale and their value. That is, for example, some effects may be relatively insignificant economically if they occur on only a minor scale and/or cause relatively little inconvenience to other water users. A comprehensive review of information needs is beyond the scope of this report but a number of issues identified in the supporting literature are described briefly below.

Linkage complexity

20. The precise biophysical mechanisms linking agricultural activities to pollutant levels are complex and imperfectly understood. This largely reflects the (predominantly) diffuse, non-point nature of agricultural pollution which makes it difficult both to observe polluting activities directly and to link them explicitly to pollution outcomes. For example, originating activities may be separated from pollution outcomes by both physical distance and time as pollutants move slowly from upstream fields to downstream sites through transboundary hydrological systems that can span several countries. Moreover, pollutants may be reduced during their movement through natural assimilation processes or dilution, or conversely increased from other sources. In addition, observed impacts may not be solely attributable to pollution. For example, lower fishing catches may also arise due to over-fishing. Improved monitoring data on management practices and water quality can help in this regard as can modelling to identify linkages within hydrological systems, but both can be expensive.

Spatial and temporal variability

21. The polluting effect of any given agricultural activity is highly context-specific, depending not only on an activity's characteristics but also upon local site conditions, prevailing weather conditions, the management of neighbouring land and past management practices. For example, the same application of fertiliser can lead to different in-stream nitrate levels depending on the type of soil and topography in a field, the intensity and duration of rainfall immediately following application, and the timing and level of fertiliser treatments on surrounding fields. Again, improved monitoring data on site conditions and management actions can help. However, the time-lag between pollution entering an hydrological system and becoming detectable can also be highly variable. For example, whilst contamination of surface water may become apparent almost immediately, contamination of groundwater may not become apparent for years or even decades. This poses a challenge for monitoring but also for policy responses since observed water quality may reflect past rather than current agricultural practices and policy-induced changes may take considerable time to appear. Such time-lags also make comparing costs and benefits less straightforward and necessitate the use of discounting of future impacts, a topic in its own right.³

Non-agricultural sources

22. Agriculture is not the only potential source of water pollution. For example, forestry operations can also involve soil disturbance and the application of fertilizers and chemicals, as can activities across private and municipal gardens, golf courses, airports and road and rail networks. Equally, municipal sewage from private residences and commercial premises also typically contains a mix of chemicals,

³ See, for example, Price (1993), Portney & Weyant (1999), http://nordhaus.econ.yale.edu/stern_050307.pdf

nutrients and pathogens. Consequently it is often necessary to apportion any changes in water quality between different sources, something that can be difficult to do accurately.

Total economic value, non-market valuations and commercial confidentiality

23. Even if the causal links between specific agricultural activities and resultant water quality can be clarified, the economic significance of such linkages may still not be clear. That is, the total economic value of water quality encompasses several components lacking market prices. For example, in contrast to a tangible “direct use” such as irrigation, “indirect use” though amenity and recreational activities is less tangible and often unpriced, as are “non-use” values associated with altruistic and bequesting behaviour. Hence recourse is required to non-market valuation techniques such as hedonic pricing, contingent valuation and conjoint analysis to identify citizens’ or households’ willingness to pay (WTP) for different levels of water quality per year. Although widely used, such approaches are not without criticisms, including assumptions about the ability of people to articulate their WTP for non-market effects and difficulties in transferring valuations between different locations and contexts.⁴ Separately, information on the market costs of some mitigation and adaptation activities may be obscured by commercial confidentiality. For example, private water companies are often reluctant to reveal treatment costs.

Other externalities

24. Jointness between producing agricultural commodities and water pollution also extends to other externalities. For example, sedimentation of watercourse arises from soil erosion which itself represents an environmental degradation cost in terms of lowering capacity for agricultural production and carbon sequestration. Equally, air quality can be reduced by nitrous emissions but subsequent deposition may also cause water pollution. This means that care needs to be taken to avoid misallocating values between different externality effects and/or to avoid double-counting. It also means that attention needs to be paid to pollution-switching. For example, whether reductions in water pollution cause an increase in other pollutants such as greenhouse gas (GHG) emissions.

4. A survey of impact estimates

25. Across OECD members, a search for information relating to agriculture’s impact on water quality revealed a variety of studies both in academic journals and in the “grey” literature of government and NGO reports. The search was primarily conducted on-line, using personal recommendations and web search engines to identify and access published studies, academic databases and official websites.

26. Many studies focused on physical impacts, far fewer on economic valuations. The coverage of impact categories varied and relatively few countries had consistent or comprehensive figures for all impact categories. Moreover, studies varied greatly in the time period to which they related and the methodologies that they followed. Many were focused on water quality in general rather than agricultural aspects specifically. Given this variation, selecting studies to include in the report was essentially a subjective process, guided by the reputation of journals, authors and funding bodies but also in some cases simply by the availability and vintage of any published information. Local contacts and/or familiarity with the situation in any given country would be expected to reveal further information in many cases.

4. A detailed discussion of such issues is beyond the scope of this paper, but see (e.g.) Turner (1977), Navrud (2007) & Bateman et al. (2009).

27. The variation in coverage, methodology and provenance of studies makes it difficult to present figures on a like-for-like basis and comparisons over time and/or between countries will be misleading. Nevertheless, brief summaries are offered below to outline the reported nature and scale of water quality issues associated with agriculture in each OECD country. To avoid cluttering the text with numerous references, only the most recent and/or relevant are cited explicitly with selected others listed in Annex B for each country.

28. The emphasis of most valuation exercises cited here was on the degradation costs arising from current production patterns and management activities rather than the mitigation potential of adjusting agriculture. This is neither to deny the importance of potential mitigation through agricultural adjustments nor to deny the range of positive externalities associated with agriculture, merely to highlight the current negative externalities and thus the scale of resource misallocations needing attention. Importantly, some current production systems do already deliver water quality improvements. For example, paddy fields in Japan and Korea. Adjustments to other production systems may entail more explicit trade-offs with commodity production. For example, through devoting land to created wetlands or buffer strips rather than to cultivation or grazing. That is, although some “win-win” situations may exist⁵, improved water quality is generally not produced jointly with agricultural commodities and improving quality will in many cases entail some reduction in agricultural output.

29. The need for caution in making comparisons and interpretations needs to be stressed again. In particular, although agricultural impacts were acknowledged in all countries, relatively few valuation studies related exclusively to agriculture. Rather, they mostly addressed water quality in more general terms as summarised in Table 1. Conversely, because few studies encompassed all of the categories of impact suggested in section 1 the cited figures may under-state overall impacts. As such, all figures must be viewed as purely illustrative rather than definitive. The survey of studies in this section estimating household WTP to improve water quality cover a range of situations over the period late 1990s to 2010, although are rarely applicable to only agriculture. Household WTP for improvements in non-use values of surface water, including lakes and marine waters damaged by eutrophication, are typically in the range of EUR 10 – 50. But for improvements to drinking water quality household WTP estimates can be much higher up to EUR 250-270, while there are very few WTP estimates for improvements to groundwater quality.

5. For example, farmers themselves may benefit from lower input costs and/or higher yields by reduced nutrient and soil losses.

Box 1. National costs of water pollution (not necessarily all due to agriculture)

Country (Sources)	Type of water quality impact	Cost (millions)		
		National currency	EUR	USD
Australia (Atech, 2000)	Algal blooms associated with excessive nutrients in freshwater	AUD 180–240 ¹	109 – 145	116-155
Belgium (Dogot <i>et al.</i> , 2010)	Drinking water treatment costs		120-190	167-264
France (Bommelaer, 2010)	Eutrophication of surface and coastal waters		70 – 1 000	97-1 389
Netherlands (Howarth <i>et al.</i> , 2001)	Nitrate and phosphate damage		403 – 754 ²	371 – 695
Spain (Hernandez-Sancho <i>et al.</i> , 2010)	Nitrate and phosphate damage		150	208
Sweden (Huhtala <i>et al.</i> , 2009)	<ul style="list-style-type: none"> • Costal eutrophication • Baltic Sea eutrophication 		860 492 – 1 466	1 257 719 – 2 143
Switzerland (Pillet <i>et al.</i> , 2000)	Agricultural pollution ³	CHF 1 000	608	690
United Kingdom (Jacobs, 2008) ⁴	Agricultural pollution of surface water, estuaries and drinking water treatment costs	GBP 229	335	458
United States (Dodds <i>et al.</i> , 2009)	Freshwater eutrophication		1 500	2 200
(Pimentel <i>et al.</i> , 2005)	Pesticide contamination of groundwater		1 610	2 000
(Anderson <i>et al.</i> , 2000)	Marine algal blooms		32 – 46	34 – 49

Source: see main text for references.

1. Of this total around AUD 60 million were costs incurred by agriculture itself, and about AUD 100 million due to lost recreational value.
2. This estimate is a projection to 2010.
3. Agricultural pollution estimated for 1998.
4. This is the total of the costs shown in Box 2.

Australia

30. The importance of water resources is acknowledged with natural resource monitoring and management policies in place with respect both to agriculture's impact on water quality but also water quality impacts on agriculture. Problems arising from agricultural contaminants and salinity have been exacerbated by low flow conditions caused by abstraction and less rainfall in recent years. Most rivers exhibit a high degree of degradation, particularly within the Murray-Darling catchment. Drinking water quality is impaired in many locations and coastal regions downstream of large agricultural areas suffer from sediment and nutrient loadings.

31. Atech (2000) report estimated national costs arising from algal blooms associated with excessive nutrients in freshwater to be between AUD 180 (EUR 109) and AUD 240 million (EUR 145 million). Of this, around AUD 60 million (EUR 36 million) were incurred by agriculture itself and around AUD 100 million related to lost recreational value. Coastal eutrophication has contributed to a number of incidents harming commercial fish and shellfish catches, imposing smaller periodic losses (ABS, 2003 & 2006; OzCoasts, 2010). Total environmental protection expenditure related to water quality is in excess of AUD 3 billion (EUR 1.7 billion), of which around AUD 350 million (EUR 202 million) may be inferred as attributable to sedimentation and groundwater issues caused by agricultural activities (Trewin, 2003).

Austria

32. The influence of farming practices on the quality of freshwater is recognised particularly in terms of deterioration of groundwater and eutrophication throughout the Danube river basin. Although industrial and municipal sources are important, agriculture is estimated to account for around half of Austrian nutrient loadings into the Danube and onwards to the Black Sea. This contributes significantly to around 3% of groundwater sources failing to meet domestic standards for nitrates and nearly 20% of surface waters failing to meet "good ecological status" relating to nutrient pollution under the EU's Water Framework Directive.

33. Although drinking water treatment costs arising specifically from agricultural contaminants are not available, Zessner *et al.* (2010) imply total annual treatment costs of around EUR 200m. Studies relating to impacts on freshwater recreational or biodiversity values are apparently scarce, but Aquamoney (2009) results for Austria report household WTP for water quality improvements of EUR 45 to EUR 75. Partial estimates of eutrophication costs in the Black Sea are available, although apportioning contributions between neighbouring countries and different sectors is difficult (Borysova *et al.*, 2005).

Belgium

34. Although industrial and municipal sources are important, intensive agricultural practices are acknowledged to have increased nutrient loadings to rivers and to Belgian coastal waters. Nitrate concentrations are elevated in a proportion of groundwater sources and rivers. Almost all coastal bathing water meets mandatory quality standards, but between 10% and 20% of freshwater fails due to the presence of algal blooms and/or bacterial contamination. Nitrate concentrations are also excessive in over 15% of groundwater and over 10% of surface water sources.

35. Although estimates of drinking water treatment costs arising specifically from agricultural contaminants are not available, Dogot *et al.* (2010) imply that total treatments costs amount to between EUR 120m and EUR 190m. Whilst noting caveats, Brouwer *et al.* (2007) imply household WTP for primarily non-use values from improved freshwater quality of between EUR 19 and EUR 33.

Canada

36. Agricultural runoff is acknowledged to contribute to freshwater pollution and eutrophication in some locations, but coastal eutrophication is not currently a major problem. Moreover, industrial and municipal sources are more important around several of the Great Lakes and problem coastal areas. Water quality in rivers and lakes is generally good, but 18% of monitored sites are rated as “marginal” or “poor” in terms of aquatic ecosystem health. Similarly, drinking water quality is also generally good but bacterial and chemical contamination is an issue in over 1/3 of rural supplies.

37. Although national level valuation studies are apparently absent, Olewiler (2004) and McCandless *et al.* (2008) imply that altering agricultural practices could yield water quality value improvements of between CAD 28/ha (EUR 19/ha) and CAD 60/ha (EUR 41/ha) on a local scale. Similarly, for Novo Scotia alone, Wilson (2000) estimates that degraded water reduces recreational fishing and commercial shellfish values by CAD 8 million (EUR 5 million) and imposes water treatment costs of around CAD\$ 40 million (EUR 25 million), although agriculture’s share in these totals is not made explicit.

Chile

38. Farming has an acknowledged impact on water quality arising both from the intensity of chemical and nutrient applications but also changes in land use from (e.g.) forestry. Impacts include contaminating drinking water and eutrophication of lakes and coastal water that lowers recreational and fishing values. However, biophysical measurement of impacts is relatively scarce and actual valuations of costs incurred are not reported. Moreover, pollution from other sources such as aquaculture, heavy industry and municipal sewage are generally regarded as more pressing issues. Progress with general policies and investments addressing water quality issues has been made, and a need for research into the size and relative importance of agricultural impacts has been recognised if problems observed in other countries are to be avoided (Pizarro *et al.*, 2010).

39. No economic valuation studies relating specifically to agriculture and water quality were identified.

Czech Republic

40. Although greater attention has been paid to industrial and municipal pollution, agricultural influences on water quality are acknowledged. Bathing water quality is generally good with over 90% of sites meeting mandatory standards, and heavy metals are a more common contaminant of ground water than agricultural sources. Nevertheless, agriculture accounts for around 65% of nutrient loadings to the Danube River, causing surface water eutrophication problems and contributing to eutrophication of the Black Sea.

41. Melichar & Ščasný (2005) note a scarcity of valuation studies relating to water, but Czajkowski & Ščasný (2010) suggest a WTP for improvements to eutrophication status in case study lakes of EUR 31 – EUR 45 per household.

Denmark

42. Agriculture has an acknowledged impact on water quality. Policy measures have reduced nitrate loadings in recent decades but have been less successful for phosphates. Groundwater quality for drinking is generally good and treatment is typically restricted to oxygenation rather than removal of contaminants, but there are localized problems and public concern is rising over nitrates and pesticides. Curbs on industrial and municipal sources have improved river quality but many rivers and most lakes, particularly in intensive agricultural areas, still suffer from eutrophication. Some coastal areas are also affected by eutrophication and Denmark contributes to nutrient loadings into the Baltic Sea.

43. Hasler *et al.* (2008) note a scarcity of consistent information, but review a number of valuation studies. In particular, different studies offer estimates of the value of waterside amenity and some recreational activities. A comparison of remedial and preventative actions suggests a WTP for improved surface water quality of up to EUR 171 per household. Although current drinking water treatment costs are low, the WTP for naturally clean drinking water was estimated at up to EUR 269 per household..

Finland

44. Agricultural loadings of sediment and nutrients are acknowledged to contribute significantly to water quality degradation. This applies particularly to the coastal Gulf of Finland and the rest of the Baltic Sea, but also to some inland surface waters. Although large lakes and reservoirs are generally of good ecological status, smaller lakes and a high proportion of rivers are not. Such problems are typically associated with more intensive agricultural areas, meaning that they are more common in the south than the north. A high proportion of coastal sites are not of good quality, although agriculture is not solely responsible and neighbouring countries also pollute the Baltic Sea.

45. Although not explicitly separating agricultural and non-agricultural influences, Vesterinen & Pouta (2008) imply that improvements to inland surface water quality would deliver recreational benefits of EUR 75 million to EUR 227 million. Similarly, Kosenius (2010) suggests that reduced eutrophication of the Gulf of Finland could be valued at EUR 271 to EUR 448 per Finnish household. Ahtiainen (2009) estimates the water quality effects using a meta-regression analysis, which summarises the findings of existing valuation studies on the benefits of protecting the Baltic Sea (see also Huhtala *et al.*, 2009). The annual mean WTP per person range from EUR 40 to EUR 120. Artell (2010) assesses water quality value held in summer houses in Finland. Compared to a summer house lot with satisfactory, the middle category, water usability status, a lot in excellent status, the best category, commands a price premium of between 20 and 30% of the property price, or, compared to an average lot costing approximately 40 000, a premium of between EUR 5 600 and EUR 9 700. Agricultural effects would account for a proportion of all of these values.

France

46. Agricultural influences on water quality are acknowledged, particularly with respect to nitrate and pesticide contamination but also via abstraction effects. Around 20% of drinking water sources breach standards and eutrophication of surface and coastal waters is common. Less than half of surface waters are in good ecological condition and meeting tighter EU standards in 2015 is likely to be challenging.

47. Citing analysis undertaken in 2005/06 and updated in 2009/10, Bommelaer *et al.* (2010) report cost estimates for a range of impacts. For example, eutrophication of surface and coastal waters is estimated to cost between about EUR 70 million – EUR 1 billion whilst additional water treatment costs are estimated to lie between EUR 540 million – EUR 1.2 billion (approximately doubled if bottled water

usage is included). Aquamoney (2009) estimated a WTP of around EUR 40 per household to improve groundwater quality in Eastern France.

Germany

48. Agricultural influences on water quality are acknowledged, particularly with respect to nitrate leaching into groundwater and soil phosphate runoff into surface waters. Although both have reduced in recent decades, agricultural loadings have become relatively more significant as industrial and municipal point sources have been addressed. Coastal eutrophication of both the North and Baltic Seas is acknowledged, as is eutrophication of many lakes and rivers. Around 14% of surface waters are not in good ecological condition. Pesticide contamination of ground water is limited but nitrate concentrations are high in some areas.

49. No valuation studies were identified relating directly to agricultural influences on water quality. However, Meyerhoff & Dehnhardt (2007) estimate individual WTP for water quality benefits of EUR 12 from wetland restoration whilst Lienhoopm & Messner (2009) estimate household WTP of EUR 10 – EUR 16 for lake restoration in East Germany.

Greece

50. Despite some monitoring gaps, agricultural influences on water quality are acknowledged. These include pesticide and nitrate contamination as well as phosphates from soil erosion. In addition, irrigation usage has contributed to many aquifers being over-exploited and sea water intrusion is a problem in some coastal areas. Around 20% of groundwater sources have raised levels of pesticides and nitrates, although these are declining. Phosphate levels remain and eutrophication is an issue for some surface and coastal waters.

51. No valuation studies were identified relating directly to agricultural influences on water quality. However, Genius & Tsagarakis (2006) and Aquamoney (2009) report household WTP for improved water quality of EUR 60 and EUR 23 – EUR 277 respectively. Similarly, Jones *et al.* (2008) estimate household WTP for improved coastal water quality of around EUR 20.

Hungary

52. Although improving, water quality issues remain challenging in many areas. Over half of water bodies and rivers are possibly at risk of failing tighter EU standards from 2015. The same applies to around 40% of groundwater sites, mainly due to nitrate concentrations. Although industrial and municipal sources are present, agriculture is considered responsible for the majority of nutrient loadings to the Danube and the Black Sea.

53. Although environmental water accounts have been compiled, they relate to physical rather than monetary flows. However, Mourato (1998) estimated WTP of around USD 27 (EUR 25) for quality improvements to Lake Balaton and Aquamoney (2009) estimated household WTP of EUR 25 – EUR 53 for quality improvements in the Altaler Basin.

Iceland

54. Although monitoring efforts are being increased, agricultural water quality issues are not prominent with industrial and municipal sources more problematic. This largely reflects the limited spatial coverage of agriculture and relatively limited use of fertilizers and pesticides. Nevertheless, there is an awareness of the potential for localized pollution incidents and of more diffuse runoff and soil erosion problems from over-grazing. Water quality is generally good.

55. No valuation studies relating to water quality were identified.

Ireland

56. Agricultural influences on water quality are acknowledged, with bacterial, pesticides and nitrate contamination causing localized groundwater and drinking water problems and sediment and nutrient loadings causing eutrophication issues. Such problems vary spatially with nitrates being more of an issue in the South and South East and inland eutrophication a problem in the midlands. Over 90% of coastal bathing waters meet mandatory standards, but many inland surface waters and around 25% of rivers are in poorer condition.

57. Although environmental accounts have been constructed, monetary water values are not included. However, O'Leary *et al.* (2004) report WTP values of EUR 115 – EUR 249 per person for adjusting agricultural practices to achieve improved river and lake quality.

Italy

58. Eutrophication from industrial, municipal and agricultural sources has long been recognized as an issue. Many inland rivers and lakes are of a poor standard, as are some coastal regions – most notably the north Adriatic Sea. Over 90% of monitored coastal bathing waters meet mandatory and guide standards, but less than 50% of inland bathing waters do. Contamination problems are often exacerbated by excessive abstractions, including for agricultural irrigation. Meeting tighter EU standards is likely to be challenge.

59. Although environmental accounts have been constructed, monetary water values are not included. However, Aquamoney (2009) report household WTP estimates of EUR 62 – EUR 136 for improved water quality in the Po river basin. Raggi *et al.* (2007) suggest that agriculture accounts for 1/3 of pollution in the Po basin. Similarly, Travisi & Nijkamp (2008) estimate household WTP of EUR 23 for modest reductions in pesticide contamination.

Japan

60. Efforts over recent decades to address point-source pollution from industrial and municipal sources has greatly improved water quality in Japan. However, problems remain and whilst over 90% of rivers meet domestic standards, around 25% of coastal waters and lakes do not. Nitrates, pesticides and sediments from agricultural activities are acknowledged to be among the causes of these problems and monitoring and mitigation efforts have been improved. Moreover, the potential of paddy fields to mimic natural wetlands and filter excess nutrients is emphasized.

61. Although some progress has been made with environmental and economic accounting, agricultural impacts on water are not separated explicitly from those of other sectors and physical rather than monetary measures of water quality are used. In two older studies of freshwater eutrophication, Kitabatake (1982) estimates costs to aquaculture of JPY 1.5 million (EUR 6 110) to JPY 22 million (EUR 89 600) whilst Magaraa and Shoichi (1986) suggest that algal blooms can easily double water treatment costs, although neither study reports agricultural effects explicitly. Aizaki *et al.* (2006), Shiratanie *et al.* (2006) and MAFF (undated) all report significant net environmental benefits from agriculture. These include gains to water and soil quality from paddy fields, although Matsuno *et al.* (2006) note that this can depend on local circumstances and management practices.

Korea

62. Despite some recent improvements, around 1/3 of rivers fail to meet domestic quality standards and over 1/4 of lakes are eutrophic. Groundwater quality is higher, but 6% still fails domestic standards.

Coastal eutrophication is a localized problem for fisheries and aquaculture. Diffuse pollution, including from agriculture, is acknowledged as an issue and is being addressed by specific policy measures. Increases in livestock numbers and associated imported animal feed are a particular concern. However, the potential of paddy fields to mimic natural wetlands and improve water quality is emphasized.

63. Although some progress has been made with environmental and economic accounting, agricultural impacts on water are not separated explicitly from those of other sectors and physical rather than monetary measures of water quality are used. However, Kim *et al.* (2000) suggest agricultural eutrophication costs of around KRW 155 billion (EUR 123 million), mostly attributable to livestock. By contrast, Dong-Kyun (undated) cites the total amount of contaminated water which is purified in paddy fields each year as an estimated 704 mt with a value of USD 1.65 billion (EUR 1.55 billion).

Luxembourg

64. Groundwater quality is generally acceptable, but nitrate levels can be excessive in some rural areas. The vast majority of watercourses are of a satisfactory standard, but less than half are of good ecological or bathing quality and may struggle to meet tighter EU standards from 2015. Mitigation efforts to reduce agricultural pollution are in place, but nutrient and pesticide application rates and implied surpluses remain relatively high. Although landlocked, Luxembourg is a signatory to the convention on reducing agricultural loadings to the North Atlantic.

65. Despite some progress with environmental and economic water accounts, neither estimates of treatment costs nor degradation costs were identified.

Mexico

66. Agriculture is the dominant user of both groundwater and surface water. Irrigation is widespread and has caused salination and drainage problems in some areas. Many groundwater sources are over-exploited, leading to low river flows that concentrate pollution levels and degrade ecological conditions. Around 25% of surface water is considered contaminated or highly contaminated. Monitoring of water quality is improving, but nitrate and pesticide levels cause less concern than bacterial contamination which has promoted significant investment in water treatment and infrastructure to address industrial and municipal pollution sources. Mexico shares major watersheds with the Belize, Guatemala and the USA, meaning that some effects are transboundary.

67. Valuation studies are apparently scarce, but Vásquez *et al.* (2009) estimate that Mexican citizens would be willing to pay up to 7.6% more for cleaner drinking water. It is difficult to relate this figure to agriculture specifically. By contrast, Ojeda *et al.* (2008) explore the value of restoring environmental conditions through improving surface water flow and quality in a river affected by agricultural irrigation. They estimate a WTP for quality improvement of MXN 876 (EUR 58) per household.

Netherlands

68. Agriculture is estimated to account for around 75% of nutrient loadings to inland and coastal waters. Although there has been an improvement in recent decades, some water quality issues remain. Some areas are below sea-level and more generally the watertable is close to the surface. Although surface, ground and coastal water quality has improved, tighter EU standards represent a challenge. Four major European rivers end in Dutch coastal waters, meaning that surface and coastal water quality is also highly dependent on upstream as well as domestic activities.

69. Ligtoet *et al.* (2008) identify potential benefits from improved water quality, but cite a scarcity of relevant valuation studies as a barrier to quantifying such benefits. Similarly, water quality is not

monetized in the environmental economic accounts. However, Joosten *et al.* (1998) estimate treatment of drinking water to remove nitrates to cost USD 35 million (EUR 31 million – USD 70 million (EUR 62 million) and, whilst noting numerous caveats, Howarth *et al.* (2001) suggested total damage costs arising from nitrogen and phosphorus might amount to EUR 403 million to EUR 754 million by 2010. More recently, again noting caveats, Brouwer *et al.* (2007) estimate household WTP of EUR 24 to 43 for improvements in freshwater quality.

New Zealand

70. Point sources of water pollution have largely been addressed, leaving diffuse sources such as agriculture as the dominant concern. This has been exacerbated by increased use of fertilizers and higher livestock densities, including a switch from sheep into dairy cattle. Surface water quality is generally good, but is highly spatially variable with upper sections of river catchments cleaner than lower sections. Similarly, most ground water sources are of good quality but nitrate concentrations are an issue in some locations. About 5% of drinking water sites breach domestic standards. Eutrophication is a problem in some lakes and reservoirs and around 10% of freshwater bathing sites regularly fail domestic recreational standards, but only 1% of coastal sites do so.

71. Although water accounts are compiled, these are for physical rather than monetary flows and in any case do not feature quality adjustments. However, water quality impacts are acknowledged and in a several related studies, Baskaran *et al.* (2009a & b) and Takatsuka *et al.* (2009) estimate household WTP for reduced nitrate pollution of NZD 11 (EUR 5) – NZD 79 (EUR 38).

Norway

72. Agricultural influences on water quality are acknowledged, particularly with respect to sediment and phosphate loadings from soil erosion plus nitrates from fertilizer applications. These contribute to eutrophication issues in some inland lakes and coastal areas, particularly in the south. However, surface water quality is more commonly degraded by acidification unrelated to farming activities. Similarly, although agricultural loadings to coastal waters are significant, they are exceeded by those from aquaculture, especially with respect to phosphates. Nonetheless, attention is being paid to mitigating agricultural sources.

73. Although Norway has compiled environmental economic accounts for over 30 years, explicit separation of agricultural influences on water quality from other sources has been hindered by data issues. However, Navrud (2001) suggests improved recreational fishing associated with improved water quality would be valued at EUR 80 million to EUR 154 million. Similarly, Aquamoney (2009) suggest household WTP for water quality improvements in selected lakes of between NOK 1070 (EUR 129) and NOK 2000 (EUR 242). In both cases a proportion of the value will be attributable to reduced agricultural influences.

Poland

74. A legacy of severe pollution from heavy industry has overshadowed concerns about agricultural impacts on water quality. Moreover, reductions in farming intensity since the 1990s have further reduced perceived pressures. Nevertheless, agricultural loadings of nutrients to surface and groundwaters are acknowledged to occur and are being targeted by policy measures. The relative significance of agricultural sources is not identified explicitly, although eutrophication of some lakes and reservoirs is reported along with excessive nitrate concentrations in some groundwater sources. Polish agricultural nutrient loadings add to eutrophication pressures in the Baltic Sea.

75. Howarth *et al.* (2001) cite studies from the mid 1990s that estimated WTP to improve water quality in the Baltic of EUR 28 to EUR 200 per Polish citizen. Czajkowski & Ščasný (2010) suggest a WTP for improvements to eutrophication status in case study lakes of EUR 13 – EUR 17 per household.

Portugal

76. Agriculture is acknowledged to influence water quality through nutrient and pesticide contamination. This is often exacerbated during summer months when agricultural abstractions can lead to reduced flow levels. However, pollution issues are highly variable spatially. Freshwater eutrophication of rivers, lakes and reservoirs is commonplace. Around 35% of surface waters are not of a good standard and although over 90% of inland waters meet mandatory bathing standards, only 42% meet guide standards. Coastal eutrophication is not a significant issue with around 90% meeting guide standards and 99% mandatory standards.

77. No economic valuation studies relating specifically to agriculture and water quality were identified. However, Machado & Mourato (2002) estimated WTP for cleaner coastal bathing water at selected locations. This was not restricted to agricultural influences, but suggested total amenity and recreational costs of water degradation of between USD 10 million (EUR 11 million) and USD 51 million (EUR 57 million) with health costs raising this to around USD 80 million (EUR 89 million) for the Estoril Coast near Lisbon.

Slovak Republic

78. Agricultural influences on water quality are acknowledged, particularly for nitrate and phosphate loadings. However, although some local problems persist, significant reductions in fertilizer applications and livestock numbers since the 1990s have generally reduced these pressures. Over 90% of surface waters and groundwater sources meet current mandatory standards, although meeting tighter standards may be challenging. Industrial pollution is more problematic on the East, agricultural pollution in the West.

79. No valuation studies relating to agriculture and water quality were identified.

Slovenia

80. Almost all drinking water is taken from groundwater sources and these are of a generally good quality, but contamination from industry and agriculture is an issue. Industrial pollution of surface waters had diminished, possibly due to changes in neighbouring countries, but agricultural loadings of nitrate and phosphate remain high. Over 25% of surface waters are not in good condition. Several river catchments are shared with neighbouring countries and Slovenian agriculture contributes to nutrient loadings into the Adriatic and Black Seas.

81. No valuation studies relating to agriculture and water quality were identified.

Spain

82. Agriculture is the major user of both surface and ground water, with irrigation being widespread. Nutrient surpluses are high and increasing. Nitrate, phosphate and pesticide contamination of surface water is acknowledged as an issue. Many groundwater sources are over-exploited and quality is degraded in some areas. The nature of the Atlantic coastline limits marine eutrophication but localized problems do occur on the Mediterranean coast.

83. Although satellite accounts for water are available, they report physical rather than monetary flows. However, Sánchez-Chóliz & Duarte (2005) and Morilla *et al.* (2007) use the accounts to explore

economy-wide pollution effects and imply that agricultural production is inefficient in its use of water. Hernandez-Sancho *et al.* (2010) estimate general improvements in water quality from reduced nitrate and phosphate levels to be worth around EUR 150 million.

Sweden

84. Farming practices, particularly the application of fertilisers but also the (often historical) draining of land and clearance of natural vegetation are acknowledged to have led to degradation of water quality. Although problems are noted in relation to freshwater, particular concern has been expressed about eutrophication in the Baltic Sea. Here, agriculture's share of Swedish nutrient loadings is estimated to be between 50% and 65%, although this varies year to year and is also affected by loadings from neighbouring countries. Efforts to improve coastal water quality are being made, but problems persist and impacts are felt in various ways including on commercial fishing, recreational water sports, visual amenity and ecosystem health.

85. Various economic valuations have been conducted, mainly focused on coastal rather than freshwater eutrophication although Ahlroth (2007) suggests the latter may impose costs of around EUR 860 million. Huhtala *et al.* (2009) conduct a meta-analysis of over 40 previous studies and suggest annual Swedish social costs of between EUR 492 million and EUR 1 466 million for Baltic eutrophication from all sources. The range reflects differences arising from different valuation techniques and assumptions. Similar, but less severe, impacts on Sweden's other coast means that such figures are likely to be under-estimates of total marine eutrophication costs. Aggregate figures for removing agricultural contaminants from drinking water are not readily available but reported incidences of nitrate or pesticide levels breaching standards are relatively rare and declining and current expenditure on all water treatment is around EUR 20 million against total supply costs of EUR 600 million.

Switzerland

86. The quality of most ground and surface water is good but some local problems do occur, particularly with respect to nitrate and pesticides levels in intensive agriculture areas. Three-quarters of nitrate leaching into groundwater is estimated to be from farmland, leading to some eutrophication problems and breaches of drinking water standards. Mitigation policies are in place, but have been more successful for phosphates than nitrates.

87. National water treatment costs are low at around CHF 130 million (EUR 84 million) (Vermont, 2005) although total infrastructure and operational costs for water supplies are around CHF 1.5 billion (EUR 947 million) (Moser *et al.*, 2009). Pillet *et al.* (2000) estimated total water pollution costs attributable to agriculture at approaching CHF 1 billion (EUR 608 million) in 1998, but declining steeply thereafter.

Turkey

88. Approximately 5.3 million ha are irrigated, and agriculture is estimated to account for about 75% of total water consumption. Surface water quality in most agricultural catchments is degraded to some extent and groundwater contamination from nutrients and pesticides occurs locally, as do salinity problems in some cases. Coastal pollution, particularly of the Black Sea, is problematic, although sectors other than agriculture and neighbouring countries also contribute significantly to this situation.

89. Cost estimates for drinking and waste water treatments are dominated by a need to address industrial and municipal sources. However, Dadaser-Celika *et al.* (2009) suggest that wetland degradation due to irrigation abstractions for around 35 000 ha in the Devali Basin imposes subsequent treatment costs of around USD 0.3 million (EUR 0.2 million). Similarly, Atis (2006) identifies significant costs to cotton

production from salinisation and water-logging due to poor irrigation practices in the Gediz delta. Impacts on recreational values are acknowledged, but empirical studies are scarce.

United Kingdom

90. Widespread agricultural influences on water quality are acknowledged and various policy efforts to mitigate negative impacts on drinking water and ecological conditions are in place. The majority of nitrate loadings and almost half of phosphate loadings into surface and coastal waters are attributed to agriculture, with freshwater eutrophication common and elevated nitrate concentrations found in some groundwater and drinking water sources.

91. Numerous valuation studies have been conducted, with formal Environmental Accounts for Agriculture offering a recent and useful collation mechanism (Box 2). Hence Jacobs (2008) report that the removal of agricultural contaminants from drinking water incurs costs of GBP 129 million (EUR 190 million) and degradation of rivers, lakes and estuaries imposes social costs of over GBP 100 million (EUR 151 million). Such estimates are broadly in-line with previous figures, but are acknowledged to probably be under-estimates due to incomplete geographical coverage and on-going refinement of scientific understanding.

Box 2. Water quality costs as reported in the UK Environmental Accounts for Agriculture (2007)

Category	Description	Value (GBP) Million	Comments
Rivers	Rivers of less than "good" quality due to agricultural diffuse pollution	62 (EUR 91)	Likely to be under-estimate in light of more recent work
Lakes	Eutrophication in lakes due to agricultural diffuse pollution	27 (EUR 40)	Under-estimate in light of more recent work and lack of spatial coverage.
Bathing waters	Bathing waters failing to meet FIO standards	11 (EUR 16)	Under-estimate in light of more recent work and lack of data on marine eutrophication.
Estuaries	Estuaries of less than "good" quality due to agricultural diffuse pollution	3 (EUR 4)	Likely to be under-estimate in light of more recent work
Drinking water	Removal of contaminants	129 (EUR 190)	Uncertainty due to data gaps and lack of spatial coverage.

Source: derived from Tables 30/31, pages 104/105 in Jacobs (2008).

United States of America

92. Although varying regionally in nature and severity, agricultural influences on water quality are acknowledged. In particular, sediment loadings, bacterial contamination and chemical run-off all contribute to problems in various locations. Indeed agriculture is estimated to account for around 60% of river pollution, 30% of lake pollution and 15% of estuarine and coastal pollution. For the latter, for example, agriculture accounts for around 75% of nitrogen and 50% of phosphate loadings into the Gulf of Mexico and into Chesapeake Bay.

93. A large number of valuation studies have been conducted, encompassing different impacts and/or different regions. At the national level, Dodds *et al.* (2009) examined freshwater eutrophication and estimated total costs of USD 2.2 billion (EUR 1.5 billion), of which USD 813 million (EUR 556 million)

were attributed to drinking water treatment and the remainder was dominated by effects on recreational and waterside property values. Similarly, Tegtmeier & Duffy (2004) estimated national drinking water treatment costs of USD 419 million (EUR 371 million) whilst Pimentel (2005) estimated the costs of pesticide contamination of groundwater to be USD 2 billion (EUR 1.6 billion). Anderson *et al.* (2000) report estimated national costs arising from marine algal blooms of USD 34 million (EUR 32 million) to USD 49 million (EUR 46 million). Bockstael *et al.* (1988) estimate water quality improvements in Chesapeake Bay to range up to US USD 100 million (1984 values) with Morgan & Owens (2001) updating this to USD 358 million – USD 1.8 billion (1996 values).

5. Further research requirements and some concluding observations

94. The preceding section identified water quality impacts of agriculture as reported across all OECD members. In some cases, impacts were reported purely in biophysical terms, in most cases they were also reported in monetary terms. Many studies were unclear about the precise category of costs being estimated, but eutrophication effects on amenity, recreational and ecosystem values were reported most commonly and tended to have higher values than other impacts. Treatment costs were less readily available and explicit valuation of health costs was rare. Treatment costs can provide a fairly reliable source of data compared to other cost estimates of pollution (e.g. estimates of non-market costs). However, calculation of treatment costs depends on: the sources of pollution, and thus may over estimate specific costs related to agriculture: and the stringency of health and environmental objectives and policies across countries. Comparisons over time are difficult to make, with costs apparently rising in some countries as agricultural intensification and/or regulatory standards increased but falling in others as resource allocations and technologies adjusted.

95. The variation in figures reflects a range of causes including differences in national situations in terms of regulatory standards, monitoring and baseline water quality but also differences in the coverage and methodology of cited valuation studies. For example, studies varied in terms of the degree of degradation or improvement they considered and in how specific they were to agriculture. Equally, inclusion of more impacts tended to increase overall costs with, in particular, inclusion of marine eutrophication sometimes leading to significantly higher cost estimates. Consequently, comparisons between countries are likely to be misleading.

96. Importantly, some studies reported total costs whilst others reported marginal costs. From an economic policy perspective the latter are of greater interest since it is *changes* in water quality and how such changes might be achieved and valued that are of most relevance. However, cross-study and cross-country comparisons are difficult if not impossible since the magnitude of change in water quality (e.g. poor to good, good to excellent) investigated varies considerably across studies.

97. That the reported impacts related overwhelmingly to degradation rather than improvement of water quality through agricultural practices reflects the general relationship between commodity production and pollution. Specifically, with the exception of paddy fields, higher water quality is not generally produced jointly with agricultural outputs. Of course, the relationship is not linear and it is perfectly possible to adjust management practices to reduce negative impacts on water quality. For example through establishing farm wetlands, improving on-farm nutrient management or lowering the intensity of grazing. The degree to which such adjustments impose on-farm costs varies, with some actually improving farm profitability but many reducing it.

98. However, interpretation of water quality improvements delivered by on-farm mitigation activities as an agricultural benefit depends on both the degree of jointness between commodity production and water quality and on the reference baseline level of water quality. For example, arguably, mitigation activities that displace agricultural production may be land-based but are not agricultural per se. Equally, improvement from a current level of degradation may be viewed as a benefit delivered by agriculture or simply as removal of an undesirable agricultural impact on a more pristine water system. Discussion of such competing perspectives is beyond the scope of this paper, but is clearly relevant to policy choices and the distribution of mitigation costs across farmers, other industries, taxpayers and consumers.

99. This short survey exercise also revealed that the existing evidence base is fragmented, incomplete and of variable quality. That is, although numerous relevant studies have been conducted in many countries, their results are rarely collated consistently at a national level and individual studies vary greatly in terms of their focus and sophistication. This suggests several (related) themes requiring further work.

Underpinning science

100. Economic valuation cannot be attempted without some prior information on biophysical impacts. Yet, although the types of water quality externalities associated with agricultural activities may be identified relatively easily, scientific understanding and measurement of the underlying biophysical relationships is often imperfect. For example, simply distinguishing between agricultural and non-agricultural sources of nutrients is often difficult and the consequences of nutrient loadings depend upon volumes of water as well of the nutrients themselves. Such imperfect understanding reflects both a lack of monitoring data in some instances but also that biophysical relationships are highly complex. For example, pollutants from a given agricultural activity can vary across different locations and time periods and can be difficult to trace as they pass through, and are transformed, by hydrological systems.

101. This points to a continuing need for scientific research into the underlying processes but also, at least in some countries, better monitoring of conditions. Both tasks are made more complicated by the typically transboundary nature of water pollution, with river catchments and marine areas often encompassing more than one country, and by the time-lags between cause-and-effect in complex hydrological systems. Hence international efforts are needed in some cases to co-ordinate monitoring and modelling activities in order to better inform joint policy responses over time.

Non-market valuation

102. Consensus on how to conceptualize and value changes to water quality does not yet exist. Some commentators disagree with the premise of monetary valuation, whilst others accept the premise of non-market valuation but are critical of the design and interpretation of particular valuation techniques. This applies particularly to the aggregation or transfer of results between locations and to differences between public and scientific perceptions of quality where the former's typical reliance on visual condition may be at odds with alternative indicators of chemical or ecological purity. The time-lags involved in some diffuse pollution processes add a further complication by necessitating some form of discounting to compare costs and benefits accruing at different rates over a longer period of time.

103. Such issues have long been acknowledged (Turner, 1977; Vatn & Bromley, 1994) and may be reduced if it is stressed that policy and resource allocation decisions must and will be taken, that they are likely to be improved by access to information and that valuation estimates are but one source of information on the nature and scale of environmental issues.⁶ There is clearly a need to continue arguing this case. With respect to technical design, continual improvement is being sought through academic research into the framing and implementation of valuation studies and into how "benefit transfer" can be used to draw wider inferences from limited studies. For example, recent work related to the Water Framework Directive (WFD) in the European Union has suggested guidelines for standardizing techniques and using more spatially-explicit data to account for heterogeneity in both environmental conditions but also the values held by different sections of society (Bateman *et al.*, 2009). Continuation of such research effort is merited.

Environmental Accounts

104. Summarizing impact estimates at a national level through environmental accounts provides a convenient means of reporting water quality externalities alongside more conventional economic statistics. By avoiding the need to collate individual results in an ad hoc manner and by systematically placing impact estimates in context, such an approach should facilitate clearer and more routine recognition of the scale of problems requiring policy attention.

6. See <http://cylkene.uwa.edu.au/~dpannell/pd/pd0175.htm> for a nice discussion of some points related to this.

105. Several countries already have environmental accounts. However, many do not and of those that do, not all express water quality impacts in monetary terms. Hence there is scope for further work to develop environmental accounts.

Collation & aggregation

106. Assembling national-level estimates, however, is not necessarily straightforward since valuation studies often focus on a sub-national scale and/or on a sub-set of water quality impacts. For example, many studies are conducted at a catchment scale and aggregation from this to a national scale requires additional data and/or assumptions about how representative local results are. Equally, aggregation across different types of impact can be problematic if not all impacts have been valued and/or if different valuation techniques have been used in different studies. In addition, whilst on-line databases and previous meta-analysis of valuation studies are extremely helpful, collating results from individual studies remains impaired by the practicalities of searching across varied and scattered sources and by the variable degree of methodological detail reported in different studies.

107. Such aggregation difficulties are encountered regardless of whether the task is attempted in an ad hoc manner or more routinely for environmental accounting purposes. However, the discipline and repetition of environmental accounting is likely to improve the consistency of aggregation process by imposing some standardization to allow comparisons and refinement over time. Hence there is scope for further work on clarifying both how aggregation may be attempted and in commissioning studies to address valuation gaps. For example, Hunt & Ferguson (2010) note that health impacts of water pollution are less well researched than for air pollution. Indeed, perhaps reflecting perceived policy priorities, it is notable that air pollution and especially greenhouse gas emissions from agriculture are generally addressed more prominently and comprehensively than water issues (Olmstead, 2010).

Diminishing marginal returns

108. Notwithstanding their endorsement above, further efforts to improve the evidence base are not costless. That is, improved monitoring data, scientific understanding and valuation accuracy are desirable but all incur effort. Moreover, insights gained will typically be subject to diminishing marginal returns. Hence there is a trade-off to be made between striving for a possibly unattainable level of information necessary to achieve an optimal resource allocation and accepting a level of information sufficient to achieve a desirable direction of travel towards an improved position. That is, pragmatically, even partial and imperfect valuation estimates may still be sufficient to demonstrate the need for change when viewed alongside estimates of positive externality values and the mitigation potential of agricultural activities. Importantly, the need for accuracy may differ between national-level strategic decisions and regional-level implementation decisions. For example, relatively crude national figures may be sufficient to shape overall policy directions but more accurate figures may be needed to guide practical (marginal) design issues for individual catchments and negotiations between local stakeholder groups.

Some concluding observations

109. That degraded water quality imposes costs on society is generally accepted. Point sources of pollution, such as sewage works or factories, are highly visible and are often subject to early policy interventions to mitigate their negative effects. By contrast, diffuse sources of pollution, such as agriculture, are less easily observed and often remain relatively free of relevant policy interventions.

110. This difference in treatment partly reflects uncertainties about complex diffuse processes. For example, agricultural effects vary both geographically and temporally and vary with both the level of pollutants emitted and the volume of water diverted. Yet the difference in treatment also often reflects

policy priorities relating to agricultural production and farming income plus the historical tendency for property rights to favour land managers in terms of water usage. The latter point is important since it sets the baseline or reference point against which reductions in pollution are viewed under the “polluter pays principle”.

111. Yet agricultural activities clearly do influence water quality in terms of emitting contaminants and altering water levels and this affects society in a number of ways. Whilst the valuation figures reported here are partial and almost certainly contain inaccuracies, they do confirm the existence of and convey a sense of the scale of such impacts across OECD countries. Moreover, in most cases, they are acknowledged as probably being under-estimates since they do not encompass all impact categories. As such, whilst more accurate figures would be desirable, the figures presented may be sufficient to demonstrate the need for policy interventions to correct resource misallocation even without identifying an optimal solution.

112. How this is translated into policy responses depends on a number of factors. For example, whilst it may be cheaper to reduce agricultural pollution at source than to remove contaminants from drinking water at a later stage, doing so may need to work with existing or legacy policy support measures that inadvertently encourage polluting activities. Reconciling such policy differences may not be easy and the distribution of costs across, for example, farmers, taxpayers and water company customers may be politically contentious. Scientific uncertainty in attributing cause-and-effect when sources and manifestation of pollution can be separated by considerable physical distance and time-lags further complicates policy decisions.

113. Equally, presumed property rights may lead to policy incentives rather than regulatory requirements being applied to encourage the adoption of mitigation measures. For example, reductions in agricultural pollution through the use of buffer strips or farm wetlands can be interpreted as delivering water quality benefits that merit reward under the “provider gets principle”. By contrast, failure to mitigate pollution through adopting appropriate farm practices could be penalized via regulatory controls under the “polluter pays principle”.

114. To conclude, identifying and estimating the significance of agriculture’s impact on water quality is of relevance to policy makers seeking to promote sustainable agricultural and wider economic development. A failure to account for externality effects leads to a misallocation of resources, to an inappropriate mix of land uses and inappropriate management of individual parcels of land.

115. Whilst detailed policy issues are beyond the scope of this paper, as are more detailed discussions of the technical aspects of improving valuation figures, the externality effects identified here and the reported illustrative valuations for them across OECD countries are hopefully indicative of the nature and scale of the issues remaining to be addressed.

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