Chapter 2

Agriculture and water quality: Sources, trends, outlook and monitoring

The impact of agriculture on water quality is either stable or deteriorating, with few cases where significant improvements are reported across OECD from the mid-2000s to 2010. While the current situation varies within and across OECD countries, agriculture is often the main source of water pollution. Achieving further reductions is a challenge for policy makers, especially as a major part of agricultural water pollution is from diffuse sources. The outlook over the next ten years for agriculture and water quality suggests that the growth and intensification of agricultural production could further heighten regional pressures on water systems in some countries. But whatever the projections hold for the future, the task of achieving water quality objectives in agriculture will become more difficult in the coming years as a result of climate change, although this is a poorly understood and researched aspect of climate change science to date.

2.1 Sources of water pollution from agriculture

Agriculture has had considerable success in increasing production to meet the growing food, feed, fibre and fuel needs of the global population. The expansion of agricultural production has been, in part, made possible through greater use of nutrients, pesticides and intensification of crop and livestock production systems, including irrigation. Farming systems, however, have not been fully efficient in their use of farm inputs and intensification has led to degraded fragile soils, removal of vegetation from land, increased land drainage, and other changes altering the natural environment.

These changes, combined with a great range of landscapes from mountains to floodplains, climates, rainfall patterns, soil types, and vegetative cover, have led to varying exports of nutrients, pesticides, soils and other pollutants from agriculture into water systems (Table 2.1). The pollutants are transported into surface water and groundwater through various processes including in dissolved form (leaching), pollutants attached to eroding soil sediments (runoff) and gaseous release (volatilisation) which may get deposited into water, such as from manure and pesticides (Figures 2.1 and 2.2). Sub-surface field drainage and irrigated agriculture can also heighten pollutant releases into water.

This has mainly resulted in water eutrophication, soil siltation, and chemical deterioration of water (e.g. from nutrients, pesticides, salts, pharmaceuticals and chemical farm wastes). Under certain farm management practices and systems, however, agriculture can be beneficial to water quality, or cause little impact on water systems, as previously discussed. Elevated levels of pollutants from agriculture have damaging effects on the following (Table 2.1; Chapter 3).

- *Environment*, this includes not only aquatic ecosystems (e.g. from wetland to marine ecosystems) but also fauna dependent on the viability of these ecosystems.
- *Agriculture fisheries and other commercial users*, both fresh and marine water fisheries, and other commercial water uses.
- *Non-consumptive values of water systems*; mainly recreational uses (e.g. swimming), visual (waterscapes), and social values (e.g. spiritual).
- *Human health*, mainly through contaminants in drinking water and the quality of bathing water.

Table 2.1. Sources of water pollution from agricultural activities[1]

Pollutant	Key water quality issue related to pollutant	Main agricultural activities that are the source of the pollutant
– Nutrients mainly nitrates and phosphates)	– Eutrophication and impairment of drinking water mainly harmful to aquatic life, but also human health in some cases	– Agricultural production (runoff of excess nitrates and phosphates from fertilisers and animal manure into water)
– Toxic contaminants (largely heavy metals, pesticides)	– Harmful to aquatic life and impairs drinking water (contamination of water)	– Spreading sewage sludge on agricultural land (heavy metals) and plant protection (pesticides)
– Soil sediments	– Harmful to aquatic life and water transport ystems (turbidity of water)	– Inappropriate soil conservation practices (wind and water soil erosion)
– Organic matter	– Harmful to aquatic life (deoxygenation of water)	– Manure-spreading on livestock farms
– Acid substances	– Harmful to aquatic life (acidification of water)	– Livestock production (ammonia volatilisation)
– Biological contaminants	– Impairs drinking water (pathogenic bacteria and viruses) and bathing water	– Faecal discharge from livestock into water
– Mineral salts	– Impairs drinking water, the use of water for irrigation, and aquatic life (salinisation of water)	– Inappropriate land use (clearing of perennial vegetation and irrigation practices)

1. While agriculture is an important source of the pollutants described in this table, other sources can also contribute to these pollutants, e.g. pesticides and fertilisers from urban uses.

Figure 2.1. Nutrients in water: A schematic diagram of pathways from agricultural use

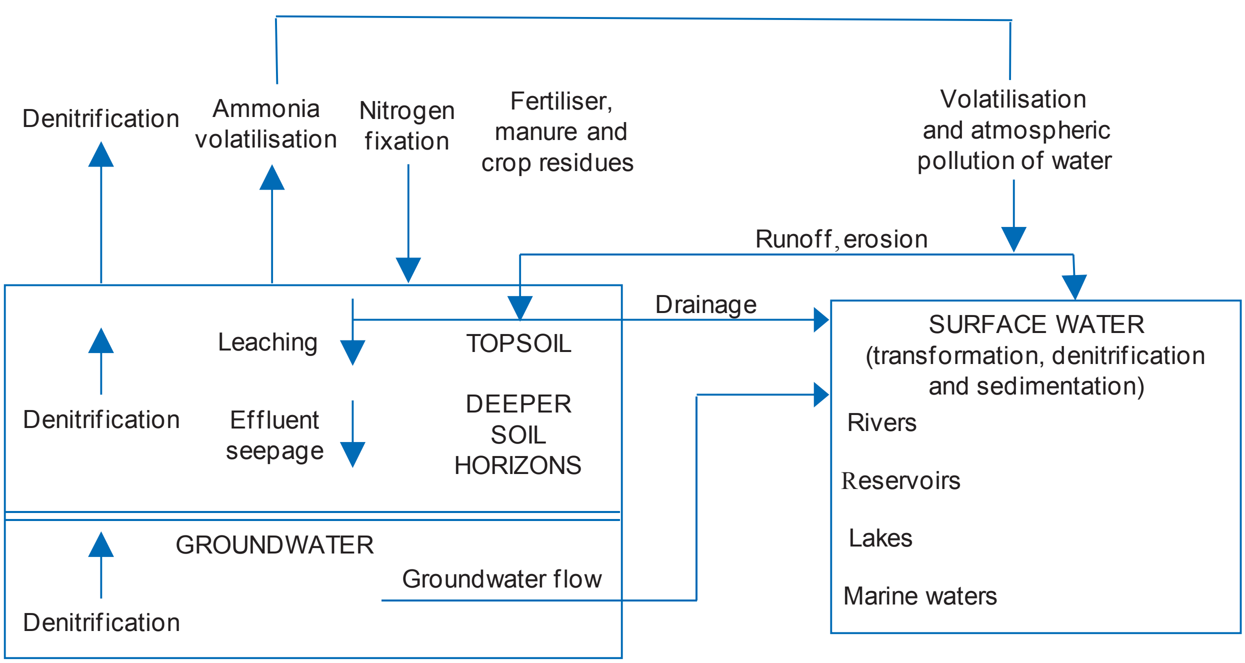
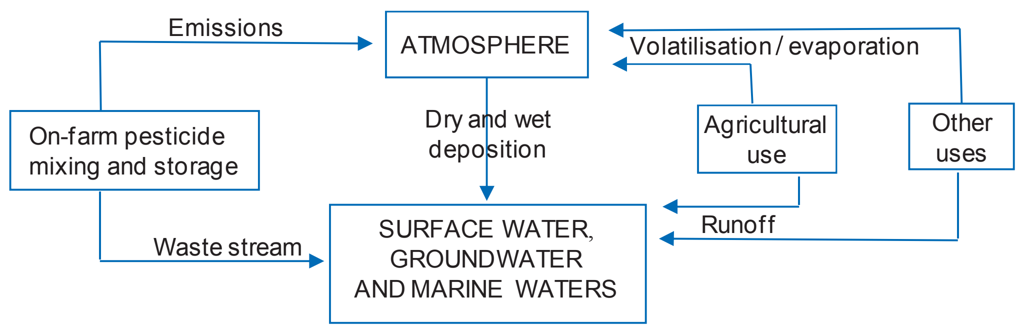


Figure 2.2. Pesticides in water: A schematic diagram of pathways from agricultural use



2.2 The contribution of agriculture as a source of water pollution

It is important to recognise that while agriculture contributes to pollution of water systems it is not the only source. Natural, urban and industrial sources of pollution of water systems continue, through runoff, including contaminants commonly associated with agriculture, such as urban use of pesticides, soil sediments from natural erosion and construction sites, and atmospheric pollution of water from industry (Farzin and Grogan, 2008; Wittmer *et al.*, 2011). Agricultural activities will usually involve some lost of contaminants, as it is technically impossible to achieve zero pollution in most situations. Even in pristine water environments natural sources (e.g. soil minerals) can cause changes in the physical, chemical and biological characteristics of water. Rather the challenge in agriculture is to seek ways to increase production while minimising farm contaminant lost and its subsequent damage to water quality (Galloway *et al.*, 2008).

Background (or natural) loss of nitrogen is usually small compared with human induced forms of nitrogen loss to water systems, and is typically estimated at around 1-2 kg/ha, derived from nitrogen fixing organisms, lightning and other sources (Dubrovsky *et al.*, 2010; European Environment Agency, 2005). This background loss of nitrogen does not reflect a reference condition, because many areas across OECD countries are subject to substantial atmospheric depositions of ammonia and nitrous oxide. For phosphorus the background loss is usually considered to be about 0.1 kg/ha, and occurrence will mainly depend on underlying geological conditions in sediment and rocks (Dubrovsky *et al.,* 2010; European Environment Agency, 2005).

Even so, agriculture is a significant source of nitrogen, phosphorus, pesticides in surface water, groundwater and marine waters for most OECD countries. Agriculture is also the main contributor to the siltation of surface water from eroded soils (European Environment Agency, 2005; OECD, 2008a).

For many countries the share of agriculture in the total pollution of surface water by ***nitrates*** is over 40% (OECD, 2008a). Evidence of the contribution of agriculture in groundwater pollution is limited, but some information suggests it may be lower than for rivers and lakes but increasing. Agriculture's contribution of nitrogen loadings into estuarine and coastal water is also above 40% for many countries, and often reported as the main cause of eutrophication (OECD, 2008a). But the share of agricultural nitrates in surface and coastal waters can reveal significant fluctuations depending on seasonal and annual river flows.

In most cases, agriculture's contribution of ***phosphorus*** to water bodies is lower than for nitrates, mainly because households and industry tend to be the most significant source (European Environment Agency, 2005; OECD, 2008a). Agriculture, however, is a major source of phosphorus in surface water and coastal waters accounting for a share of over 40% in some OECD countries (OECD, 2008a).

While agriculture is usually the main source of ***pesticide*** pollution in water systems, recent research points to the need to give more attention to other sources of pesticide pollution when formulating mitigation strategies, such as forestry, urban gardens, and golf courses (Wittmer *et al.*, 2011). In the **United States**, for example, agriculture accounts for 75% of pesticide use, and about 65-70% in **Belgium** (OECD, 2008a).

Soil erosion can originate from a number of economic activities (e.g. forestry, construction, off-road vehicle use) and natural events (e.g. fire, flooding and droughts). In many cases, however, the major share of soil erosion is accounted for by agricultural activities. In general, cultivated arable and permanent crops (e.g. orchards) are more susceptible to higher levels of soil erosion compared to pasture areas. This is because land under pasture is usually covered with vegetative growth all year. In some situations, however, where there is a lack of natural vegetative cover, agriculture crops and pasture can help reduce erosion.

Agriculture can also be subject to pollution itself from other sources. Irrigated agriculture is particularly prone to this problem, where it draws water either polluted by other agricultural producers upstream or where it has been polluted upstream by urban and industrial sources. In **Chile**, for example, the Fondo Quimavida irrigation district in central Chile, is downstream from the city of Rancagua which is depositing untreated sewage water into the river system used to supply the irrigation district and has led to microbiological (e.g. faecal coliforms) deterioration of the water used by the irrigators.[1] Equally, if properly treated wastewater can provide an asset for irrigated agriculture, as recent experience in **Israel** has shown (Box 1.2).

2.3 Overall trends of the impacts of agriculture on water quality

The scale of the impairment of water systems due to agriculture described in this section needs to be placed in some perspective. Across most regions in OECD countries drinking water quality is high and there is limited health risks linked to impaired drinking water, although water treatment costs can be high to remove pollutants (Chapter 4). In some rural areas of OECD countries, however, which are not connected to treated water infrastructure systems, health concerns can be more significant, especially where water is draw from wells.

Agriculture is also not the only source of contamination of water systems, as discussed previously. Eutrophication of water systems due to agriculture is becoming widespread and significant, leading to damage to ecosystems, commercial fisheries and detrimental to recreational and other social benefits attached to water systems. There is also growing unease with emerging contaminant pollution of water from agriculture, raising concerns for both human health and the environment. These issues are discussed in more detail at the end of this chapter.

The OECD (2008a) survey of the overall impacts of agriculture on water systems over the period from 1990 to the mid-2000s across OECD countries concluded that the:

- Pressure of agriculture on water quality in rivers, lakes, groundwater and coastal waters eased since the early 1990s due to the decline in nutrient surpluses and pesticide use, and improvements made in soil conservation leading to a reduction in soil erosion rates.
- Nearly a half of OECD countries recorded that nutrient and pesticide concentrations in surface water monitoring sites in agricultural areas exceed national drinking water limits for these contaminants. But the share of monitoring sites of rivers and lakes that exceeded recommended national limits or guidelines for environment and recreational uses was much higher, with agriculture a major cause of nutrient and pesticide pollution in many cases.
- With respect to groundwater (shallow wells and deep aquifers), agriculture over the review period was the major and growing source of pollution across many OECD countries, especially from nutrients and pesticides, although evidence of groundwater pollution is limited. This is a particular concern for countries where groundwater provides a major share of drinking water supplies for both human and livestock populations, and also as natural recovery rates from pollution can take many decades, in particular, for deep aquifers. There is also some evidence of increasing pollution of groundwater from pesticides despite declining pesticide use, largely explained by the long delays pesticides can take to leach through soils into aquifers.

Since the OECD (2008a) survey of water quality trends related to agriculture described above, ***a review of more recent national surveys from the mid-2000s to 2010***, suggests the situation of water pollution from agriculture is either stable or deteriorating in most cases. The absolute levels of agricultural pollutants also remain a challenge to achieve further reductions for most OECD countries, especially diffuse source pollution. There appear few situations where significant improvements are reported, according to the selected reports summarised below.[2]

- **European Union** (Chapter 5.1): The EU Commission's assessment has identified that 40% of surface water and 30% of groundwater is at risk across the European Union of failing to meet the objectives for good chemical and ecological status established under the European Union's *Water Framework Directive* (WFD) (Kanakoudis and Tsitsifli, 2010). Across most EU member states agriculture is an important source of nutrients and pesticides into surface and groundwater (European Environment Agency, 2010). While there are differences in trends and absolute pressures from agricultural nutrient surpluses on water systems across member states, the contribution of agriculture remains high. More specifically in most member states agriculture is responsible for over 50% of the total nitrogen discharge to surface water, although the overall trend in agricultural nitrogen discharges has been declining since the early 1990s (European Environment Agency, 2010; European Commission, 2010; OECD, 2008a). Even so, around a third of EU15 surface water and groundwater monitoring stations still show an upward trend in nitrate concentration levels in water and eutrophication of fresh and marine waters is significant (European Commission, 2010).
- **Baltic Sea** (Chapter 5.7): In the Baltic Sea catchment area, the major anthropogenic source of waterborne nitrogen is diffuse inputs, mainly agriculture (HELCOM 2009a; Malmaeus and Karlsson, 2010). They constitute 71% of the total load into surface waters within the catchment area. Agriculture alone contributed about 80% of the

reported total diffuse load. The largest loads of phosphorus originated from point sources (56%), with municipalities as the main source, constituting 90% of total point source discharges in 2000, with 44% from diffuse sources. For some Baltic countries, such as **Finland** and **Sweden**, agriculture is the major contributor of phosphorus into the Baltic.

- **Switzerland**: 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.
- **Norway**: Agricultural influences on water quality are recognised with respect to sediment and phosphate loadings from soil erosion plus nitrates and phosphates from fertiliser and manure 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. Agricultural loadings to coastal waters are significant, 60% of nitrogen and 45% of phosphorus released to coastal areas of the North Sea classified as sensitive under the North Sea Declaration, although aquaculture is important, especially with respect to phosphates (OECD, 2011d).
- **Turkey**: 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.
- **Israel** (OECD, 2010c): Pollution of water from agricultural activities is a long standing problem in Israel. Salinity of water arising from irrigation practices, and pesticide and nutrient run-off from cropping and livestock activities are the main forms of water pollution. Other forms of agricultural pollution occur from soil sediments in water and air, as well as abattoir and plastic wastes. While agriculture is an important source of water pollution other sources also contribute to the problem, notably from industrial activities and urban sewage disposal. The issue of water quality is inextricably linked to water resources, as the pressure on water resources has led to deterioration in quality. In general the quality of surface water, groundwater and coastal waters have been impaired from agricultural activities. Almost all rivers are polluted with only limited sections open to use for recreational purposes, although for some rivers water quality has improved.
- **Canada** (Eilers *et al.,* 2010): Agriculture's environmental performance with respect to risks to water quality currently has a good status, but represents an overall decline from a desired state in 1981. Increased application of nutrients (N and P), as fertiliser and manure, was the main driver for the declining trend in the performance index for water quality throughout Canada. The shift of animal numbers from Eastern Canada to the Prairies has resulted in a declining agri-environmental performance for risk of contamination of water by coliforms, whereas in the rest of Canada, particularly Eastern Canada, overall declining animal numbers have resulted in a relatively stable situation for coliforms. Increased efforts are required throughout Canada to minimise the risk of nutrient, pesticide and coliform movement to surface water bodies and leaching beyond

the rooting depth of vegetation. This is particularly so in higher rainfall areas of the country.

- **United States** (Chapter 5.2): Although varying regionally in nature and severity, agricultural influences on water quality are important according to the US Geological Survey *National Water Quality Assessment Program* (USGS, 2010). In particular, sediment loadings, bacterial contamination, nutrients and pesticides all contribute to problems to varying levels across the country, with five major ecosystems especially vulnerable to agricultural pollutants, including the Great Lakes, Chesapeake Bay, the Everglades and South Florida, the California Bay Delta, and the Mississippi River basin and Gulf of Mexico (White House, 2011). Nationally, 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 is the major source of sediment, nitrogen and phosphorus loadings into Chesapeake Bay. The Gulf of Mexico's hypoxic (dead/eutrophic) zone, first detected in the 1970s, has increased in size substantially, with the U.S. National Oceanic and Atmospheric Administration estimating the area of the zone could be over 2 million ha in 2011, although the area of the zone varies annually according to climatic conditions (Devine, Dorfman and Rosselot, 2008; Rabotyagov *et al.,* 2010). Agriculture also contributes significantly to groundwater contamination (wells and aquifers) across the nation, especially from leaching of nutrients and pesticides (USGS, 2010). Of increasing concern to groundwater quality is the increasing and widespread detection of contaminant mixtures, including mixtures of pesticides and veterinary products from agriculture with other man-made and natural contaminants (USGS, 2010).

- **Mexico**: Irrigation is widespread and has caused salinisation 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 **United States**, meaning that some effects are transboundary.

- **Chile**: Farming has an acknowledged impact on water quality arising both from the intensity of chemical and nutrient applications but also changes in land use, for example, from forestry. Impacts include contaminating drinking water and eutrophication of lakes and coastal water that lowers recreational and fishing values. But biophysical measurement of impacts is relatively poor and pollution from other sources, such as aquaculture, heavy industry and municipal sewage, are generally regarded as more pressing issues. 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).

- **Japan** (OECD, 2010d): Whilst over 90% of rivers meet health related water quality standards, many lakes, reservoirs and coastal waters do not. Nitrates, pesticides and sediments from agricultural activities are acknowledged to be among the causes of these problems, as well as discharges from other sources (e.g. sewage, industrial). Eutrophication continues to be a concern with nutrients, including from agriculture, especially intensive livestock operations but also fertiliser use leading to frequent algae blooms (red and blue tides) that damage aquatic life in coastal areas and increase costs of water treatment from inland water intakes (Ileva *et al.,* 2009). The quality of groundwater is improving, with nitrogen (from all sources including agriculture) exceeded in 4% of monitored wells and less than 0.1% of wells for pesticides. The potential of paddy fields to mimic natural wetlands and filter excess nutrients, provide some benefits for water quality (Chapter 1.4).

- **Korea**: Despite some recent improvements, around a third of rivers fail to meet domestic quality standards and over a quarter of lakes are eutrophic. Groundwater quality is higher, but 6% still fails domestic standards. Coastal eutrophication is a localised problem for fisheries and aquaculture. Diffuse pollution, including from agriculture, is acknowledged as a source of pollution with increases in livestock numbers a growing pressure on water systems. Paddy fields mimicking natural wetlands hold the potential to improve water quality.
- **Australia** (Chapter 5.3): 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, Australia's main agricultural producing region. Drinking water quality is impaired in many locations, and coastal regions downstream of large agricultural areas suffer from sediment and nutrient loadings. In terms of the environmental health of the Great Barrier Reef (GBR), recent research indicates that quantities of sediment, phosphorus and nitrogen entering the GBR have been increasing, with agriculture a key contributor to water quality issues in the GBR (Rolfe and Windle, 2011). But given the lack of a national monitoring system it is difficult to assess national trends in water quality related to agriculture (OECD, 2008a).
- **New Zealand** (Chapters 5.4 and 5.6): Overall water is of high quality, but the quality of a number of lowland rivers and streams is causing concern. There are expensive restoration clean-ups going on in some iconic lakes and there are questions over the state of groundwater. At a national level, diffuse discharges now greatly exceed point source pollution. Around 64% of monitored lakes in pastoral landscapes are classed eutrophic or worse (Ballantine and Davies-Colley, 2009; Land and Water Forum, 2010; Verburg *et al.,* 2010). Similarly groundwater quality has been deteriorating, with one third of sites monitored between 1995 and 2008 showed increasing trends in nitrate levels (Daughney and Randall, 2009).

Eutrophication of rivers, lakes and coastal waters

Eutrophication is the leading cause of water quality impairment around the world, and results in the over-enrichment of water with nutrients (nitrogen and phosphorus) as a result of human activity, including agriculture (Díaz, Rabalais and Breitburg, 2012). Eutrophication can be defined simply as the increase in the rate of production and accumulation of organic carbon in excess of what an ecosystem is normally capable of processing. Eutrophication can be harmful to both freshwater and marine ecosystems, and leads to a progression of symptoms that include:

- Excessive phytoplankton and macro algal growth that is the source of organic carbon. This can also reduce light penetration and lead to a loss of submerged aquatic vegetation.
- An imbalance of nutrient ratios that can lead to a shift in phytoplankton species composition and creating conditions that are favourable to toxic algal blooms. Harmful

algal blooms can cause kills of living marine resources and shellfish poisoning in humans.

- Changes in species composition and biomass of the benthic (bottom-dwelling) community, eventually leading to reduced species diversity and increased dominance of gelatinous organisms, such as jellyfish.
- Low dissolved oxygen and formation of hypoxic or dead zones (oxygen-depleted waters). These oxygen-starved areas stress aquatic ecosystems, often leading to kills of living marine resources, altered ecosystem energy flows, and in severe cases ecosystem collapse. Hypoxia is the most severe symptom of eutrophication and can make some rivers, lakes and coastal waters unfit for recreational uses.

Eutrophication is widespread across OECD countries and globally, affecting rivers, lakes, and reservoirs to varying degree of severity. But the most severe impacts of eutrophication are on estuarine, coastal and deep sea ecosystems, with damaging consequences for aquaculture and marine water fisheries.

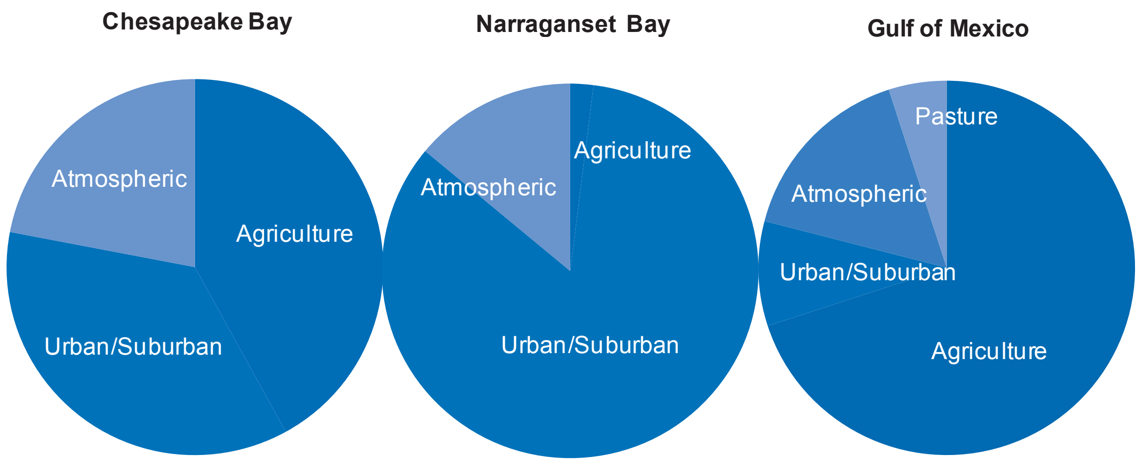
Current estimates are that hypoxia related to eutrophication annually affects at least 240 000 km^2 globally. About 70 000 km^2 are inshore (estuarine and brackish waters and embayments), and about 170 000 km^2 are coastal offshore waters. There is also another 1.1 million km^2 of bottom areas in the outer continental shelf affected by natural oxygen minimum zones. In total, about 4% of estuarine/brackish water and about 5% of shelf area are affected globally by hypoxia of some type. This translates to losses in ecosystem services estimated to be billions of US dollars (Díaz, Rabalais and Breitburg, 2012).

Sources of nutrients to coastal waters are diverse and vary from ecosystem to ecosystem (Díaz, Rabalais and Breitburg, 2012). Nutrients enter coastal ecosystems through atmospheric deposition, surface water runoff, and groundwater. Within the **United States**, for example, municipal wastewater is the primary driver of eutrophication in Narragansett Bay (an estuary in the North-East of the United States), in the northern Gulf of Mexico it is agriculture, and in Chesapeake Bay (an estuary of the US East Coast) atmospheric, urban/suburban, and agricultural sources are all co-equal (Figure 2.3). Broad scale regional differences also exist in the relative importance of nutrient sources, for example, in the United States and the European Union, agricultural sources are generally the primary contributors to eutrophication, while in some other OECD countries nutrient pollution is primarily attributed to municipal wastewater.

Human health risks with water pollution from agriculture

High concentrations of pollutants in water systems derived from agriculture can be dangerous to human health, especially where pollutants impair drinking and bathing water, such as from nitrates, heavy metals, pesticides and bacterial contaminants (Table 2.1). Overall for OECD countries harmful human health effects from agricultural contaminants is extremely low where water is drawn from treated water networks. There are concerns, however, for rural areas where water is consumed from untreated wells, as reported, for example, in the **United States** (USGS, 2010); and water quality close to large intensive confined livestock feeding operations (West *et al.*, 2011).

Figure 2.3. Comparison of the relative contribution of major sources of nitrogen pollution in three United States coastal ecosystems experiencing hypoxia



Note: Urban/suburban includes both point (industrial and sewage effluent) and diffuse sources (residential runoff).

Source: Díaz, Robert J., N.N. Rabalais and D.L. Breitburg (2012), *Agriculture's Impact on Aquaculture: Hypoxia and Eutrophication in Marine Waters*, OECD Consultant Report, available at: *www.oecd.org/agriculture/water,* based on Jewett, E.B., *et al.,* (2009), *Scientific assessment of hypoxia in U.S. coastal waters*, Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology, Washington, D.C., United States.

Human health impacts due to agricultural contaminants in drinking water is an issue under debate both in the scientific and policy arena, and the evidence for increased health risks is unclear or absent (Sutton *et al*., 2011; US Department of Health and Human Services, 2010). This is in part because of the lack of scientific understanding of the effect of contaminant mixtures in the environment, which may derive from various sources, including agriculture, and link to the issue of emerging contaminants, as discussed below.

Illustrative are nitrates in drinking water which can cause cancers and (albeit rarely) infant methaemoglobinaemia (blue baby syndrome). In the **EU15**, for example, 3% of the population is potentially exposed to levels of nitrate exceeding the drinking water standard of 50 mg NO_3 per litre. This may cause a 3% increase in the incidence of colon cancer, but nitrate is also considered to be beneficial to cardiovascular health (Sutton *et al*., 2011). It is estimated that this corresponds to an economic cost to the EU public that exceeds the costs of lowering nutrient input use in areas of intensive farming and/or the cost of improved water treatment abatement (van Grinsven, Rabl and de Kok, 2010). The authors of this study note that the epidemiological evidence for increased risk of colon cancer linked to nitrates is weak or absent, but that in view of the potential health gain from lowering nitrates in drinking water, improved epidemiological studies would be merited.

In recent years there has been increasing concern over the ***environmental and health risks of the so-called "emerging contaminants"*** (ECs) from agriculture and other sources into water systems. ECs originate from a variety of product types including human pharmaceuticals, veterinary medicines, transformation products of synthetic chemicals, nanomaterials, personal care products, paints and coatings. Some ECs, namely natural toxins, may be formed in the environment by animals, plants and microbes. A range of non-standard effects have been reported for different ECs. These effects are often seen at concentration levels close to those measured in the environment. However, the implications of these effects in terms of ecosystem functioning have yet to be established (Box 2.1).

Box 2.1. Emerging water contaminants from agriculture

Until very recently, the main focus on the impacts that agriculture causes on water has been on nutrients, pesticides, and soils. However, in recent years, there has been increasing concern over the human health and environmental risks to water of so-called "emerging contaminants" (ECs). ECs originate from a variety of product types including human pharmaceuticals, veterinary medicines, nanomaterials, personal care products, paints and coatings. Some ECs, such as natural products and transformation products of synthetic chemicals, may be formed in the environment by biochemical processes in animals, plants and microbes.

The increasing concern over the risks of ECs is reflected by a rapid increase in the numbers of scientific publications exploring the impacts of ECs over the past decade and the appearance of numerous articles in the popular press across the world. ECs are not necessarily new chemicals, they may be substances that have been present in the environment for a long time but whose presence and significance are only now being recognised. Data for ECs are often scarce and methods for detection in the natural environment may be non-existent or at an early stage of development.

ECs are released to the agricultural environment via a number of routes. They may be released directly to the environment (e.g. veterinary medicines used to treat livestock grazing). They may also enter the environment indirectly during the application of manure, biosolids or other solid waste materials to soil. Once in soil the ECs may be transported to water bodies by leaching, runoff and drainage processes. The extent of the transport is dependent on the persistence of the EC and how it interacts with soil and sediment particles. Many ECs appear to behave differently in agricultural systems than other agricultural contaminants (such as pesticides). This means that modelling approaches that have been developed for predicting fate properties and exposure of other contaminants are not always appropriate for ECs.

While a large number of studies have investigated the occurrence of a wide range of ECs, only a few have specifically investigated occurrence of ECs in agricultural systems. The studies that have looked at agricultural systems have detected a range of ECs, such as veterinary drugs and pesticide transformation products. Generally, reported concentrations are very low. Detection of ECs in environmental media can be challenging. However, robust methods are now available for many ECs. But methods are currently poorly developed for the detection and characterisation of engineered nanoparticles in soils and natural waters.

The environment is exposed to a mixture of ECs and other contaminants. The impact of these mixtures is likely to be greater than the impact of the single substance on its own. It is therefore important that greater effort is made to consider the potential implications of these mixture interactions in terms of risk. This is a general problem that is also relevant to non emerging contaminants, such as pesticides and heavy metals.

New ECs are likely to emerge in the future due to changes in demographics, socio-economic factors, land-use and climate. It is important that a start is made to develop approaches to anticipate these changes, including identifying ECs of most concern so that resources can be focused on the bigger problems. A number of prioritisation approaches already exist for horizon scanning for different classes of ECs. However, these approaches need further development and applied more widely. In order to co-ordinate resources, it may be appropriate to establish international oversight on EC's and to promote greater international co-operation.

Source: OECD Secretariat adapted from Boxall, A. (2012), *New and Emerging Water Pollutants arising from Agriculture*, OECD Consultant Report, available at: *www.oecd.org/agriculture/water*.

2.4 Medium-term outlook and implications of climate change

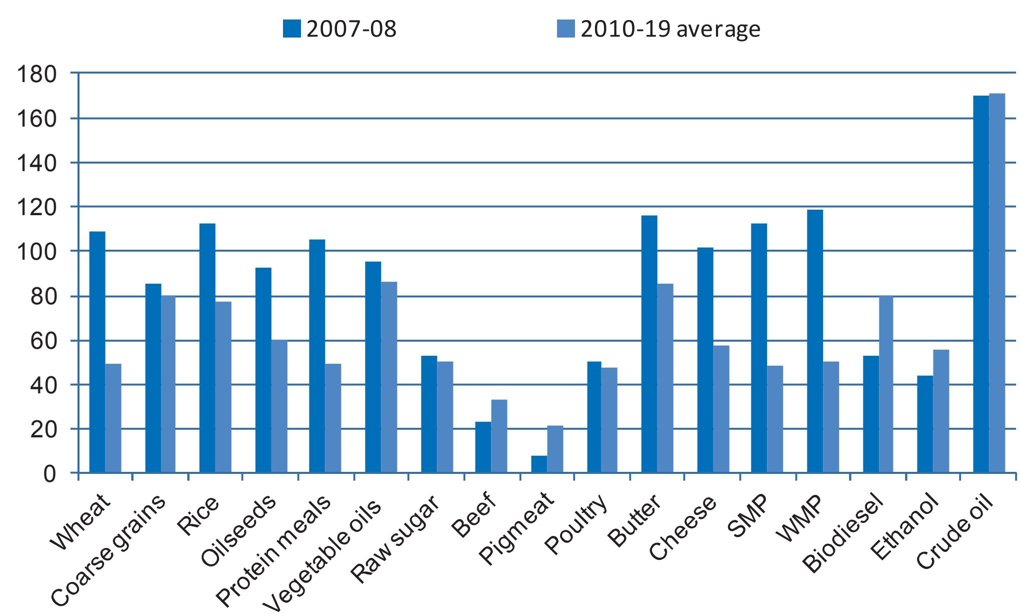
Medium-term outlook

The *OECD-FAO Agricultural Outlook* (OECD, 2011e) projects over the next decade to 2020 a trend of sustained rises in crop, sugar and vegetable oilseed product prices, in nominal and real terms (allowing for inflation). These commodity price projections are expected to remain well above the levels observed over the past decade, but fall from recent price peaks*,* i.e. during 2007-08 and 2010-11 (Figure 2.4).

Projections also indicate a similar trend to crops for bioenergy, with rising real prices for biodiesel and ethanol. More modest increases are expected for livestock prices, other than pig meat, over the coming decade, but average dairy prices are expected to be 30-70% higher in 2011-20 relative to 2001-10 (shown in terms of dairy products in Figure 2.4) (OECD, 2011e). -

The outlook for agricultural commodity prices translates into projected growth in agricultural production for nearly all OECD countries over the coming decade (Figure 2.5). From the trends in national agricultural production projections in Figure 2.5 it is possible to discern two broad groupings of OECD countries in terms of their potential pressure on water systems over the coming decade:

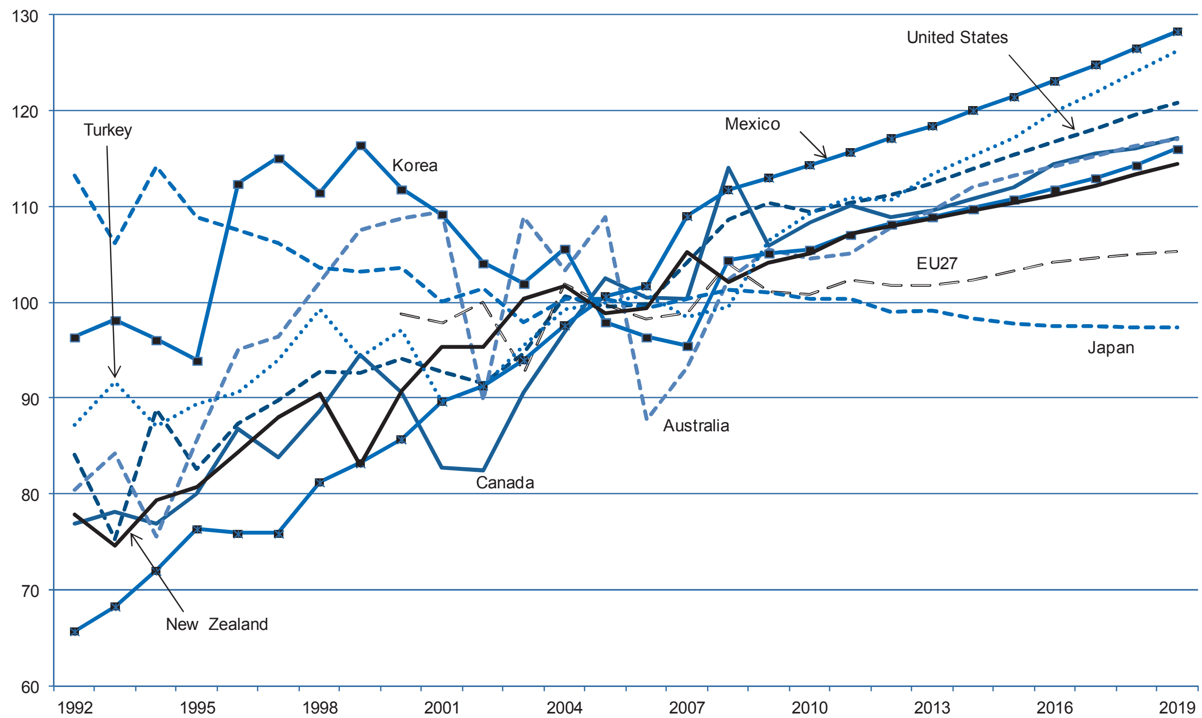
Figure 2.4. OECD projections for international commodity prices in real terms to 2019



Note: SMP – Skim Milk Powder; WMP – Whole Milk Powder. For biodiesel and ethanol the base period is 2001-06.

Source: OECD (2010), *OECD-FAO Agricultural Outlook 2010-2019*, www.agri-outlook.org.

Figure 2.5. Index of net agricultural production trends for selected OECD countries, 1992-2019 (Index 2004-06 = 100)



Note: Net agricultural production measures gross value of product produced, net of "internal" feed and seed inputs to avoid double counting (for example maize and livestock production), so that the production measure approximates a value added concept. There are no projections for Chile, Iceland, Israel, Norway and Switzerland.

Source: OECD (2010), *OECD-FAO Agricultural Outlook 2010-2019*, www.agri-outlook.org.

- **Group 1**: Countries which are projected to continue with strong growth in production over the coming decade, including: **Canada, United States, Mexico, Turkey, Australia and New Zealand.** Most OECD countries in this group have over the past decade largely expanded production by raising productivity and intensifying production on a reduced land area. However, in regions within some of these countries there is a risk of expanding production onto environmentally fragile land or marginal land not previously cultivated. **Korea** is the exception in this group, with production declining from the late 1990s to present but then projected to expand back to the levels of the late 1990s, largely explained by growth in beef production stimulated by a rise in Korean consumer demand and higher government support to producers. For this group of countries, the potential consequences for water quality of the projected growth in agricultural production might include (trends may vary within and across countries) the following.

  - Heightened pressure on water quality from the increased use of fertilisers and pesticides, and greater quantities of livestock manure, although absolute levels of pollution for many of these countries is below the OECD average (e.g. nutrient surplus/ha).

  - Elevated soil erosion leading to greater siltation of water systems as a result of farming more intensively environmentally fragile lands and/or expanding production onto marginal land not previously cultivated.

- Expanded production of bioenergy, especially using cereals, oilseeds and sugar crops as feedstocks for manufacturing biofuels, especially in the **United States**, which may lead to a rise in fertiliser and pesticide use (Box 2.2).
- Regionalised pressures on water systems could alter as a result of the continued structural changes in livestock production toward larger and more concentrated livestock operations, notably in the pig, poultry and dairy sectors, although in some cases larger, concentrated livestock operations do provide high levels of waste disposal management.
- Increased concerns with the growth in emerging contaminants, especially the release of medicines, veterinary products, etc., resulting from the growth in livestock production (Box 2.1).

➢ **Group 2**: Countries where projected production growth over the coming decade is expected to be modest for the **EU27** or decline in the case of **Japan**. Within the EU27, however, there could be some diverging trends, with the agricultural sector continuing to contract in many of the former EU15 countries, but expanding in some of the new EU member states (European Environment Agency, 2010). In addition, crop and livestock production could undergo further intensification and concentration of production on less land to maintain increases in productivity and profitability. For this group of countries, the potential consequences for water quality of the projected low growth or decrease in agricultural production might include (trends may vary within and across countries) the following.

- Reduced overall agricultural pollutant loadings into water, with this trend more pronounced in Japan given the projected decrease in agricultural production, although the absolute levels of pollution for many of these countries might remain above the OECD average (e.g. nutrient surplus/ha).
- Localised increases in water pollution, with structural changes in the livestock sector towards larger concentrated operations.

For all OECD countries over the medium term there are a number of developments that may generally help toward lowering the pressure of agriculture on water quality, including the following.

- Efficiencies in lowering farm chemical input use per unit of output, partly induced by higher prices for inorganic fertilisers and pesticides due to the projected increase in crude oil prices (Figure 2.4), which might also encourage greater use of livestock waste as a bioenergy feedstock.
- Improvements in farm management practices, and pollution related technologies, especially biotechnologies and use of global positioning systems (GPS).
- Increases in public pressure to reduce the health and environmental costs of water pollution from agriculture, likely to result in strengthening of environmental pollution policies, especially those policies addressing diffuse source pollution from agriculture.
- Reforms likely to continue with agricultural policies leading to further declines in overall OECD agricultural support and a continued shift towards decoupled support.
- Innovations in policy and market approaches to address water quality issues in agriculture, that seek to change the behaviour of farmers, the agro-food chain and other stakeholders to improve water quality (Chapter 4.3), and national water quality policies more generally (e.g. **Australia**'s *National Water Quality Management Strategy)*.

Box 2.2. Bioenergy production using agricultural feedstocks: Implications for water quality

Bioenergy production from agricultural feedstocks (e.g. grains, cereals, oilseeds, grasses, woody materials) can have significant impacts on water quality and availability, although impacts on water resources has already been considered by OECD (2010). The water quality impacts may be caused by the use of agro-chemicals in intensive bioenergy feedstock production systems, such as the use of fertilisers which pose a risk for eutrophication. In addition, the feedstock processing plants to convert raw materials to bioenergy can also have impacts on water quality, although this will vary depending on a range of factors, including for example, biorefinery technology, effluent controls and water recycling practices (FAO, 2008; Fingerman *et al.,* 2010; USEPA, 2011).

In the **United States**, for example, much of the increased production of biofuels is produced from maize, which usually entails large applications of inorganic fertilisers. As a result sediment and nutrient pollution from agricultural land is likely to increase, particularly where maize is cultivated on marginal agricultural land which contributes to the highest nutrient loads. This may have substantial consequences for water quality, especially in the Mississippi river and the northern Gulf of Mexico (De la Torre Ugarte *et al.,* 2010; Donner and Kucharik, 2008; National Research Council, 2008a, and 2008b; OECD 2008; USEPA, 2011).

For wood plantations used as bioenergy feedstocks, the clearance of streamside vegetation in wood management systems may also change physical properties of water systems, such as the turbidity, stream temperature and light infiltration of water bodies. If nutrient inputs are required for wood plantations, infiltration and runoff of nitrogen may also pose a risk to groundwater (Lattimore *et al.,* 2009).

A key conclusion from most studies on the links between bioenergy production from agricultural feedstocks on water quality is that in general feedstocks from annual crops such as maize and oilseeds can have a more damaging impact on water systems than feedstocks produced from grass and woody materials, such as reed canary grass and short rotation woodlands (FAO, 2008; OECD, 2008; USEPA, 2011). Another important conclusion is that the location of production and the type of tillage production, crop rotation system and other farm management practices used in producing feedstocks for bioenergy production will also greatly influence water quality (De la Torre Ugarte *et al.,* 2010; European Environment Agency, 2008; Lankoski and Ollikainen, 2011; Thomas, Engel and Chaubey, 2009). But a note of caution is important when considering the discussion here as the potential impacts on water quality from growing agricultural feedstocks for bioenergy production, have not been fully evaluated (National Research Council, 2008a; OECD, 2008).

With the expansion in the bioenergy industry it will be important to optimise benefits while minimising adverse outcomes on water quality, as well as other environmental impacts. Since many of the known adverse impacts on water quality from bioenergy production are due to the type of feedstock cultivated, there is potential to mitigate these impacts through the adoption of conservation practices and systems (USEPA, 2011).

Sources: De la Torre Ugarte, D.G., *et al.* (2010), "Expanded ethanol production: Implications for agriculture, water demand, and water quality", *Biomass and Bioenergy*, Vol. 34, pp. 1586-1596; Donner, S.D. and C.J. Kucharik (2008), "Corn based ethanol production compromises goal of reducing nitrogen run-off by the Mississippi River", *Proceedings of the National Academy of Sciences*, Vol. 105, pp. 4513-4518; European Environment Agency (2008), *A review of the possible impact of biomass production from agriculture on water*, Copenhagen, Denmark, available at: *www.eea.europea.eu*; Fingerman, K.R., *et al.* (2010), "Accounting for the water impacts of ethanol production", *Environmental Research Letters*, 5 014020, *iopscience.iop.org/1748-9326/5/1/014020;* Lattimore, B., *et al.* (2009), "Environmental Factors in Woodfuel Production: Opportunities, Risks, and Criteria and Indicators for Sustainable Practices", *Biomass and Bioenergy,* Vol. 33, pp. 1321-1342; Lankoski, J. and M. Ollikainen (2011), "Biofuel policies and the environment: Do climate benefits warrant increased production from biofuel feedstocks?", *Ecological Economics*, Vol. 70, pp. 676-687; National Research Council (2008a), *Mississippi River water quality and the Clean Water Act: Progress, challenges and opportunities*, The National Academies Press, Washington, D.C., United States, *www.nap.edu/catalog/12051.html;* and National Research Council (2008b), *Water implications of biofuels production in the United States*, The National Academies Press, Washington, D.C., United States, *books.nap.edu/catalog.php?record_id=12039*; OECD (2008), *Biofuel Support Policies: An Economic Assessment*, OECD, Paris, *www.oecd.org/agr*; OECD (2010), *Sustainable Management of Water Resources in Agriculture,* OECD, Paris, *www.oecd.org/agr/env*; OECD/IEA (2010), *Sustainable Production of Second-Generation Biofuels,* OECD/IEA, Paris, *www.iea.org/papers/2010/second_generation_biofuels.pdf;* Thomas, M.A., B.A. Engel and I. Chaubey (2009), "Water quality impacts of corn production to meet biofuels demands", *Journal of Environmental Engineering*, Vol. 1 235, No. 11, pp. 1123-1135; U.S. Environmental Protection Agency (USEPA) (2011), *Biofuels and the environment: First triennial report to Congress,* External Draft Review, EPA/600/R-10/183A, Washington, D.C., United States, *cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=217443*.

Climate change

The medium and long-term outlook for agriculture is expected to be increasingly impacted by climate change and climate variability. Changes in climate and climate variability that affect the profitability of agriculture will in turn lead to changes in locations of crop and livestock production, and technologies and management practices used to produce individual crops and livestock (Abler *et al.*, 2001). These economic responses to climate change could lead to indirect consequences in changing pollutant runoff and leaching rates as well as soil erosion rates, which may increase or diminish pollution from agriculture assuming no economic or policy response.

Recent research studies, although currently limited, that have explored the potential impacts of climate change and variability on the risks of water quality contamination related to agriculture have concluded that climate change could have the following impact.[3]

- Influence the amounts and types of contaminant run-off and leaching from agriculture, with the magnitude of the increases highly dependent on the contaminant type, although risks from pathogens might be highest.
- Fuel increased use of pesticides and biocides, as farming practices intensify and in some areas are subject to higher temperatures.
- Mobilise contaminants from soils and faecal matter as a result of extreme weather events; potentially increasing their bioavailability, as illustrated by the possible aggravation from climate change of chemical reactions in acid sulphate soils (Box 2.3).
- Affect the fate and transport of contaminants in agricultural systems, for example the increase in salinisation due to the intrusion of salt water when water discharge volumes are low, and the higher concentrations of nutrients with a greater chance of algal blooms (Box 2.4).
- Reduce, through increases in temperature and changes in moisture content, the persistence of contaminants, while changes in hydrological characteristics are likely to increase the potential for contaminants to be more easily transported to sources of water supplies.
- Lead to an impoverished ecological status of water systems, such as the decrease or disappearance of species, and shifting the range of distribution of species from elevated agricultural pollution.
- That climate change could be managed for the most part by farm management and policy adaptations, including through better regulation, monitoring and the development of long-term research programmes. Also various strategies for mitigating greenhouse gases in agriculture would for the most part be beneficial for water systems, such as through afforestation and other increases in green cover providing a buffer for soil sediment and contaminant flows across agricultural land (Wilcock *et al.,* 2008).

In summary, relationships between climate change and pollution from agriculture are likely to be complex, as increased flooding, for example, could mobilise sediment loads and associated contaminants and exacerbate impacts on water systems. On the other hand, more severe droughts could reduce pollutant dilution, thereby increasing toxicity problems (Collins and McGonigle, 2008). But the expectations are that whatever the impacts on water quality, the task of achieving water quality objectives in agriculture will become more difficult in the coming years as a result of climate change.

These conclusions are tentative, not only because of the overall uncertainties of current climate change research, but more specifically that the linkages between climate change, agriculture and water quality are not yet extensively researched. Indeed there is a pressing need for more studies in this area, especially through the use of climate and water catchment modelling (Delpha *et al.,* 2009 and 2011; Ficklin *et al.*, 2010; Jennings *et al.*, 2009; Kronvang, Rubaek and Heckrath, 2009; Stuart *et al.,* 2011).

Box 2.3. Climate change, agriculture, acid sulphate soils and water quality: A case study of Finland

From an environmental point of view, acid sulphate soils (ASS) are regarded as the most problematic soils in the world. Finland has Europe's largest areas of ASS (c. 2 000-4 000 km^2). By reclamation, burning of peat cover and heavy liming they constitute some of the most productive farmland in Finland.

As a result of these farm practices groundwater level is strongly lowered during dry spells, enabling oxygen to penetrate the soil. When exposed to oxygen, sulphides oxidise and produce sulphuric acid and make the soil extremely acid (pH 2.5-4), which in turn mobilises enormous quantities of metals (e.g. cadmium, zinc) stored in the soil. Together with acidity, these metals are flushed from the soils into recipient estuaries during wet spells. Metal discharges from ASS are estimated to significantly exceed the corresponding total discharges from Finnish industry.

The extensive pool of toxic metals with high risk of mobilisation in these soils has not been fully understood until very recently. The chemical composition and quality of drainage water from ASS, resembles those of sulphur rich metal ores, which cause similar acidity problems in Europe and worldwide. In Finland, leaching of acidity and heavy metals from ASS is the most common cause for bad or poor ecological and chemical status of surface water bodies, affecting more than 30 coastal rivers and estuaries. Depleted or eradicated fish stocks in numerous rivers and estuaries are the most visible effect. Impacts of acid runoff vary according to the quantity, quality and proximity of ASS and the catchment characteristics of water bodies.

Climate change is likely to increase and widen the extent of environmental damage unless targeted mitigation measures are developed. High peak concentrations of toxic compounds occur especially after long dry periods and subsequent heavy rainfall. As a result of climate change, these hydrological extremes are expected to become much more common in river basins with small lakes and rapidly fluctuating discharges. For aquatic ecosystems and fish stocks this means increased probability of exposure to toxic metal compounds. In order to adapt ASS land use and water pollution control measures to climate change, the following actions are necessary:

- Increase knowledge on the location, quality and quantity of ASS;
- Develop cost-effective mapping tools and tools for identification of potential hotspot areas;
- Collate data on loading levels and degree of environmental degradation in water bodies affected by ASS;
- Construct climate change risk scenarios and identify future problem areas;
- Evaluate effectiveness and constraints of the current pollution control measures under changing climate;
- Develop and demonstrate pollution control techniques tailored for changing climate conditions; and,
- Assess the socio-economic impacts and feasibility of the adaptation tools.

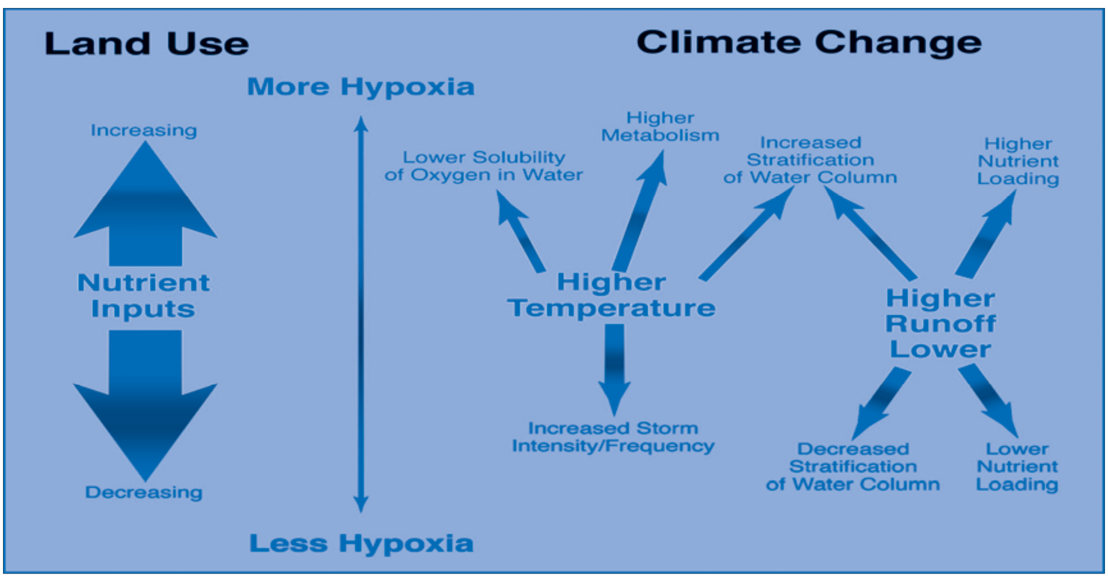
Source: Drawn from material provided to the OECD Secretariat by the Finnish Delegation to the OECD.

Box 2.4. Climate change, marine eutrophication and agriculture

Recent studies have shown that after years of eutrophication, it may not be as simple as reducing nutrients to reverse water quality problems, especially associated with hypoxia. If in the next 50 years humans continue to modify and degrade coastal systems as in previous years, human population pressure will likely continue to be the main driving factor in the persistence and spreading of coastal dead zones. Expanding agriculture for production of crops to be used for food and biofuels will result in increased nutrient loading and expand eutrophication effects.

Climate change, however, may make systems more susceptible to the development of hypoxia through direct effects on stratification, solubility of oxygen, metabolism, and mineralisation rates, as shown in the Box Figure below. This will likely occur primarily though warming, which will lead to increased water temperatures, decreased oxygen solubility, increased organism metabolism and remineralisation rates, and enhanced stratification.

Relative contribution of global climate change and land use to future hypoxia



Note: The thickness of the arrows indicates relative magnitude of effect.

Source: OECD Secretariat, adapted from Díaz, Robert J., N.N. Rabalais and D.L. Breitburg (2012), *Agriculture's Impact on Aquaculture: Hypoxia and Eutrophication in Marine Waters*, OECD Consultant Report, available at: www.oecd.org/agriculture/water.

2.5 Issues related to monitoring water quality in agriculture important for policy makers

Monitoring efforts are crucial to provide information to policy makers and other stakeholders about the state, trends and outlook in water quality related to agriculture. There are a number of issues related to monitoring which are important in the policy making process to address water pollution from agriculture, including standards, targets and goals to measure progress, and developing water quality monitoring systems.

Standards, targets and goals to measure progress

All OECD countries have general drinking water quality chemical standards covering nutrients and pesticides, and nearly all have ecological standards (mostly lower) for environmental water quality. For example, in most OECD countries the drinking water threshold value for nitrate is 50 mg nitrate per litre. Agriculture is not usually directly implicated in meeting drinking water quality standards, as this is usually the task of the public/private water suppliers. The source of water – rivers, lakes, reservoirs and groundwater – from which water suppliers draw, often requires treatment to remove nutrients, pesticides and other contaminants to meet drinking water standards, often at considerable cost (Chapter 3).

In situations where mains drinking water supplies are not available to the farm household, then the farm will draw water from wells on-farm, which do not necessarily meet the same chemical standards as mains water supplies. In the **United States**, for example, privately owned wells are not regulated under the Federal Safe Drinking Water or in most cases by State laws. About 15% of the US population rely on these wells, and where they are in or near agricultural settings have the highest probability of consuming nitrate concentrations, for example, at elevated levels (Dubrovsky *et al.,* 2010).

Few countries have comprehensive water quality standards, targets or goals specific to agriculture. **Sweden**, for example, has set agriculture specific water quality targets for surface, groundwater and marine water (OECD, 2008a). The **European Union** in the case of nitrates, through the *Nitrates Directive* (which forms part of the European Union *Water Framework Directive*), requires member states to designate as Nitrate Vulnerable Zones all areas of land where the corresponding surface water or groundwater contain more than 50 mg nitrates per litre or where the corresponding freshwater bodies, estuaries, coastal and marine waters are found to be, or risk being, eutrophic. Member states must establish and implement mandatory measures for farmers located in these zones (Chapter 5.1) (OECD, 2008a).

Broader national standards for water quality do have, however, implications for the policy abatement strategies that agriculture can pursue to meet the standards. Illustrative are the **United States** Total Maximum Daily Load (TMDL) regulation under the US *Clean Water Act*, and the **European Union's** water quality standards under the *Water Framework Directive*.

The TMDL is the **United States** Environmental Protection Agency's major initiative to remedy the nation's water quality problems. Under the Federal TMDL framework, states are responsible for compiling lists of water bodies not meeting their designated use which are then reported as impaired waters (Helmers *et al.,* 2007). For each listed water body, the states need to identify the amount by which pollution loads from diffuse and point sources of pollution must be reduced to meet the standards, and to develop and implement plans to achieve the load reductions (Borisova *et al.,* 2003).

Until recently there has been no regulatory authority by the Federal or State governments to require that TMDL reductions occur. For the six States and the District of Colombia surrounding the Chesapeake Bay area the TMDL's will now be mandatory (Chapter 5.2) (Perez, Cox and Cook, 2009). In the TMDL process modelling and monitoring can play an important part in allocating pollutant loads to various sources, such as helping to determine the relative contributions of arable crops, intensive livestock operations and urban sources to loads of nutrients and pathogens observed in large water catchments (Helmers *et al.,* 2007).

Under the **European Union**'s *Water Framework Directive* (WFD) member states are required to regularly assess both the current ecological status of inland and coastal waters, defined as a function of deviation from an undamaged (reference) state; and also the chemical status of water bodies. The resulting classification for each water body is reported to the European Commission (Johnes, 2007). The ecological status ranges which can range from "high" to "bad", is determined by a combination of biological quality elements (aquatic flora, benthic invertebrate fauna and fish fauna) and physico-chemical quality elements (such as oxygenation conditions, nutrient conditions, salinity, as well as specific pollutants). Good chemical status means compliance with the environmental quality standards defined in Directive 2008/105/EC. This Directive comprises a list of 33 priority substances and certain other pollutants (e.g. pesticides and heavy metals). In order for a surface water body to be classified as being of good status, the criteria for both good ecological and good chemical status have to be met. The overall good status objective represents surface water conditions that are appropriate for all types of water uses and functions, besides healthy aquatic ecosystems.

Under the **European Union**'s WFD timetable of requirements, member states must classify the chemical and ecological status of each water catchment, followed by specification of River Basin Management Plans by 2009, detailing measures for addressing diffuse pollution which must be operational by 2012 (Chapter 5.1). As with the TMDL in the United States, the WFD implementation requirements mean that modelling is increasingly being used by member states to characterise current environmental conditions and to predict for policy makers the potential impact of different abatement strategies (Collins and Anthony, 2008).

Developing water quality monitoring and modelling of water catchments

All OECD countries have monitoring networks to measure the actual state of water pollution of water bodies, while some countries use risk indicators which provide estimates, usually based on models of contamination levels, for example, as described previously for the **European Union** and the **United States**. However, monitoring of agricultural pollution of water bodies is more limited with just over a third of OECD member countries monitoring nutrient pollution and even fewer countries tracking pesticide pollution. Certain farm pollutants are recorded in more detail and with greater frequency (e.g. nutrients, pesticides), whereas an indication of the overall OECD situation for water pollution from pathogens, salts and other agricultural pollutants is unclear. Moreover, pollution levels can vary greatly between countries and regions depending mainly on soil and crop types, agro-ecological conditions, climate, farm management practices, and policy (OECD, 2008a).

The limitations to identifying trends in water pollution originating from agriculture are in attributing the share of agriculture in total contamination and identifying areas vulnerable to agricultural water pollution. In addition, differences in methods of data collection and national drinking and environmental water standards hinder comparative assessments, while nation-wide monitoring agricultural water pollution is poorly developed, especially for pesticides, in a number of countries, such as **Australia, Italy, Japan** and **New Zealand**, although in some of those countries, monitoring is carried out at the sub-national level The extent of agricultural groundwater pollution is generally less well documented than is the case for surface water, largely due to the costs involved in sampling groundwater, and because most pollutants take a longer time to leach through soils into aquifers (OECD, 2008a).

Most water quality monitoring is publicly financed, but there are increasing signs of private sector initiatives to improve the regularity and quality of water quality data, including data related to agriculture. In California, **United States**, privatised intensive water quality monitoring efforts are being considered by farmers in the Central Coast district of the State as an interim approach while continuous monitoring technologies of diffuse source agricultural pollution are being developed (Dowd, Press and Los Huertos, 2008).

At a global scale the World Resources Institute (WRI), in partnership with General Electric and Goldman Sachs in the **United States**, has launched an initiative to measure water-related risks facing companies and their investors (see WRI website *www.wri.org/stories/2010/01/betting-water*). The initiative will develop a Water Index as a standardised approach to identify and mitigate water-related corporate risk, with the index aggregating nearly 20 weighted factors capturing water availability, regulations, and water quality (Stanton *et al.,* 2010). The index will allow companies and investors to capture the various components of water-related risks and enable business leaders to make more well-informed investment decisions. The index will draw on publicly available data regarding physical scarcity and water quality and overlay important factors including the regulatory regime and social and reputational issues that have not previously been incorporated into water risk measurement.

Similarly a **United Kingdom** based company, Maplecroft, is marketing a water security index to identify risks across supply chains, operations and investments of companies (see *www.maplecroft.com/*). The index measures four areas including: access to improved drinking water and sanitation; the availability of renewable water and the reliance on external supplies; the relationship between available water and supply demands; and the water dependency of each country's economy.

While physical monitoring of water quality provides a key tool to support policy makers, there are also a range of models that provide a policy support tool by linking policy and economic variables to bio-physical parameters and the ecological quality of water (Collins and McGonigle, 2008).[4] A major focus of this modelling effort is to reveal the relative economic effectiveness and environmental efficiency of different policy instruments or policy mix for diffuse source pollution (Collins and McGonigle, 2008; OECD, 2010g and 2010h). To date many modelling studies have simulated the impact of mitigation strategies on annual pollutant loss as opposed to pressures during seasonal ecological windows (Collins and McGonigle, 2008). Further development of these models to improve the targeting of policies, however, needs to pinpoint specific ecological windows of opportunity (e.g. salmon spawning season) as opposed to annual loadings and their abatement (Collins and McGonigle, 2008).

Notes

1. The Chilean Government is currently working with the irrigators and the water catchment authorities to address this problem, according to information provided by the Chilean authorities to the OECD Secretariat in 2010.
2. The country summaries mainly draw on national sources and Moxey, 2012.
3. These conclusions are based on a selected review of the literature including case studies of Denmark, Jeppesen *et al.,* 2009; Ireland, Jennings *et al.,* 2009; The Netherlands, The Netherlands Ministries of Transport, Public Works and Water Management; Housing, Spatial Planning and the Environment; and Agriculture, Nature and Food Quality, 2009; New Zealand, Wilcock *et al.,* 2008; United Kingdom, Boxall *et al.,* 2009; United States, Ficklin *et al.,* 2010; and globally see Meybeck, 2003.
4. For a review of modelling studies related to agriculture, water quality and policy choices and mixes, see for example, OECD 2010e and 2010f, and literature cited in Collins and McGonigle, 2008.

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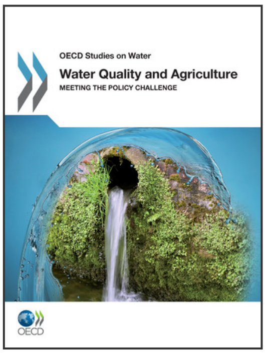

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