Diffuse Pollution, Degraded Waters
Emerging Policy Solutions

Chapter 1

The water quality challenge

This chapter takes stock of recent information and data on challenges related to water quality in OECD countries. It zooms in on the water quality issues facing OECD cities, the effects of water quantity and climate change on water quality, and the ongoing challenge of managing diffuse pollution, in particular, nutrient loading.

Key messages

Water quality continues to deteriorate despite improvements in the control of industrial point source pollution and wastewater treatment. Ongoing water quality problems in OECD countries are characterised by a number of pollutants, none more so than nutrient pollution, primarily from agricultural sources, which leads to eutrophication and harmful algal blooms. As a consequence, the relative importance of diffuse pollution loads is increasing in OECD countries, and increasing treatment and regulation of point source pollution is no longer necessarily the most cost-effective approach to improving water quality. However, maintaining these processes to manage point source pollution is essential and must not be abandoned.

OECD cities face distinct challenges, given that the negative impacts of poor water quality largely fall on cities (e.g. increased water treatment costs, health service costs), as does the value of assets at risk (e.g. corrosion and premature ageing of infrastructure and reduced property values from contaminated water), and the costs of treating pollution (e.g. wastewater and stormwater) before discharging to the environment. Diffuse pollution from stormwater runoff and combined sewer overflows is an ongoing challenge for cities. Climate change will exacerbate existing water quality challenges, due to altered precipitation, flow and thermal regimes, and sea level rise, which will mean water authorities and water and sanitation utilities will be confronted by further economic and operational challenges.

Freshwater of a high quality is also valued for environmental uses, such as the provision of fish habitat and ecosystem health. However, freshwater ecosystems are under immense pressure as a result of a legacy of industrial pollution and alteration of the natural morphology of water bodies, continuing pollution from diffuse sources (agricultural and urban), and an ever-evolving number of emerging pollutants in wastewater. This pollution, coupled with the effects of hypoxia, algal blooms, the introduction of invasive alien species and climate change, are having a devastating impact on freshwater biodiversity. Policy responses to these complex water quality challenges are required to protect freshwater ecosystems and the services they provide.

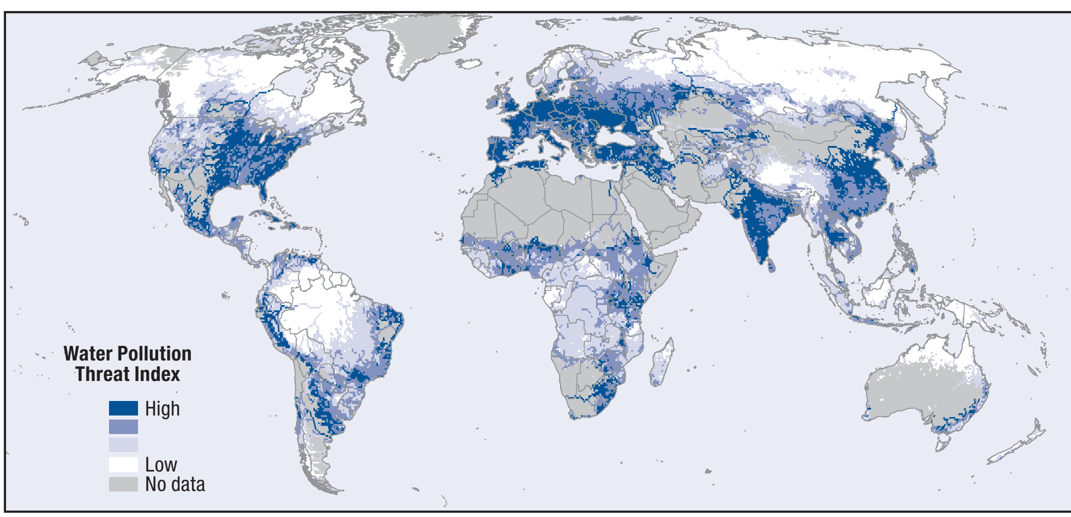
An introduction to water quality and its impact on the environment and society

Good water quality is essential for human well-being, for use in agriculture, aquaculture, and industry, and to support freshwater ecosystems and the services they provide. What qualifies as "good" water quality depends on the purpose of use and the value society holds for water quality.

Water pollution is defined as anthropogenic contamination[1] of water bodies (e.g. rivers, lakes, groundwater, estuaries and oceans) from the discharge, directly or indirectly, of a substance that changes the functioning of the system (Hanley et al., 2013). Pollution alters the composition and characteristics of a water body and its level of water quality. For example, the discharge of organic waste from sewers to rivers accelerates biological processes, and in the process uses up oxygen which can cause loss of aquatic life. Nutrients from fertilisers and livestock from the agriculture sector can lead to eutrophication of rivers and lakes, and can result in toxic algal blooms and changes in freshwater fauna and flora communities. Furthermore, poor water quality reduces the quantity of useable water and therefore exacerbates the problem of water scarcity.

Figure 1.1 illustrates the global distribution of pollution, which includes the effects of nutrient and pesticide loading, mercury deposition, salinisation, acidification, and sediment and organic loading (Sadoff et al., 2015; Vörösmarty et al., 2010). Pollution "hotspots"[2] are identified in most regions of the world, including OECD countries.

Figure 1.1. **Global distribution of water pollution hazard, 2000**



Source: Sadoff et al. (2015); based on data from Vörösmarty et al. (2010).

Population growth, coupled with climate change[3], are thought to have the greatest effect on water quality (Allan, et al., 2013), placing increasing pressure on the ability of finite water bodies to process wastewater, nutrients and contaminants before they lose their life-supporting function. So much so, that at least half the world's population suffers from polluted water (Jones, 2009). And the situation is set to worsen. Under even the most optimistic economic growth and climate change scenarios, a global and rapid increase in nitrogen (35-46%), phosphorus (15-24%) and biochemical oxygen demand (BOD[4]) (9-11%) is projected to 2050 (IFPRI and Veolia, 2015). Increases are projected in all regions of the world, but will be felt the greatest in upper-middle and lower-middle income countries, particularly Asia. This will, in turn, increase risks to human health, economic development and ecosystems.

Pollution, over-exploitation and alteration of water bodies as a result of human activities have led to the extinction, or risk thereof, of 10 000 to 20 000 freshwater species (Strayer and Dudgeon, 2010; Vörösmarty et al., 2010) - an 81% reduction in freshwater biodiversity between 1970 and 2012 (WWF, 2016). Of further concern, wetlands, which are biodiversity hotspots that deliver a wide range of ecosystem services including water purification, have declined by 64% globally since 1900 (Ramsar, 2015). Polluted freshwater also has an impact on coastal and ocean waters, for example the formation of eutrophic and hypoxic zones (also known as "dead zones") in the oceans.

Improving water quality is consistently ranked as a top environmental concern in public opinion surveys across most OECD countries (OECD, 2012a). For example, in the United States, an annual national public opinion survey from 1989 to 2014 consistently ranked water pollution as one of the top environmental concerns from a list including climate change, loss of rain forest, extinction of plant and animal species, and air pollution (Gallup Poll, 2014). A similar survey in the European Union in 2012 showed comparable results to those of the United States, with 84% of respondents listing chemical pollution as the greatest threat to a country's water environment, ahead of climate change, changes to the water ecosystem, floods, water scarcity, and other water-related threats (European Commission, 2012a). Challenges to water quality are the primary environmental concern for New Zealanders, ahead of air quality, terrestrial biodiversity, coastal waters and soils, with public attention increasingly focusing on the impact of agricultural runoff (Hughey et al., 2013).

Over recent decades, policy actions and major investment in OECD countries have helped to reduce point source pollution from urban centres, industry and wastewater treatment plants, with substantial gains for the economy, human health, environment and social values linked to water (OECD, 2012b). However, despite these improvements, diffuse pollution loads from agricultural and urban sources, combined sewer-overflows, and emerging contaminants in human and animal wastewater are continuing challenges in OECD countries (OECD, 2012b).

A typology for water pollution: sources, types and pathways

Characteristics and determinants of water quality

The quality of a water body is the function of its physical, biological and chemical characteristics. Physical characteristics relate to temperature, colour, taste, odour, turbidity and salinity, among others. Biological characteristics relate to living organisms, such as bacteria, zooplankton, algae, fungi, invertebrates, worms, aquatic plants and fish, among others. Chemical characteristics relate to pH, biological oxygen demand, and substances that dissolve in water, such as total dissolved solids, dissolved oxygen, nitrates, phosphates and other minerals.

Contaminants from naturally occurring events and human activities alter these characteristics, with a corresponding change in the composition of the waterbody and its level of water quality (Joyce and Convery, 2009). The nature of these alterations is not always linear, and can depend on a combination of variables related to the characteristics, volume and concentration of the pollutants (individually and in combination), the characteristics of the receiving water body, distance to the polluting source, the stochastic environmental conditions and timing (as outlined in Figure 1.2). Pressures from a range of policies and developments can affect water quality, such as water allocation, flood management, urban development, alterations to the natural morphology of water bodies, land and soil management practices, and climate change.

Figure 1.2. **A typology for water pollution**

Pollutant characteristics	Source type and pathways	Receiving body type and characteristics	Environmental conditions
• Toxicity • Concentration • Volume of discharge • Life span • Fate and transport • Ability to treat with current technologies • Chemical reactions (adsorption, dissolution, precipitation, decay) • Stock or Flow pollutant • Ambient or exogenous • Continuous or intermittent	**Type** • Point source • Diffuse source • Historic pollution **Pathways** • Pipe discharges • Surface runoff • Subsurface flow • Leaching • Dry and wet deposition (of atmospheric pollutants) • Re-suspension of contaminated sediment	**Type** • River • Lake • Groundwater • Wetland • Estuary/sea/ocean **Characteristics** • Physical, biological and chemical properties (ecosystem health) • Biological processes (processing pollutants, plant uptake, nutrient cycling, adsorption, mineralisation) • Natural contaminant background levels • Geographical features (morphology, topography, mountain-fed, glacier-fed, lowland, upstream or downstream) • River channel type (straight, meandering, braided) • Perennial or ephemeral • Surface-groundwater interactions • Water body modifications (e.g. dams, canals, dredging) • Lake stratification and mixing • Flow rate and residence time • Confined or unconfined aquifer • Groundwater recharge rate	• Climate and season • Hydrological conditions (precipitation, runoff, flow, currents, velocity) • Geology and soil characteristics • Drainage characteristics • Temperature • Wind • Sunlight • Catchment area • Groundcover/ vegetation • Land use and management practices

Water pollutants are commonly characterised as point or diffuse, according to their source and pathway to the receiving environment:

- *Point sources* of pollution are directly discharged to receiving water bodies at a discrete location, such as pipes and ditches from sewage treatment plants, industrial sites and confined intensive livestock operations. The most severe water quality impacts from point source pollution typically occur during summer or dry periods, when river flows are low and the capacity for dilution is reduced, and during storm periods when combined sewer overflows operate more frequently. The "first flush" of a combined sewer system after a dry spell is particularly detrimental to surface water quality. Groundwater quality can also be affected where it interacts with polluted surface water.
- *Diffuse sources* of pollution (also referred to as non-point) are indirectly discharged to receiving water bodies, via overland flow (runoff) and subsurface flow (including pipeflow) to surface waters, and leaching through the soil structure to groundwater. Examples of diffuse pollution sources include nutrient runoff and leaching from the use of fertilisers in agriculture, atmospheric deposition of nitrogen oxides from energy and transport emissions, and runoff of petroleum hydrocarbons and heavy metals from urban surfaces not serviced by stormwater collection and treatment. The most severe water quality impacts from diffuse sources of pollution occur during storm periods (particularly after a dry spell) when rainfall induces hillslope hydrological processes and runoff of pollutants from the land surface.

The distinction between point and diffuse sources of pollution is also a function of policy and regulation. Point sources of pollution are largely under control in OECD countries because they are easier to identify and more cost-effective to quantify, manage and regulate. In comparison, diffuse sources are challenging to monitor and regulate due to: *i)* their high variability, spatially and temporally, making attribution of sources of pollution complex;

ii) the high transaction costs associated with dealing with large numbers of heterogeneous polluters (e.g. farmers, homeowners); and *iii*) because pollution control may require co-operation and agreement within catchments, and across sub-national jurisdictions and countries (OECD, 2012a). For these reasons, diffuse sources of pollution and their impacts on human and ecosystem health largely remain under-reported and under-regulated.

The damage caused by pollution disposal depends crucially upon the ecosystem's ability to absorb and dilute pollutants, which depends upon the ecosystem condition. If emissions exceed the assimilative capacity (absorptive or dilution capacity) of the system, they will accumulate and cause damage to the ecosystem. The deterioration of water quality has subsequent knock-on impacts on the functioning of in-stream invertebrates, fish, and aquatic plant communities (Doledec et al., 2006; Ling, 2010). This causes negative feedbacks, particularly the ability of ecosystems to process contaminants, thereby causing pollutants to accumulate in the environment and cause further damage. Conversely, activities that enhance ecosystems can increase their ability to process pollutants. Therefore, in addition to pollutants being classified as point source or diffuse source, pollutants can also be classified by the ability of the ecosystem to adsorb them (Lieb, 2004). The distinction below is relevant from a policy perspective:

- A *stock pollutant* is a pollutant with a long lifetime and for which the ecosystem has little or no absorptive capacity. Stock pollutants therefore accumulate in the environment. Examples include heavy metals, toxic contaminants, such as dioxins and polychlorinated biphenyls (PCB's), and non-biodegradable plastics. Groundwater aquifers, lakes, reservoirs and estuaries, particularly those with low recharge rates and high residence times, are examples of water bodies where their ability to absorb pollutants is limited. By their very nature, stock pollutants create interdependencies between decisions made today and the welfare of future generations, and the costs of treatment and damages typically rise over time (although advances in technology can reduce costs).
- Conversely, a *flow pollutant* has a short lifetime for which the ecosystem has some absorptive capacity. For example, suspended sediments washed out by rainfall into rivers only have a short lifetime. Organic pollution can be transformed into less-harmful inorganic matter by bacteria in water bodies, although this process uses up available oxygen and can cause loss of aquatic life. Nutrients (nitrates and phosphates) are required for aquatic plant growth, but in excess can proliferate aquatic weeds and turn waterways eutrophic. Since rivers are flowing, the concentrations of river pollutants decline more quickly than aquifers and lakes once pollution emissions have ceased. For this reason, river pollutants are generally short-lived and are often considered as flow pollutants. It is important to also note that a flow pollutant in one place, such as a river, can result in a stock pollutant elsewhere, such as an estuary, and as such, the source and dispersal of pollutants needs to be looked at systemically.

An overview of the main pollutants

The quality of water resources are affected by a number of pollutants. Table 1.1 summarises the most common pollutants and their sources, and they are individually described in more detail in Annex 1.A1. It is important to note that many of these pollutants may occur in parallel, and may be derived from a number of different sources and actors.

Table 1.1. **Water pollutants and their typical sources**

Pollutant	Media of origin[1]	Type of source[2]	Examples of source
Excess nutrient losses	L, W, A	P, D	Nitrogen and phosphorus fertilisers from agriculture and domestic lawns, livestock manure and slurry, and wastewater treatment plants. Nitrogen deposition from atmospheric sources of nitrogen oxides (NOx), ammonia (NH^3) and nitrous oxide (N_2O).
Microbial contamination	L, W	P, D	Pathogenic bacteria and viruses from wastewater treatment plants, combined sewer overflows, animal waste, septic tanks, land application of biosolids.
Acidification	L, W, A	D	Atmospheric pollutants (sulphur, nitrogen oxides, ammonia) and acid mine drainage.
Salinity	L, W	D	Irrigation of salt-affected soils, sea level rise and over-abstraction of groundwater in coastal areas, de-icing salts used on roads.
Sedimentation	L, W	P, D	Erosion of topsoil and peatlands, livestock manure spreading on pasture, sediment release from dams, wastewater treatment plants, food processing waste.
Toxic contaminants	L, W	P, D	Pesticides and herbicides for plant and animal protection in agriculture, roadside and domestic use of herbicides. Heavy metals[3] from urban stormwater runoff, land application of biosolids, mining waste, industrial waste, and aging and corroding infrastructure. Natural arsenic groundwater pollution. Chlorinated solvents and other chemicals from transport, industry, spills, fracking, urban stormwater runoff and leaking storage tanks.
Thermal pollution	L, W	P, D	Warm water from urban stormwater runoff, and power plants and industrial manufacturers that use water as a coolant. Cool water from dam releases.
Plastic particle pollution	L, W	D	Rubbish dumping by individuals, the plastic production industry, recreational and commercial fishers and urban stormwater runoff.
Contaminants of emerging concern (CECs)	W	P	Commonly sourced from the household (through wastewater treatment plants), and to a lesser extent, from agriculture. Examples include pharmaceuticals, antibiotics, hormones, personal care products, perfluorinated compounds, flame retardants, plasticizers, detergent compounds, caffeine, fragrances, cyanotoxins, engineered nanomaterials, anti-microbial cleaning agents and their transformation products.

Notes: 1. Land (L), Air (A), Water (W); 2. Point source (P), Diffuse source (D); 3. The most common heavy metals are cadmium, mercury, lead, arsenic, manganese, chromium, cobalt, nickel, copper, zinc, selenium, silver, antimony and thallium.

Negative feedbacks on water quality

Other factors that contribute to degradation of freshwater ecosystems, and thus their ability to process contaminants, include the introduction of invasive alien species and anthropogenic geomorphological modifications to river systems. According to the IUCN, invasive alien species constitute the second most severe threat to freshwater fish species (Darwall et al., 2009), and the spread of invasive alien species is projected to increase due to a combination of increasing trade and climate change (Death et al., 2015; Rabitsch et al., 2016; Walther et al., 2009).

Changes in the natural geomorphology and flow of water bodies (e.g. channelised rivers, dams, canals, flood defences) can also have some effects on water quality and the ability of ecosystems to process and retain pollutants (Nilsson and Malm Renöfält, 2008; Wagenschein and Rode, 2008). For example, a study on the Weisse Elster River, Germany, revealed that the nitrogen retention rate is almost 2.4 times higher in a natural section of the river compared with a heavily modified and channelised section (Wagenschein and Rode, 2008).

Links between water quality and water quantity

Water quality and quantity are inextricably linked. Water pollution reduces the quantity of useable water and therefore exacerbates the problem of water scarcity. Water scarcity and droughts reduces the capacity for dilution of point source discharges to surface waters, and additional treatment of wastewater may be required to compensate for the lower dilution capacity of water bodies. Water scarcity also increases water temperatures which can affect freshwater ecosystems and nuisance algal growth. Conversely, high rainfall events and flooding induce diffuse pollution from land runoff (agricultural and urban) and trigger combined sewer overflows into rivers.

There can be competing demands for quality and quantity, driven by the requirements of the users. Different users require different volumes of water at different times and places, and different users are more or less sensitive to water quality. They also require varying levels of certainty regarding the availability and quality of water, and citizens have increasing expectations as regards the quality of water. There may be trade-offs and co-benefits between water quantity and quality management, and other important sectoral policies, such as land, energy, biodiversity, urban planning, health care, waste, construction, transport, and climate change (discussed in Chapter 4).

Ongoing challenges of diffuse pollution sources and eutrophication in OECD countries

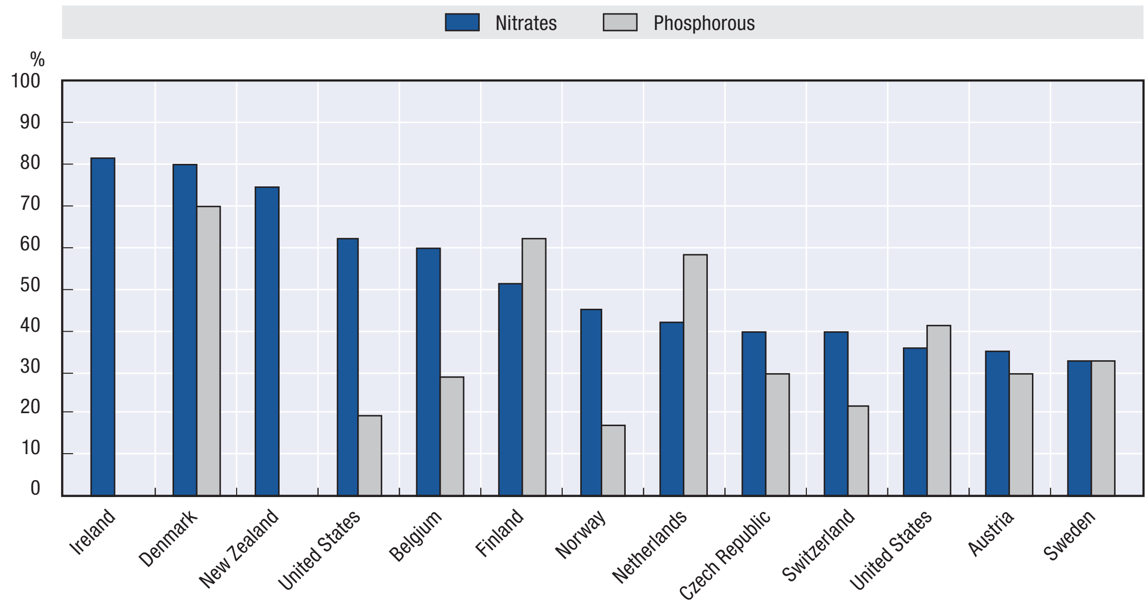
Eutrophication and harmful algal blooms in freshwater systems are quickly becoming a global epidemic. For instance, there have been reports of algal blooms in Lake Nieuwe Meer in The Netherlands (e.g. Johnk et al., 2008), Lake Erie in North America (e.g. Michalak et al., 2013), Lake Taihu in China (e.g. Qin et al., 2010), and Lake Victoria in Africa (e.g. Sitoki et al., 2012). Furthermore, the effects of climate change are expected to exacerbate existing eutrophication and algal bloom problems (Bates et al., 2008).

Figure 1.3 illustrates that the main source of nutrient loading in OECD countries is from agriculture, and this is largely because the methods and policies driving the "green revolution"[5] frequently lacked incentives for prudent use of inputs and promoted expansion of cultivation into areas that could not sustain high levels of intensification (Pingali, 2012) (advances in wastewater treatment have also increased the proportion of nutrient pollution from agriculture).

In Europe, nutrient pollution, leading to eutrophication, is a widespread problem which occurs in about 30% of water bodies in 17 member States (European Commission, 2012b). The latest assessments on the implementation of the Water Framework Directive 2000/60/EC (WFD), as well as studies carried out in the framework of international conventions, show that diffuse sources of pollution are the greatest obstacle to achieving "good" status in EU waters (European Commission, 2013). Agriculture remains the predominant source of reactive nitrogen discharged into the environment, and a significant source of phosphorus, mainly from livestock manure and fertilisers (European Commission, 2013).

In the midst of generally improving farm practices, there remain "hotspots" where water quality improvements are not yet forthcoming. For example, in the European Union between 2008 and 2011, almost 15% of groundwater monitoring stations exceeded 50 mg nitrate per litre (the WHO standard for nitrates in drinking water), and approximately 30% of river monitoring stations and 40% of lake monitoring stations were eutrophic or hypertrophic (European Commission, 2013). Some EU countries[6] have been convicted of failing to fulfil their obligations to the European Commission Nitrates Directive (91/676/EEC). In each case, the European Court of Justice has ordered member states to strengthen their regulations to comply with the Nitrates Directive.

Figure 1.3. **Percentage share of agriculture in total emissions of nitrates and phosphorus in surface water, OECD countries, 2009 or latest available year**



Notes: Countries are ranked in descending order of highest share of nitrates in surface water. For nitrates, the figures presented correspond to the year 2000 for Austria, Czech Republic, New Zealand, Norway, Switzerland and United States; 2002 for Denmark; 2004 for Finland and Ireland; 2005 for Belgium (Wallonia); 2008 for United Kingdom; and 2009 for Netherlands and Sweden. For phosphorous, the figures presented correspond to the year 2000 for Austria, Czech Republic, Norway, Switzerland and United States; 2002 for Denmark; 2004 for Finland; 2005 for Belgium (Wallonia); and 2009 for Netherlands, Sweden and United Kingdom.

Source: OECD (2013), OECD Compendium of Agri-environmental Indicators, OECD Publishing. http://dx.doi.org/10.1787/9789264181151-en.

StatLink http://dx.doi.org/10.1787/888932793015

Similar eutrophication problems have been reported in North America's Great Lakes, largely due to high phosphorus loading. For example, the water quality of Lake Erie (bordering the States of New York, Pennsylvania, Ohio and Michigan, and the Canadian province of Ontario) has been an ongoing concern in relation to nutrient overloading from fertilisers, and human and animal waste, leading to eutrophication, hypoxia and algal blooms. Despite some initial improvement in response to the 1972 Great Lakes Water Quality Agreement, and a reduction in phosphorus from sewage treatment plants and other point sources, diffuse sources from agriculture and domestic lawns have remained largely unaccounted for, and since the mid-1990s, Lake Erie has been returning to a more eutrophic state (Scavia et al., 2014).

In 2014, the eutrophication of Lake Erie resulted in a seven-day tap water ban for Toledo, Ohio when blooms of toxic algae shut down drinking water supplies from the lake, affecting more than 400 000 people, and closing local restaurants, universities and public libraries (Circle of Blue, 2014). Furthermore, the water ban occurred after the city of Toledo increased spending on water treatment chemicals - USD 4 million in 2013; double what it spent in 2010. Further upgrades estimated at USD 321 million are needed for the city's treatment plant; costs that are to be met by the tax payer. It is estimated, that in order to reduce eutrophication and the central basin hypoxic area to levels observed in the early 1990s, total phosphorus loading will need to be reduced by 46% from the 2003–2011 average (Scavia et al., 2014). In acknowledgement of the ongoing water quality problems, the hypoxia-based loading targets were revised in the 2012 Great Lakes Water Quality Agreement, and in 2016 the governments of Canada and the United States announced bi-national phosphorus load reduction targets of 40% for Lake Erie.

In the United Kingdom (UK), water quality has improved as a result of a major investment programme focusing on point source pollution from industrial discharges and wastewater treatment plants. However, diffuse pollution, coupled with remaining point source pollution, mean that approximately 15% of the urban river network in England and Wales fall into the poor or bad categories of the WFD (Royal Commission on Environmental Pollution, 2007). Furthermore, at least 50% of UK groundwater used for public supply is showing significant deterioration in quality (Royal Geographical Society, 2012; UK Environment Agency, 2015) with sources of public water supply affected (although well-treated) by agricultural pollution (including historical pollution), particularly in terms of high levels of nitrates and pesticides (Water UK, 2013).

In New Zealand, overall water quality is good by international standards, but this varies around the country depending on land use, climate and geology (MfE, 2013; MfE and StatsNZ, 2015). In particular, water quality in some regions has suffered from the steady expansion of intensive dairy farming (OECD, 2015a). Nitrogen is continuing to increase in New Zealand rivers – the result of accumulative pollution from rural and urban sources. To address water quality concerns, the New Zealand government now requires regional governments to manage point and diffuse discharges within set environmental limits (MfE, 2014a). Results have already started to show improvement, with some water bodies making significant recoveries, such as the Rotorua Lakes (MfE, 2014b). There have also been improvements in phosphorus levels in rivers due to riparian planting, reduced phosphorus fertiliser-use and soil conservation efforts over the past 10-20 years (MfE and StatsNZ, 2015).

In Chile, significant progress has been made in providing improved sanitation in both urban and rural areas such that 99% of the population now have access to improved sanitation (WHO/UNICEF, 2015) and nearly 70% are connected to a public wastewater treatment plant with secondary or tertiary treatment (OECD, 2013a). However, there are two ongoing concerns regarding water quality in Chile. Firstly, diffuse pollution from agriculture is of concern with high levels of nitrates and pesticides observed in surface water. Secondly, mining and other industrial activities, mainly in northern and central Chile, are major sources of pollution. It is estimated that over 60 % of industrial discharges (including tailings) flows into sewerage networks, mixes with domestic sewage and is deposited in the river basins and irrigation channels, or is discharged to the soil or directly into the sea. This is of particular concern, especially in regions where water flows for dilution of acidity, hazardous chemicals and heavy metals are small or non-existent.

In Japan, there has been a significant reduction in heavy metals in recent years owing to tighter regulations on industrial wastewater. Environmental quality standards for organic pollution and nutrients are not being met in approximately 10% of Japan's water bodies. In particular, there has been little improvement in enclosed water areas such as inland seas, inlets, lakes, and reservoirs (Government of Japan, 2015a). Eutrophication occurs in a large number of Japanese lakes and reservoirs, many of which are used for municipal and industrial water supply (Government of Japan, 2015b). As a result, algal blooms are frequent and disrupt water treatment facilities.

Korea has invested in water infrastructure over the last 50 years, reaching a high level of access to water supply and sanitation services with 90% of the population connected to a public wastewater treatment plant with secondary or tertiary treatment (OECD, 2013a). Regulations and economic instruments have been implemented to manage point source pollution and improve water quality since the early 1990s. However, there are ongoing challenges with nutrient pollution in the four major rivers with the occurrence of eutrophication and frequency of algal blooms increasing. It is estimated that diffuse pollution sources (from both urban and rural areas) were responsible for 68% of the total pollutant loading in rivers in 2010. This is projected to reach 72% by 2020, primarily due to urbanisation and an increase in paved impervious areas and stormwater runoff (Ahn, 2015). Korea's Second Comprehensive Nonpoint Pollution Source Control Measure (2012-2020) aims to reduce diffuse sources of BOD and total phosphorus in the four major rivers by 24.6% and 22.5% respectively, by 2020.

In summary, OECD countries face significant challenges regarding the control of diffuse pollution sources, with the most prevalent water quality problem being nutrient loading and eutrophication. In addition to the challenging nature and associated costs of diffuse pollution management, there are also ecosystem delays (the time difference between implementation of abatement measures and actual measurable effects) due to the long-time scales of eutrophication (Gustafsson et al., 2012). Ecosystem responses to measures that reduce eutrophication illustrate that feedbacks and climate change impacts can keep ecosystems in a certain state and cause delays of decadal scale in ecosystem response (Varjopuro et al., 2014). These factors are illustrated in the case of the Baltic Sea (Box 1.1).

Box 1.1. **Ecosystem delays and ongoing nitrogen and phosphorus pollution of the Baltic Sea**

The Baltic Sea has acted as sink for much of the nutrient loss from agricultural diffuse pollution sources from Scandinavia, Finland, the Baltic countries, and the North European Plain. Levels of nitrogen and phosphorus are four and eight times greater than what they were in the early 1900s (WWF, 2015). In order to achieve good ecological status under the EU Water Framework Directive, it is estimated that phosphorous and nitrogen inputs to the Baltic Sea need to be reduced by about 42% and 18%, respectively (Skogen et al., 2014). In response, the HELCOM Baltic Sea Action Plan was launched; an ambitious programme to restore the good ecological status of the Baltic marine environment.

However, despite a reduction in nutrient loading in recent years, little change in the eutrophic effects of the Baltic Sea has been observed (WWF, 2015). Furthermore, simulations indicate that no future improvement in the water quality of the Baltic Sea can be expected from the decrease in nutrient loads in recent decades (Skogen et al., 2014, Gustafsson et al., 2012). This is for three reasons:

1. The time scales of eutrophication are exceptionally long and all efforts taken to reduce nutrient loads up to now have basically resulted in maintaining the status quo (Gustafsson et al., 2012);
2. Climate change is stimulating eutrophication as higher temperatures in the Baltic Sea region increases the growth and decomposition rates of the algae, thereby enhancing oxygen depletion and counteracting land practices that reduce eutrophication (WWF 2015, Lennartz et al., 2014); and
3. The expected development of agriculture in the new EU countries around the Baltic Sea will worsen the conditions measurably if no additional action is taken to reduce the harmful effects of nutrient losses (WWF, 2015, Gustafsson et al., 2012).

Sources: Gustafsson et al. (2012); Lennartz et al. (2014); Skogen et al. (2014); WWF (2015).

Water quality and climate change

Anthropogenic warming of the climate system is "unequivocal" (IPCC, 2014a). Concentrations of greenhouse gases have increased to unprecedented levels resulting in warming of the atmosphere and ocean, reductions in snow and ice, sea level rise, ocean acidification, changes in the global water cycle, and changes in climate extremes (IPCC, 2014a).

The IPCC (2014a) predicts that climate change will have significant additional impacts on existing water quality challenges, due to altered precipitation and flow regimes, altered thermal regimes, and sea level rise. With a "high level of confidence", many forms of water pollution will be exacerbated – from sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt, as well as thermal pollution, with possible negative impacts on freshwater ecosystems, human health, and water system reliability and operating costs (Bates et al., 2008). The interaction of increased temperature; increased sediment, nutrient and pollutant loadings during heavy rainfall, runoff and soil erosion; increased concentrations of pollutants during droughts; and disruption of treatment facilities during floods, will reduce raw water quality and pose risks to drinking water quality even with conventional treatment (IPCC 2014a; Delpla et al., 2009). For example, under a drier future (projected by the CSIRO global circulation model), coupled with medium levels of income and population growth, the number of people living in environments with high water quality risks[7] due to excessive nitrogen and phosphorus loading will raise to one-third of the global population by 2050 (172% and 129% increase for nitrogen and phosphorus respectively), and for BOD, one-fifth of the population (144% increase) (IFPRI and Veolia, 2015).

Sea-level rise is projected to extend areas of estuaries and increase salt-water intrusion of freshwater aquifers, resulting in a decrease of freshwater availability for humans and ecosystems in coastal areas (Bates et al., 2008). All of these climate change induced alterations in temperature and flow regimes, water quality and salinity, will lead to shifts in freshwater species distributions, reduced ecosystem functioning and further exacerbate existing water quality problems (IPCC, 2014b). A summary of the effects of climate change on water quality is presented in Table 1.2.

Water quality issues were identified as a main concern in 15 OECD countries in the report on *Water and Climate Change Adaptation* (OECD, 2013b). For example, in Canada, warmer conditions will increase surface water temperatures, decrease the duration of ice cover and lower water levels, and is projected to result in higher pollutant concentrations. In addition, increased flooding is also expected to contribute to water quality degradation. Korea anticipates an increase in the risk of algal outbreaks in public waters due an increase in water temperature and changes in rainfall patterns. They also expect an increase in the risk of water quality degradation due to diffuse source pollution resulting from an increase in frequency and intensity of high rainfall events. In Chile, surface water quality is expected to decline due to increased flooding and storm events, and reduced capacity for dilution during droughts. Further groundwater salinisation and pollution is anticipated in coastal zones and northern areas of Chile. Denmark, the EU, Japan, Mexico, and the Netherlands are also concerned about groundwater salinisation associated with sea level rise, reduced groundwater recharge and increased demand for irrigation during the dry season (OECD, 2013b).

The effects of climate change at the local level should be interpreted cautiously, considering the type of water body, the pollutant of concern, the hydrological regime, and the many other factors identified in Figure 1.2 (Whitehead et al., 2009). In general, current information about the water quality impacts of climate change is limited, including their socio-economic dimensions (Bates et al., 2008). There is a need to improve understanding and modelling of the impacts of climate change on water quality at scales relevant to decision making, and of vulnerability to and ways of adapting to those impacts (IPCC, 2014a). Management approaches need to account for uncertainties around climate change projections regionally and locally, and the impacts on water quality.

Table 1.2. **Effects of climate change on water quality**

Direct climate change impacts and indirect effects on water quality			
Increased severity and frequency of flooding	**Increased severity and frequency of droughts**	**Sea level rise**	**Increased water temperature**
Disruption of treatment facilities during floods, subsequent risks to drinking water quality and human health (e.g. infectious diseases). Increased runoff and nutrient loading leading to increased eutrophication. Increased runoff and greater loads of heavy metals, salts and other pollutants. Increased soil erosion, sediment, organic matter and pathogens loadings, subsequent impairment of conventional drinking water treatment. Increased release of combined sewer overflow. Increased re-suspension of riverbed and lakebed sediments containing high metal concentrations, associated contamination of water and drinking water risks, transfer of contaminated sediments to floodplain soils used for agriculture. Impacts on freshwater ecosystems: extinction and shifts in distribution of species, changes in river geomorphology and habitat, increased dispersal of invasive species, reduced functioning of ecosystem services.	Reduced dilution of pollutants from point sources as a result of a reduction in rainfall, groundwater recharge and glacier retreat. Soil shrinking and damage/cracking of water infrastructure, subsequent risks to drinking water quality and environment, and increased maintenance costs. Increased severity and frequency of forest wildfires, increase in erosion and reduced filtration/regulation ecosystem services affecting water quality. Impacts on freshwater ecosystems: extinction and shifts in distribution of species, reduced functioning of ecosystem services.	Extension of estuaries and salt water intrusion of groundwater aquifers, especially in areas where rainfall (and recharge) is expected to decline and water demand to increase. Increased treatment costs for drinking water use, industrial production and agriculture. Intrusion of saline water to sewers, subsequent increase of corrosion and maintenance of water infrastructure. Impacts on freshwater ecosystems: extinction and shifts in distribution of species, loss/reduced functioning of ecosystem services.	Reduced solubility of oxygen, higher metabolism, and increased stratification of the water column, resulting in increased hypoxia, algal blooms and associated toxins, with subsequent risks to drinking water quality and recreational use. Increase of the growth and survival of pathogens, risks to drinking water quality and human health (infectious diseases). Impacts on freshwater ecosystems: extinction and shifts in distribution of species, loss/reduced functioning of ecosystem services. Increase in soil erosion associated with melting of permafrost.

Sources: Bates et al. (2008); Death et al. (2015).

Water quality challenges for cities of OECD countries

The impacts on water quality, whether rural or urban in source, largely fall on cities, where the value of assets at risk is concentrated. Future population growth, urbanisation and more stringent standards (such as those imposed under the WFD), will place extra demands on existing systems and mean that significant investment in drinking water and wastewater treatment infrastructure are required in order to prevent water-related disease outbreaks and not place additional nutrient, pathogenic and organic loads in river systems. Furthermore, as our understanding of contaminants of emerging concern (CECs) and their effects on human and environmental health improves, future regulations may require treatment to remove CECs (conventional water purification and wastewater treatment plants are not effective at removing CECs).

Continual control of point source pollution is essential for water quality. However, some countries have reached the economic limit in terms of public water supply and sewerage connection and must find other ways of serving small, isolated settlements (OECD, 2011). Decentralised water and wastewater systems, and water fit for purpose, are potential solutions to this problem (see OECD, 2015b). Without effective wastewater treatment plants and sewerage systems, wastewater effluent can add to the existing problems of diffuse pollution from agriculture in the following ways:

- *Wastewater effluent without the removal of nitrogen and phosphorus* (i.e. from primary or secondary wastewater treatment plants[8]) adds to the concentration of nutrients in receiving water bodies from diffuse sources of pollution. The problem is exacerbated during dry periods when a reduction in river flow decreases the capacity of river systems to dilute wastewater effluent discharges;

- *Combined sewer overflows* discharge untreated wastewater directly into watercourses during storm events, when the storage and treatment capacity of wastewater treatment plants are exceeded. A classic example is the River Thames in London which essentially acts as an open sewer during periods of significant rainfall (Box 1.2).
- More modern separate sewer systems isolate wastewater from stormwater for separate treatment. However, during extended storm events, when the stormwater storage and treatment capacity of wastewater treatment plants are exceeded, *untreated (but screened) stormwater* and associated contaminants are discharged directly to the receiving environment. In addition, there are reported occurrences of *accidental cross connection of pipes* which result in the direct discharge of untreated wastewater to the environment. For example, cross-connections have been recognised as a problem in the United Kingdom (Royal Commission on Environmental Pollution, 2007);
- *Leakages from aging sewer infrastructure, and lack of maintenance,* contribute to diffuse pollution of groundwater; and
- *Dumped or landfilled sewage sludge* can leach nutrients, pathogenic organisms and heavy metals to groundwater (Van Den Berg, 1993). *Land application of sewage sludge and irrigation with wastewater* that is not adequately treated can also contribute to surface runoff and leaching of nutrients, pathogens and heavy metals.

Box 1.2. **Combined sewer overflows contribute to diffuse pollution: Example of the London sewer system**

The London sewer system discharges untreated sewage and diluted stormwater to the River Thames, on average, once per week (Thames Tideway Tunnel, 2015). This is because the existing infrastructure, now 150 years old and designed for a maximum capacity of 4 million people, can no longer cope with the stresses of serving 8 million people and the change in weather patterns associated with climate change. In order to protect the River Thames from increasing pollution, and to meet European environmental standards, a major new sewer - The Thames Tideway Tunnel – will be constructed at considerable cost (GBP 4.1 billion) to intercept current overflow discharge points in the system and transfer the sewage to Beckton Sewage Treatment Works for treatment before discharge (a case study on financing the Thames Tideway Tunnel is presented in Chapter 3).

Source : Thames Tideway Tunnel (2015).

The effects of climate change on water quality detailed in the prior section will mean water and sanitation utilities will be confronted by further economic and operational challenges requiring additional or new treatment facilities and technologies:

- *Higher water temperatures* will stimulate more algal blooms and increase human health risks from cyanotoxins and natural organic matter in water sources (IPCC, 2014b). Temperature increases and precipitation pattern changes associated with climate change are also predicted to increase the growth, survival, and transport of enteric bacteria (Liu et al., 2013) and therefore increase the risk of water-borne diseases [“very high confidence”] (IPCC, 2014b). This will require additional or new treatment of drinking water. On the plus side, warmer water can increase biological reactions in drinking and wastewater treatment, particularly biological nitrogen removal, thereby potentially reducing treatment costs (Kadlec and Reddy, 2001). Conversely, cooler water from increased snow and glacier melt can have the opposite effect (Plósz et al., 2009).

- *Drier conditions* will increase pollutant concentrations, due to reduced environmental flows and dilution capacity (IPCC, 2014b), and therefore may require effluent to be treated to a higher quality. The risk of contamination of water supplies will also increase in response to reduced dilution of upstream pollution and potential increases in water-related disease outbreaks, harmful algal blooms and other health effects. Wastewater reuse will increasingly be a cost-effective alternative of conventional water supply. Soil shrinking due to reduced soil water content may induce cracking of water mains and sewer pipes, making them vulnerable to infiltration and exfiltration of water and wastewater. The combined effects of warmer temperatures, increased pollutant concentrations, longer retention times, and sedimentation of solids may lead to increasing corrosion of sewers, shorter asset lifetimes, increased risk of drinking water pollution, and higher maintenance costs (IPCC, 2014b).
- *Wetter conditions* will increase runoff, which increases loads of pathogens, nutrients, and suspended sediment (IPCC, 2014b), particularly following a dry period, and increases the risk of combined sewer flooding, water-related disease outbreaks, harmful algal blooms and other health effects. The maximum loading and capacity of wastewater treatment plants may need to be increased, and overflow infrastructure adapted, to cope with increased volumes of wastewater in short periods (Plósz et al., 2009). Increased storms, floods and sea level rise may be harmful to infrastructure, particularly given that wastewater treatment plants are often located in low-lying, coastal areas. Rising downstream water levels may make pumping drinking water and effluent a requirement, increasing energy needs and costs.
- *Sea level rise* will increase the salinity of coastal aquifers, in particular where groundwater recharge is also expected to decrease (IPCC, 2014b). This will require additional or new treatment facilities to treat water for potable consumption, and increased maintenance to reduce the effects of infrastructure corrosion associated with high salinity. High salinity may also have consequences for industrial production and agriculture as water quality standards are exceeded (Zwolsman et al., 2011). Sea level rise and strong waves during storms may endanger the location of wastewater treatment plants in low-lying coastal areas.
- *Reliance on green infrastructure and ecosystem services*, such as regulating ecosystem services provided by forested catchments and wetlands, may be jeopardised with increased forest wildfires, pest and disease outbreaks, increased tree mortality and other indirect effects of climate change (such as land use change and increased irrigation for food security) (Smith et al., 2011). Further investments in the protection and conservation of green infrastructure and natural capital may complement conventional grey infrastructure and may be more cost-effective than conventional grey infrastructure alone.

Challenges also remain regarding the upgrade of ageing water supply and sewage systems (OECD, 2014; OECD, 2015b). For example, in some parts of the United Kingdom, sewerage systems are approaching 200 years old (Royal Commission on Environmental Pollution, 2007). In the city of Flint, Michigan, United States, a contaminated public water supply, ageing infrastructure and inadequate maintenance of the city's water distribution network were part of what caused the Flint Water Crisis (Box 1.3). The case study highlights the importance of historic pollution, financing and investment in water infrastructure and maintenance, compliance with water quality standards, and transparency and communication to the public. Drinking water risk assessments can help identify and prioritise where interventions (e.g., water source protection, wastewater treatment upgrades, water distribution system repairs or replacements, and/or optimisation of filtration and disinfection) are required to reduce risks (DeFelice et al., 2015).

Box 1.3. **The Flint Water Crisis, Michigan, United States**

The Flint water crisis of 2014-2015 was the result of a series of governance and infrastructure failures that resulted in drinking water being contaminated with lead and associated ill health effects to the city's 100 000 residents. The crisis provides a number of lessons regarding the political cost of deferring critical infrastructure investments and prioritising economic concerns over the provision of clean, safe water.

The Flint authorities switched the public water supply in April 2014 from Lake Huron (treated and supplied by the Detroit Water and Sewerage Department), to the local Flint River, which had not been used for consumption since the early 1960s because of high industrial pollution. The decision to switch was made in an attempt to obtain more affordable water rates for residents, 40% of which live below the poverty line. However a series of problems was associated with this switch to the Flint River source:

- The water from Flint River required significant chemical treatment before distribution which subsequently caused corrosion of ageing lead pipes which led to extremely elevated levels of lead in drinking water. Officials failed to apply corrosion inhibitors.
- Residents began complaining about the colour, taste and odour of public water supply almost immediately.
- High levels of chlorine used to disinfect the drinking water, in combination with the organic matter present in the supply, resulted in elevated levels of Trihalomethanes (with which long term exposure has been linked to cancer and other diseases) in August 2014. A violation notice by the Michigan Department of Environmental Quality (DEQ) was issued to the city in January 2015.
- The first indication of any corrosion was with a General Motors plant in Flint complaining that the water was corroding car parts. It stopped using Flint water in October 2014.
- In February 2015 the first independent studies were released showing lead contaminated drinking water and elevated levels of lead in children.
- EPA officials warned the state DEQ repeatedly, beginning in February 2015, that the lack of corrosion control in Flint water mains would lead to a serious lead safety hazard in drinking water supplies.
- In October 2015, the Governor admitted the situation was far graver than he initially understood and announced a USD 12 million plan to transfer Flint back to its previous supply with the city of Detroit.

The above problems resulted in a state of emergency declared by the Governor on 5 January 2016, and a federal state of emergency declared by President Obama on 16 January 2016. Researchers estimate between 6 000 and 12 000 children have been exposed to extremely high levels of lead that has the potential to cause irreversible health and neurological problems. As such, the Flint water crisis will have long term impacts associated with the public trust of government official and regulators, and long term health costs to the residents of Flint.

The evidence is mounting that federal, state and local officials ignored or neglected indicators of a growing water crisis. A number of investigations have been opened, several government officials have resigned over the mishandling of the crisis, and a number of lawsuits have been filed against government officials.

Sources: AWWA (2012); Circle of Blue (2016); Fisher (2016); The Guardian (2016); The Guardian (2015); USA Today (2016); Walton (2016).

Notes

1. Pollution is due to the influence or activities of people. Water contamination may be natural or caused by pollution (anthropogenic).
2. Pollution "hotspots" are specific locations that are identified as suffering from high pollution, or most likely to be subject to water pollution risks in the future, due to higher hazard, exposure and/or vulnerability.
3. Climate change is projected to increase water temperatures and precipitation intensity, and induce longer periods of low flows which will "exacerbate many forms of water pollution, including sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution" (Bates et al., 2008).
4. Biochemical Oxygen Demand (BOD) is an indicator of the total load of organic matter in a water body. A high BOD reduces available supply of dissolved oxygen and causes mortality of aquatic organisms.
5. A significant increase in agricultural productivity beginning in the 1940s and resulting from the introduction of high-yield varieties of grains, the use of irrigation, fertilisers and pesticides, and improved farm management techniques.
6. In recent years, France, Greece, Poland and Luxembourg have been taken to court over nitrate pollution (European Commission 2015), and Estonia has been warned (European Commission, 2016).
7. High pollution risk is defined as adverse impacts on humans, the environment, and the economy are likely to occur. These figures are conservative as populations living in basins without water quality data are excluded.
8. Effective secondary treatment typically removes 85% of the suspended solids and BOD, and some heavy metals. When coupled with a disinfection step, these processes can provide substantial, but not complete, removal of bacteria and viruses. Secondary treatment removes little phosphorus, nitrogen, non-biodegradable organics, or dissolved minerals. Tertiary (advanced) treatment is required to remove more than 99 % of all the impurities from sewage (including nitrogen and phosphorus), producing an effluent of almost drinking-water quality. Advanced treatment processes are sometimes combined with primary or secondary treatment to remove phosphorus (FAO, 1992; World Bank, 2015).

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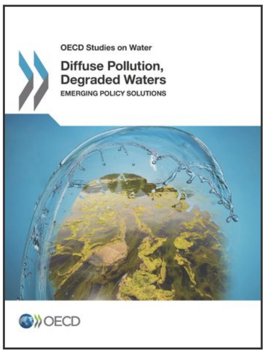

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