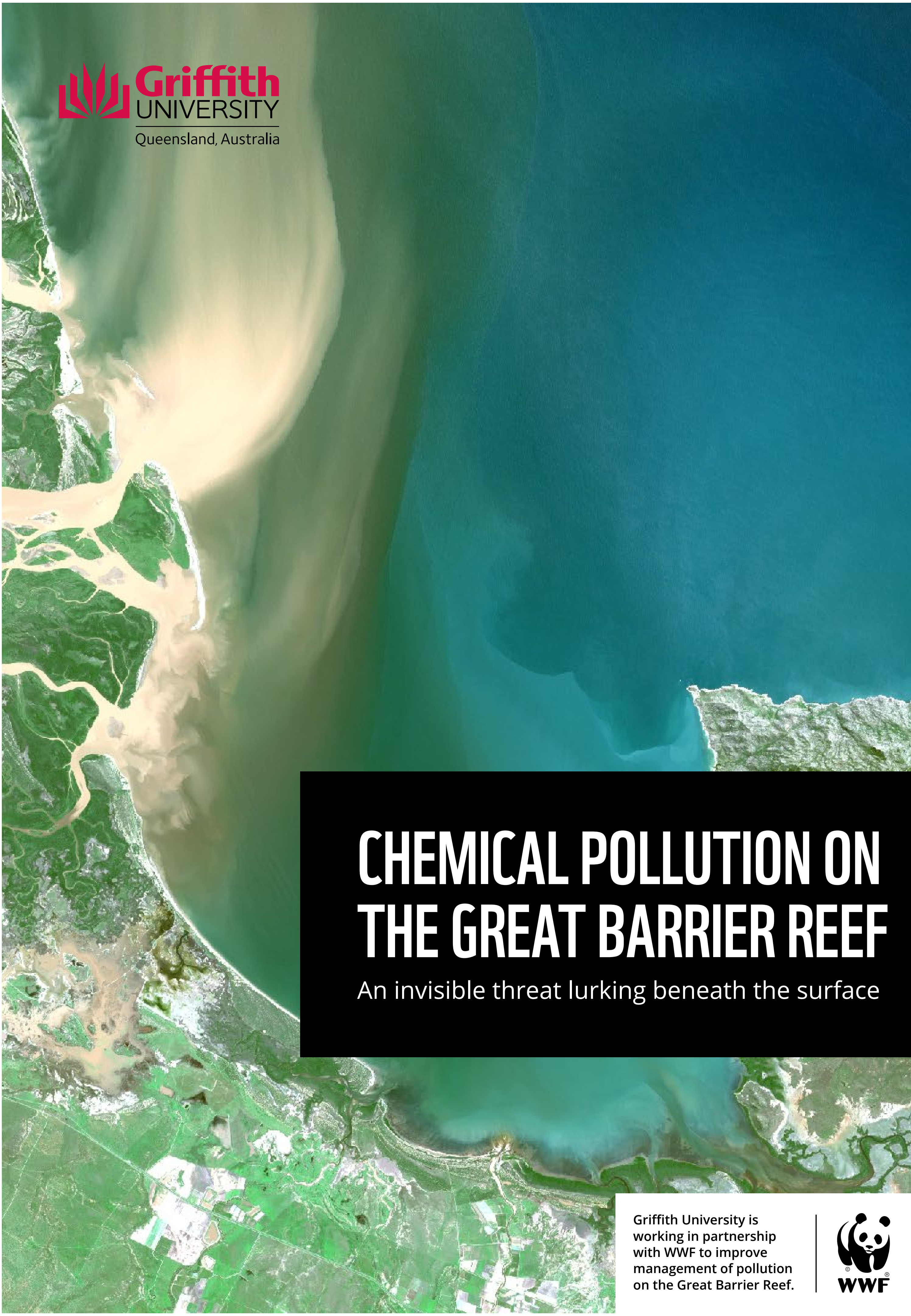

Griffith UNIVERSITY Queensland, Australia

CHEMICAL POLLUTION ON THE GREAT BARRIER REEF

An invisible threat lurking beneath the surface

Griffith University is working in partnership with WWF to improve management of pollution on the Great Barrier Reef.

WWF

Acknowledgements

This report was written by Griffith University and WWF-Australia. We would like to thank Frederieke Kroon (The Australian Institute of Marine Science), Michael Warne (The University of Queensland, Queensland Department of Environment and Science and Coventry University), Nick Heath, and Jo Immig (National Toxics Network) for reviewing the science in this document, and thank Caitlin Smith (WWF-Australia) and Kimberly Riskas (Blue Dot Scientific) for their significant contributions and review of final drafts. This report was funded by philanthropic donations through Elizabeth Gabler Charitable Trust and Perpetual Foundation Alan (AGL) Shaw Endowment.

Suggested citation: van de Merwe, JP, Neale, PA, Madden Hof, C, Leusch FDL (2020). Chemical pollution on the Great Barrier Reef: An invisible threat lurking beneath the surface. Griffith University and WWF-Australia Report, Queensland, Australia.

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WWF

WWF is one of the world's largest and most experienced independent conservation organizations, with over 5 million supporters and a global network active in more than 100 countries. WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

Published in December 2020 by WWF – WWF-Australia.

Edited by Kimberly Riskas.

Designed by Candy Robertson.

ISBN 978-2-940529-95-7

Cover photography:
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KEY MESSAGES

- The Great Barrier Reef is being polluted with chemical contaminants
- Toxic chemicals are accumulating in many reef species, including those eaten by humans
- The Rivers to Reef to Turtles Project uncovered unsafe levels of trace elements and thousands of organic chemicals, including pharmaceuticals and industrial chemicals, in coastal green turtles
- Most of the 4,000+ chemical compounds detected could not be identified in a global chemical database – meaning green turtles are being exposed to new and emerging contaminants
- Chemical pollution, a contributor of poor water quality, is negatively impacting the health of green turtles on the Great Barrier Reef
- The full extent of environmental and human health effects of chemical pollution is not well understood
- Routine water quality monitoring programs only screen for a small number of chemicals – just the tip of the iceberg

KEY RECOMMENDATIONS

IDENTIFY toxic hotspots on the Great Barrier Reef through expanded chemical contamination monitoring

OVERHAUL catchment-wide chemical identification and regulation to eliminate unsafe use

DEPLOY improved and innovative monitoring techniques as early warning signals of harmful chemical change

REGULATE to ensure industry reef users deliver Reef Plan 2050 land and catchment management targets

ACT quickly to remediate toxic hotspots to help futureproof the Reef

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We now know that thousands of chemicals are lurking within our waters, accumulating in our food and harming our wildlife. Identifying these toxic substances and understanding their effects will be the key to protecting human health and safeguarding clean, sustainable seas - in the Great Barrier Reef, Australia and globally.

1. CHEMICALS ARE ACCUMULATING IN THE ENVIRONMENT AND HARMING FRAGILE HABITATS, WILDLIFE AND HUMANS

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From sunscreens to cleaning products, chemicals are ubiquitous in our daily lives. There are over 160 million unique chemical substances on our planet, with 15,000 new ones recognised every day – equivalent to one new chemical every 6 seconds.[1]

Around 350,000 of these chemicals are registered for widespread production and use.[2] In 2017, the global chemical industry produced 2.3 billion tonnes of chemicals worth a staggering AU$8 trillion.[3] While modest by global standards, **Australian chemical production—including plastics—is the nation's second biggest manufacturing industry.**[4] Chemical production is expected to increase significantly in the coming decades, outpacing the rate of human population growth[5] (Figure 1).

GLOBALLY, ONE NEW CHEMICAL IS REGISTERED EVERY 6 SECONDS.[1]

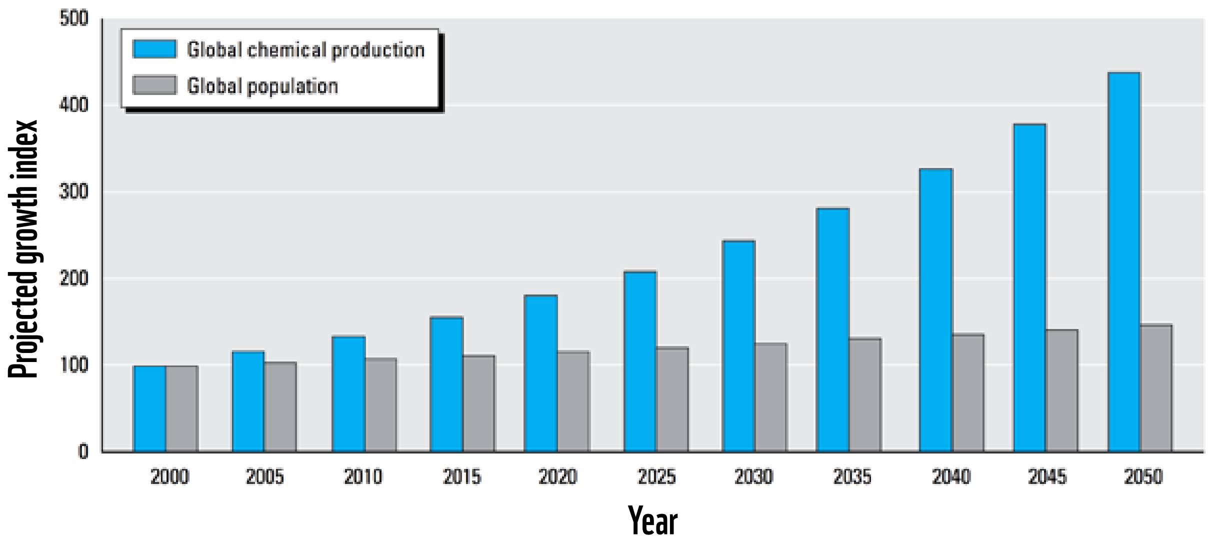

Figure 1: Projected growth of global chemical production (blue) and human population (grey).[5]

Despite regulations surrounding proper use and disposal, a variety of chemicals are released into the environment and transported into rivers, waterways and eventually the ocean. Sources of chemical pollution include agricultural runoff, bushfires, wastewater discharge, oil spills, mismanaged waste disposal and urban stormwater (Figure 2). The types of chemical substances include pesticides, fuel products, pharmaceuticals and personal care products, metals, industrial by-products, toxicants leached from mismanaged plastic waste and flame retardants from bushfires (Appendix 1).

Once in the marine environment, chemicals can enter the food web. They accumulate in plants and animals and can cause harm by disrupting important biological processes, such as reproduction, growth, development and behaviour.[6,7] Studies show that algae, seagrass, coral, invertebrates and reef fish are negatively affected by pesticides and herbicides used in agriculture.[8,9,10,11,12] Emerging contaminants, such as pharmaceuticals and ultraviolet (UV) filters in sunscreens, have also been shown to cause coral bleaching[13,14] and liver dysfunction in green sea turtles (*Chelonia mydas*).[15,16]

Compounding the problem, toxic chemicals don't always break down. Rather, they can be passed up the food chain and concentrated at higher trophic levels.[17,18] Known as biomagnification, this accumulation of persistent contaminants affects long-lived marine megafauna such as dolphins[19] and marine turtles,[20,21,22] which have important environmental, cultural and tourism value.[23]

In response to concerns about long-lasting environmental contamination, the global community created the Stockholm Convention on Persistent Organic Pollutants (POPs) in 2001. The agreement initially focussed on 12 POPs (the so-called "Dirty Dozen"), but is continually being expanded, and now includes 35 chemicals and chemical classes, including several flame retardants used to fight bushfires (Box 1).

As awareness grows, more than 40,000 chemicals have been identified as contaminants of emerging concern, including pharmaceuticals, disinfectants, UV filters in sunscreens, flame retardants and others.[24,25]

It is now vitally important to thoroughly understand which emerging contaminants are present in the marine environment, how they are affecting environmental health and what this means for the humans that depend on healthy oceans.

BOX 1. BUSHFIRES AND CHEMICAL CONTAMINATION

Australia's bushfire crisis has dealt a heavy blow to many terrestrial species and landscapes. The catastrophic fires of summer 2019/2020 burned 12.6 million hectares of forest and bushland, destroyed over 3,000 homes and killed and displaced almost 3 billion Australian animals, according to a WWF-commissioned study. On top of this devastation, bushfire combustion releases airborne toxic chemicals called dioxins and furans,[26] which are types of persistent organic pollutants (POPs). To extinguish the blazes, firefighters use foams containing flame retardants—chemicals which can be harmful to environmental and human health.[27,28]

Wind and rain transport bushfire ash, dioxins, furans, flame retardants, metals and other combustion by-products into rivers, lakes and oceans. Dioxins and furans are persistent, accumulative and extremely toxic to aquatic organisms.[29] Contamination from flame retardants has been shown to damage habitat and cause fish death.[30,31] While these effects are concerning, there is still much we do not know. More research is needed to understand the effect of bushfires on marine and coastal ecosystems.

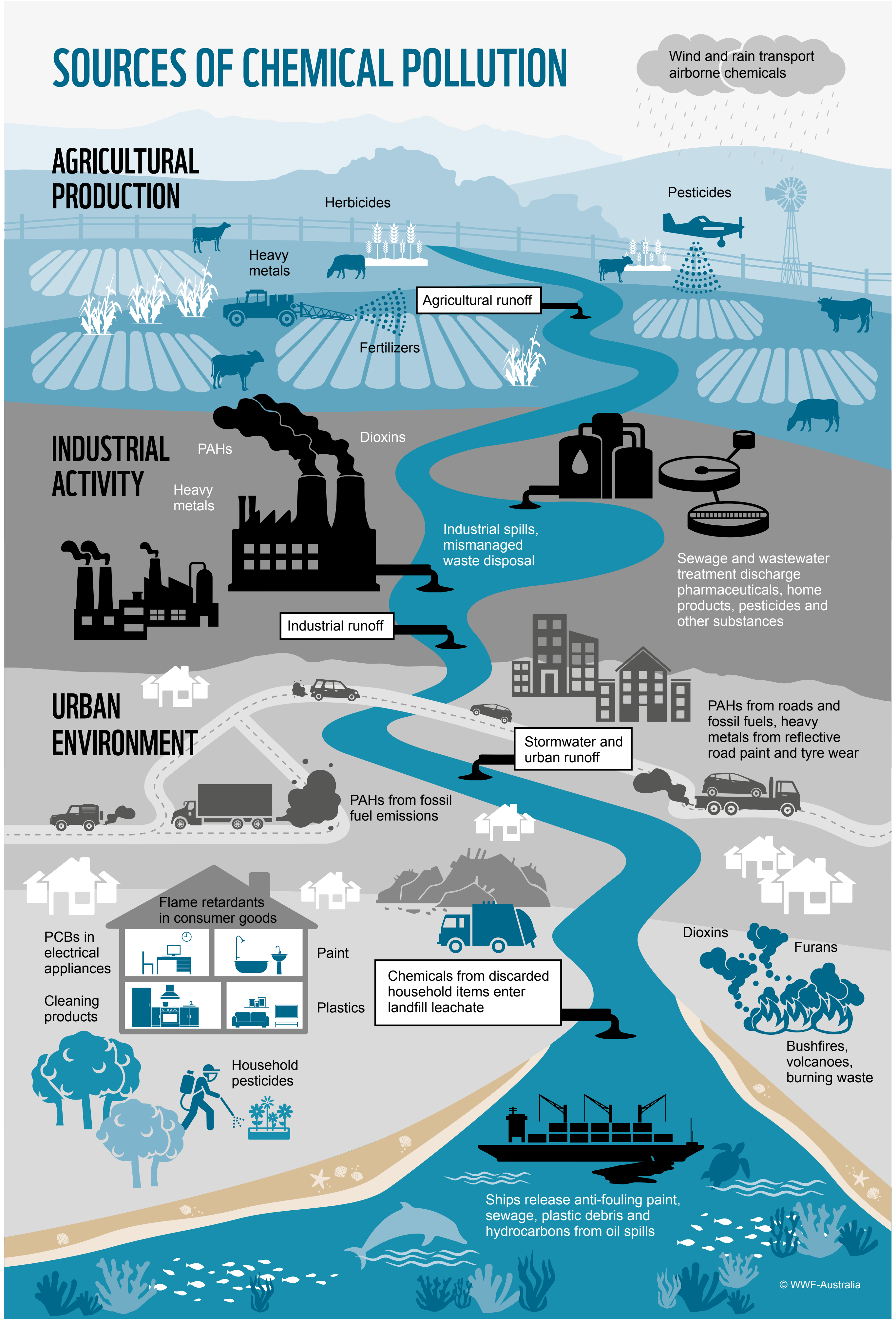

Figure 2: Chemical toxicants enter the marine environment as a result of human and natural activities throughout a catchment area.

IMPLICATIONS FOR HUMAN HEALTH

Since "you are what you eat", there is an intimate relationship between environmental contamination and the accumulation of chemicals in humans. People are exposed to chemicals through drinking water[32] and contaminated food.[33,34,35] Pesticides have been shown to cause poor health in several species eaten by humans, including barramundi (*Lates calcarifer*)[36,37] and coral trout (*Plectropomus spp*).[38] Indigenous peoples, in particular, consume long-lived species, such as marine turtles and dugong, as part of their cultural activities—placing Traditional Owners at risk of ingesting high quantities of chemicals through biomagnification. In addition, a recent study commissioned by WWF found that the average person consumes 5 grams of microplastics each week, mainly through contaminated drinking water.[39] Water-borne plastic pieces can both concentrate and release chemicals into the water column, including known carcinogens (Box 2).

Exposure to chemicals like pesticides and metals can cause an array of serious health effects in humans, including cancer,[40] hormonal disruption,[41] immune suppression,[42] respiratory and cardiovascular illness[43] and ultimately death.[44]

The human health effects of these more common pollutants are relatively well studied. However, the toxicity of many other chemicals—from disinfectants and flame retardants to sunscreens and the chemicals in many plastic products—is poorly understood.

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BOX 2. PLASTIC POLLUTION AS A SOURCE OF TOXIC CHEMICALS

Plastic pollution is widely recognised as a global threat to biodiversity and ecosystem health. There are over 5 trillion pieces of plastic estimated to be floating in the world's oceans.[45] In Australia, approximately 130,000 tonnes of plastic leak into the ocean each year, posing a grave threat to marine life, including multiple iconic species such as marine turtles, dugong, cetaceans, sharks and rays. Plastic entanglement can result in damaged limbs and drowning,[46] and ingestion can cause internal injuries, intestinal blockage, starvation and death.[47]

Plastics contain petrochemicals and other toxic substances, such as bisphenol A, POPs and certain carcinogens, that are released into the environment as plastics degrade. Plastic debris can become even more toxic by attracting chemicals from the surrounding water, acting as a kind of "magnet" for chemicals in the environment.[48] The exact degree of toxicity of degraded, ocean-borne plastic debris is currently unknown; however, a recent study suggests the majority of consumer plastics contain toxic chemicals.[49] Most plastic litter entering the ocean breaks into smaller pieces and sinks to the seafloor—and **there are now an estimated 14 million tonnes of microplastic on the ocean floor.**[50] This is of concern for species that ingest plastic or plastic particles, such as marine turtles, cetaceans, seabirds and filter-feeders such as molluscs, sponges and jellyfish.

As plastic production accelerates and millions of tonnes enter the world's oceans, there is an urgent need to understand the toxicity of marine plastics and which species are affected—as well as finding ways to "turn off the plastic tap."

Encouragingly, a growing number of countries and a coalition of major global businesses are uniting in calling for a United Nations treaty to address plastic pollution and accelerate progress towards a circular economy for plastics. The business manifesto is open to new signatories at www.plasticpollutiontreaty.org.

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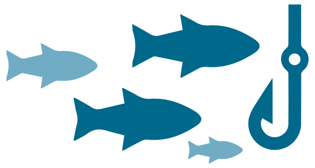
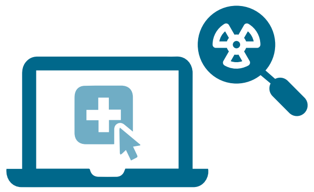


Toxic chemicals are seeping into every part of the food chain, including the fish and seafood that we eat



With the vast majority of common chemicals not fully evaluated for environmental and human health impacts,[51] the true toxicity of these substances remains unknown

We now know that thousands of chemicals are lurking within our waters, accumulating in our food and harming our wildlife. Identifying these toxic substances and understanding their effects will be key to protecting human health and safeguarding clean, sustainable seas - in Australia and globally.[52]

2. THE GREAT BARRIER REEF: A WORLD HERITAGE AREA UNDER THREAT

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The Great Barrier Reef (GBR) is the world's largest coral reef system. It's more than 2,900 reefs and 900 islands span a distance of over 2,600 kilometres and support at least 5,500 species of invertebrates, fish, birds and marine megafauna.[53]

© WWF-Australia / Kerry Trapnell

Ten major commercial and many recreational fisheries harvest seafood for human consumption in GBR waters,[54] and Traditional Owners rely heavily on the GBR for sustenance and cultural practices.[55] In recognition of its "outstanding universal value" and world-class biodiversity, the GBR was designated a UNESCO World Heritage Area in 1981.[56,57,58] With approximately 2 million tourists visiting the GBR each year, the reef contributes AU$6.4 billion per year to Australia's economy and supports over 64,000 full-time jobs.[59] In short, the GBR has enormous environmental, cultural and economic value.

But this iconic ecosystem is in trouble, and chemical contamination puts further stress on an environment already struggling with the impacts of invasive species, coastal development and global warming.[60] Inshore water quality of the GBR is rated as "poor" (see 2017-2018 Water Quality Report Card) due to inputs of sediment, agricultural runoff, pesticides and other substances throughout the catchment area.[61] While significant resources are being dedicated to improving GBR water quality,[62] these efforts focus disproportionately on reducing the input of sediments, nutrients and pesticides from agricultural operations in adjacent catchments. Without more resources to assess the presence and effects of chemicals on the GBR, the issue of chemical contamination continues to fly under the radar.

Current water quality monitoring does not go far enough to detect all the chemicals entering the GBR, its wildlife and the people who rely on it. Under the Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan), multiple programs track water quality and reef health throughout the GBR catchment area (Box 3). These efforts currently measure levels of sediment, nutrients and around 80 pesticides.[63,64] However, recent research shows that these criteria are too narrow and do not include many commonly used chemicals, such as antifouling paint, plasticizers, flame retardants, hydrocarbons (from fuels), UV filters in sunscreens, pharmaceuticals and personal care products.[16,63] This unseen chemical burden could be devastating for the health of GBR habitats and wildlife if allowed to continue unabated.

Further, current monitoring programs focus on levels of individual contaminants, but combinations of chemicals can be deadly to marine ecosystems.[65] We know very little about these "mixture effects" or to what extent they are contributing to reef degradation. On top of this, chemicals degrade in the environment to form new compounds called transformation products, which can be more toxic than the original chemicals themselves.[66]

It is imperative that policymakers address the emerging chemical crisis and ensure GBR water quality monitoring programs test for a wider array of chemical substances. Limiting chemical analyses to pesticides greatly underestimates the risk posed by non-pesticides and other emerging contaminants.[67] The more chemicals we look for in GBR habitats, the more we find—indicating that routine water quality monitoring programs are only detecting "the tip of the iceberg" in terms of chemical pollution on the reef (Figure 3). With more than 150,000 chemicals in production and use in Australia and over 40,000 chemicals globally identified as contaminants of emerging concern, much more research is needed to understand how these substances affect the health of the GBR's environment, wildlife and people.

Contaminant monitoring needs to expand beyond testing for a small subset of known chemicals—we need to find out what is in the environment so that we can act accordingly.

WITHOUT MONITORING TO TRACK LEVELS OF COMMON CHEMICAL SUBSTANCES, WIDESPREAD CONTAMINATION COULD BE GOING UNDETECTED IN THE GBR.

URGENT ACTION IS NEEDED TO UNDERSTAND WHICH CHEMICALS ARE PRESENT IN GBR HABITATS AND WILDLIFE, AND HOW THESE SUBSTANCES ARE AFFECTING THE ECOSYSTEM.

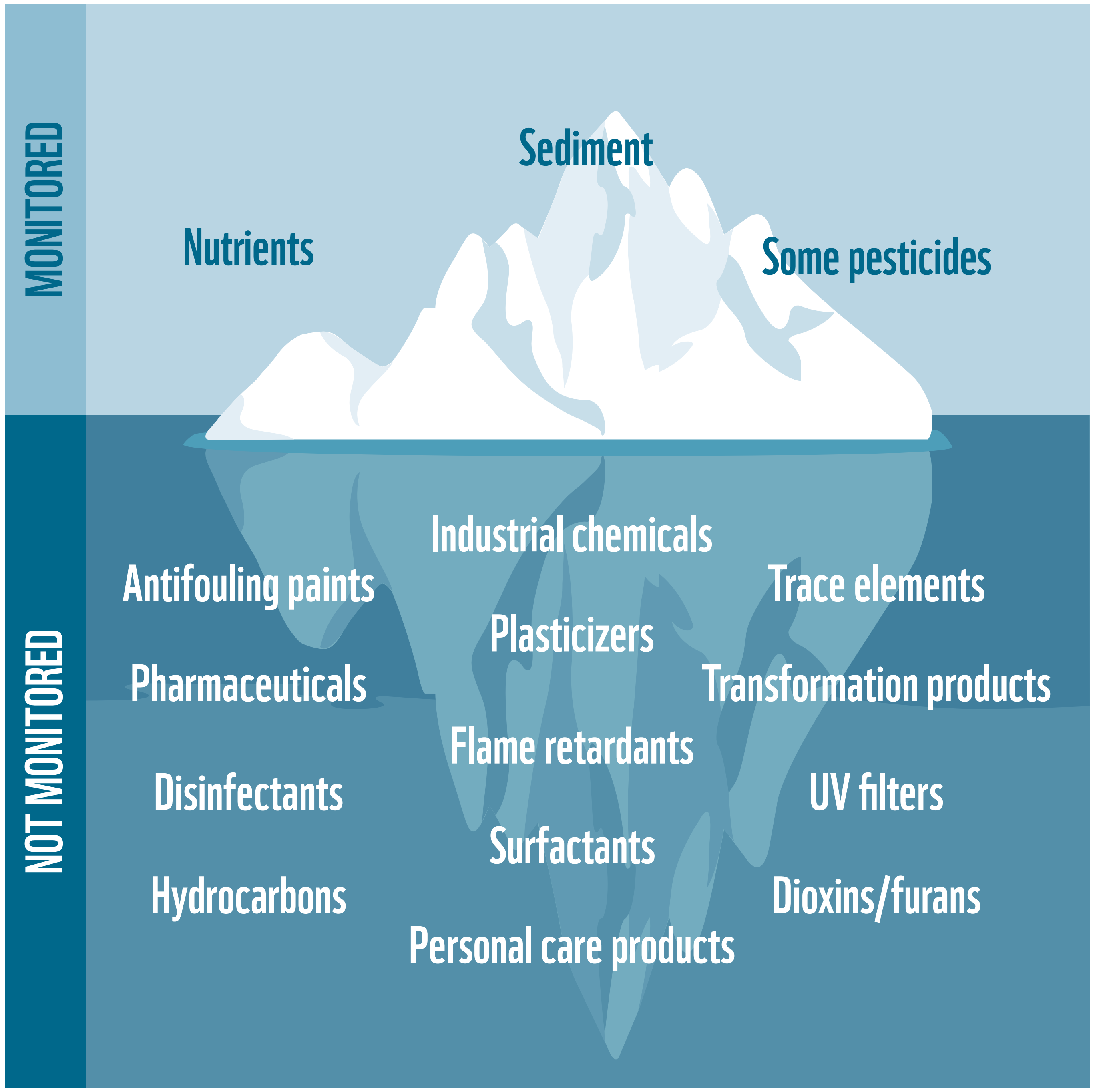
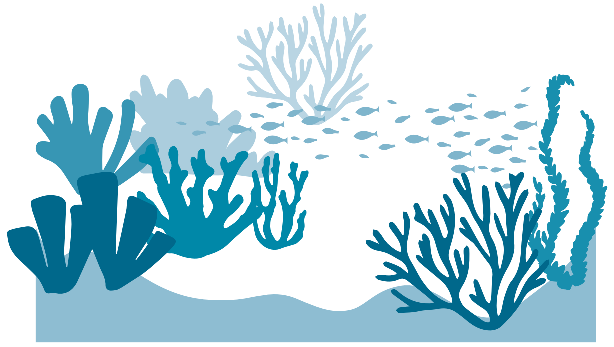


Figure 3: The "tip of the iceberg" illustrating that current water quality monitoring programs are missing a large number of toxic compounds.

BOX 3. MONITORING OF CHEMICAL POLLUTION IN THE GREAT BARRIER REEF



In 2009, the Australian and Queensland governments launched the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef Program). Consisting of more than 20 industry bodies, Natural Resource Management groups (NRMs) and other stakeholders, the Paddock to Reef Program is tasked with measuring GBR water quality to inform assessments of the reef's health, including the Reef Water Quality Report Card (Reef Report Card).

Within the Paddock to Reef Program are the two most regular and comprehensive GBR water quality monitoring programs: 1) the Marine Monitoring Program (MMP) and 2) the GBR Catchment Loads Monitoring Program (GBRCLMP).

The MMP was established in 2005 by the Great Barrier Reef Marine Park Authority (GBRMPA), with the primary aim of monitoring the inshore health of the GBR. The MMP regularly monitors elements of water quality (sediment, chlorophyll A, 11 nutrients) at 28 sites, seagrass health at 29 locations, and coral reef health at 32 inshore reefs. **With respect to chemical pollutants, the MMP only assesses 30-40 pesticides at 11 sites.**

The GBRCLMP currently monitors pesticides in 30 priority catchments adjacent to the GBR. While a general suite of over 80 pesticides are measured, a subset of 22 are used to measure and model the progress towards the pesticide water quality target of the Reef 2050 Water Quality Improvement Plan.

There are also many other government organisations, industry groups, universities,

NRMs, non-governmental organisations (NGOs) and community groups that measure water quality on the GBR. **However, this crucial data is gathered over different spatial and temporal scales, making it difficult to incorporate into established monitoring programs.** To collate all available water quality information, the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP) was established in 2016. Due to the enormity of this task, however, the RIMReP is currently still in its planning and development stages.

3. RIVERS TO REEF TO TURTLES PROJECT REVEALS WIDESPREAD CONTAMINATION ON THE GBR

Despite multi-stakeholder efforts to reduce contamination of GBR waters, recent Reef Report Cards indicate that land management, water quality and catchment management targets are still far from being met[68,69] (Figure 4).

© Christine Hof / WWF-Australia

To better understand the sources and impacts of chemical contamination in the GBR, WWF-Australia and its partner organisations recently completed the Rivers to Reef to Turtles (RRT) Project. This comprehensive study investigated how chemicals from land-based activities are accumulating in and affecting the health of GBR ecosystems, using the iconic green turtle as a case study (Refer Special Issue published in the peer-reviewed scientific journal, *Science of the Total Environment*).

The RRT Project detected over 4,000 unique organic compounds in the blood of turtles that forage in inshore waters, including substances derived from pharmaceuticals and industrial processes[20] (Figure 5). Unsafe levels of trace elements were also found, including elements like cobalt, molybdenum and antimony that are not part of regular water quality screening.[21] Concerningly, the turtles showed several signs of poor health that were associated with exposure to chemical pollution.[15] **The RRT analysis found substances that could not be identified in global chemical databases—meaning that turtles are being exposed to new and emerging contaminants.**

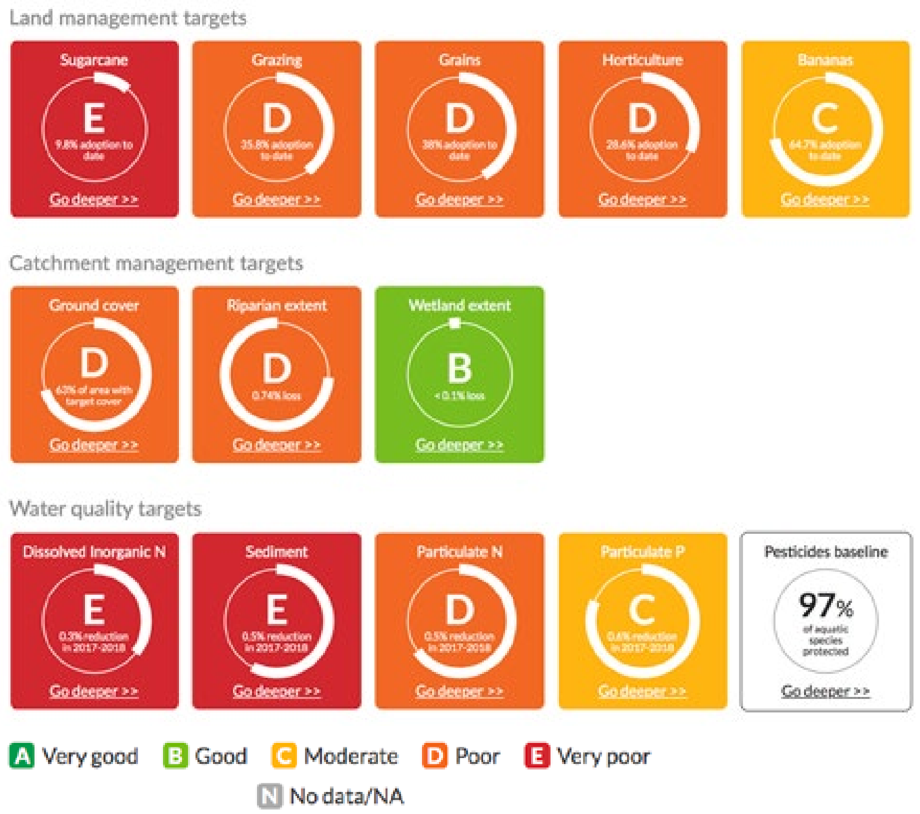
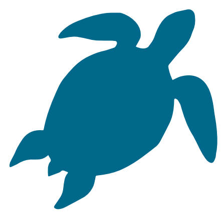


Figure 4: The most recent Reef Report Card (2017/2018) showing progress across multiple indicators for land management targets, catchment management targets and water quality targets. Available online at reefplan.qld.gov.au

The first of its kind, the ground-breaking RRT study concluded that chemical contaminants are negatively impacting the health of the GBR's iconic green turtle. Turtles are accumulating sizeable toxicant loads, with largely unknown health effects.[70] Taking turtles as "the canary in the coal mine", we suspect that contaminants are also impacting the health of other GBR wildlife, from marine megafauna (e.g. whales, dolphins, dugongs and sharks) to the fish, prawns and mud crabs caught in commercial and recreational fisheries. All these species perform vital ecosystem services, bear sociocultural significance to Traditional Owners and play a central role in GBR tourism operations. Understanding the effects of chemicals on wildlife and the greater ecological, social and economic wellbeing of the GBR is a matter of paramount importance.



THE GBR'S MARINE TURTLES ARE AN INDICATOR OF ECOSYSTEM HEALTH, AND THESE IMPORTANT ANIMALS ARE CONTAMINATED WITH HIGH LEVELS OF CHEMICALS THAT ARE POORLY UNDERSTOOD AND NOT ROUTINELY MEASURED.

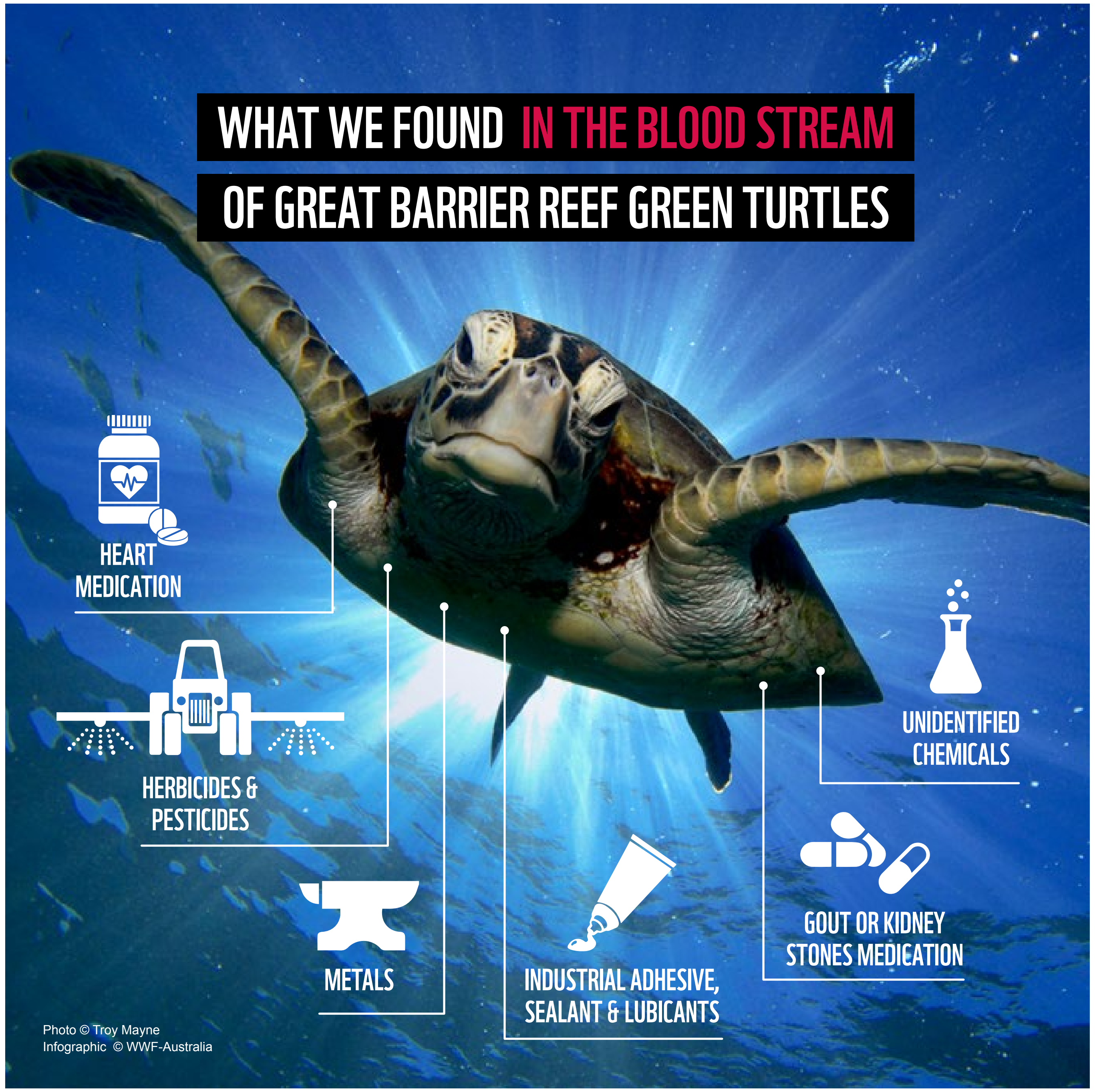


Figure 5: Substances found in the blood of green turtles (*Chelonia mydas*) during the RRT Project

We now know that marine turtle health is impacted by chemicals on the GBR. The next step is to use practical analytical and biomonitoring tools to measure toxicity and chemical change on the GBR.

4. THE PATH TO A CLEAN AND HEALTHY GBR

The GBR is awash in chemical contaminants. The time to act is now—to understand and mitigate the effects of chemical pollution on the GBR before the damage is irreversible.

Despite the creation of the Reef 2050 Plan and concerted efforts to improve water quality, the scale and effects of chemical pollution remain poorly understood. The GBR's long-term outlook has deteriorated from "poor" to "very poor",[61] chemical manufacturing continues to soar and substances of unknown toxicity are polluting the reef. It is vital that the public is aware of the health risks associated with chemical contamination through GBR seafood and the marine habitats we rely on and enjoy. Policymakers must listen to the science and tackle this emerging problem.

Fortunately, new analytical tools make it easier to detect a wider range of chemical contaminants,[20,21] including those of emerging concern (Box 4). In addition, Effects-Based Monitoring (EBM)—an approach which incorporates bioassays into monitoring programs—can help identify mixture effects, which occur when multiple chemicals in the marine environment interact with one another. These can include chemicals and transformation products not targeted in the original chemical analysis. EBM is recommended for water quality monitoring as part of the European Union Water Framework Directive.[71] However, EBM is not currently implemented as part of GBR water quality monitoring programs.

Enhancing existing monitoring programs with new analytical methods, including marine wildlife cell-based bioassays, will allow for a greater understanding of the number and type of chemicals present and how chemical mixtures affect GBR water quality, habitats and wildlife.

BOX 4. TEST TUBE TOXICOLOGY

Rather than measuring toxicity in a live animal, a technique called cell-based bioassays gets the same results using cell cultures.

A well-established technology, cell-based bioassays have been used to test drinking water and wastewater quality[72] and more recently to test toxicity effects in marine wildlife, algae and fish.[73,74,75,76] Cell-based approaches are increasingly being used in human and animal toxicology as a more ethical and efficient alternative to using live animals. Cell-based bioassays can be used to test the toxicity of individual chemicals and mixtures[73,77,78] even at very low concentrations. Crucially, this technique can determine toxicity with less biological material than traditional methods, making it highly efficient and more cost effective. Cell-based bioassays can provide important species-specific information about the effects of contaminants in protected and long-lived GBR species, such as marine turtles. Implementation of these methods into GBR monitoring programs would dramatically increase the number of chemicals that could be assessed in habitats and species.

Beyond enhancing water quality screening, identifying hotspots of chemical contamination within the GBR is a high priority. This knowledge will enable governments and reef managers to progress more focussed efforts towards identifying the sources and effects of chemical pollution, and therefore to put **stronger mechanisms in place to reduce chemical use, remediate land and regenerate coastal wetland function** (Figure 6).

Knowing the extent, sources and impacts of chemical pollutants on the GBR will empower tailored solutions across multiple sectors. To inform best management practice, landowners, farmers and governments must have a more complete picture of chemical discharge and impact on the GBR. The novel tools and baselines developed by the RRT Project can help identify which catchments pose the greatest chemical threat to reef and wildlife health.

NOVEL ANALYTICAL TOOLS CAN MEASURE THE PRESENCE AND EFFECTS OF A LARGER NUMBER OF CHEMICALS WITHIN GBR WATER QUALITY PROGRAMS, INCLUDING CHEMICALS OF EMERGING CONCERN.

2025 LAND AND CATCHMENT MANAGEMENT TARGETS

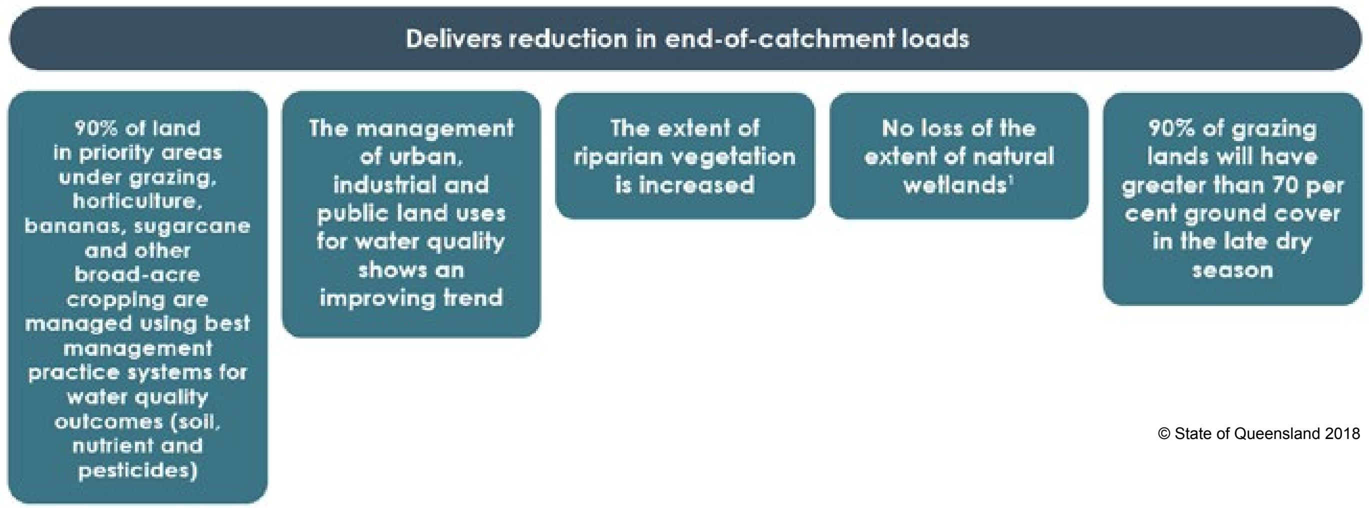


Figure 6: Land and catchment management targets from the Reef 2050 Plan.

SOLUTIONS TO CHEMICAL POLLUTION SPAN MULTIPLE STAKEHOLDERS

From governments to individuals, all stakeholders play an important role in keeping the GBR healthy for generations to come. Key strategies to gain a better understanding and to address chemical contamination of habitats and wildlife in GBR catchments include the following:

STRATEGIES FOR INDUSTRIES AND NATURAL RESOURCE MANAGERS

- **Act to reduce chemical inputs and loads** to the GBR in line with the land and catchment management targets set out in the Reef 2050 Plan
- **Report on progress against water quality targets on a sector-by-sector basis**
- **Develop and implement an investment plan** to reduce pollutant loads from industrial sites (e.g. sewerage treatment plants) by 2030
- **Invest in and adopt technology** that reduces chemical use and discharge (e.g. precision laser pesticide applicators)

STRATEGIES FOR STATE AND FEDERAL GOVERNMENTS

- **Identify high-priority chemical hotspots** (based on their occurrence and effects) and initiate strategies to support practices that reduce, remediate and regenerate chemically contaminated areas
- **Expand existing monitoring programs** upstream and into smaller waterways used by farmers and locals
- **Adopt an EBM approach with novel analytical methods and cell-based techniques** to test for a wider range of chemical contaminants, so that biological effects can be more meaningfully measured, particularly for chemicals of emerging concern
- Continue to support and enforce the Reef Protection Regulations and investment into agriculture and industry best management practice programs, but **expand to support practices that remediate chemically contaminated areas** and prevent further contamination (e.g. restoration of wetlands)
- **Undertake a review of chemicals used and/or registered** in Australia, including residual pesticides and other agricultural chemicals banned in Europe and the USA, and de-register those that cannot be applied in a reef safe way.
- **Phase out** chemicals for which movement off-farm cannot be minimised or eliminated, e.g. residual herbicides
- **Mandate the 2025 Plastic Packaging Targets** to reduce the likelihood of plastic entering the ocean and posing a contaminant risk

STRATEGIES FOR RESEARCHERS

- **Continue efforts to develop risk-based prioritisation of chemicals** and determine which ones should be monitored more closely
- **Develop and apply novel effects-based techniques** and tailor traditional toxicity tests to better understand the impacts of chemicals on the GBR and its species
- **Apply novel monitoring techniques** to identify chemical hotspots, at-risk species, sources of pollution and locations where chemical contamination can be mitigated

STRATEGIES FOR INDIVIDUALS

- **Do not discard** chemicals like paints, solvents and herbicides down the drain, as they eventually flow into our rivers and into the GBR - instead, contact your city council for safe disposal options
- **Do not discard** unused medications down the drain or in your bin – return them to your pharmacist instead who will safely dispose of them at no cost to you
- **Say no to unnecessary single use plastics** such as plastic bags, bottles, utensils and straws. Remember to use your reusable bags and bottles!
- **Be chemically responsible** at home by reducing unnecessary chemical use like cleaning products, and consume organic pesticide-free produce

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6. APPENDICES

Appendix 1.
Major groups, examples and sources of chemical pollutants commonly found in aquatic environments.

Group name	Common examples	Common uses/sources
Pesticides	Herbicides (e.g. diuron, glyphosate), insecticides (e.g. organophosphates), fungicides, faunacides	Directly released into the environment during pest control in agriculture, grazing, commercial properties (e.g. golf courses), industrial infrastructure (e.g. discharge pipes), common areas (parks, footpaths, roads), urban gardens, seasonal fumigation of municipal wetlands to reduce mosquito abundance
Fertilisers	Nitrates, phosphorus	Directly released into the environment during fertility enhancement in agriculture, grazing, commercial properties (e.g. golf courses), common areas (parks, footpaths, roads), urban gardens
Anti-fouling paints	Tributyltin (TBT), metal oxides, biocides (e.g. benzmethylamide, clorothalonil, diuron)	Prevention of the attachment of fouling organisms to vessel hulls. Leach into the environment from vessel hulls
Hydrocarbons	Polycyclic aromatic hydrocarbons (PAHs), monocyclic hydrocarbons, alkanes, cycloalkanes, vehicle/cooking oils	Petroleum products, coal seam gas fracking, coal dust, industry by-products. Released into the environment from these industrial activity and spills
Metals and metalloids	Essential metals (Zn, Na, Mg, Ca, etc), non-essential metals (Hg, Cd, As, Pb, etc)	Agricultural runoff, current and abandoned mines, wastewater discharge, industrial by-products, coal dust, weathering of rocks and soils, abandoned industrial sites
Pharmaceuticals	Antibiotics, psychotropic drugs (e.g. anti-depressants, mood stabilizers), non-steroidal anti-inflammatory drugs (NSAIDs), anti-hypertensives, anti-cholesterolemics, anti-convulsants, analgesics, contraceptives, chemotherapy drugs	Treatment of human and animal illnesses. Enter the aquatic environment primarily via wastewater discharges (municipal and from vessels)
Personal care products	Surfactants, disinfectants, anti-microbials, insect repellents, fragrances, plasticisers, microplastics, anti-corrosives, sunscreen UV filters (e.g. benzophenone-2, oxybenzone)	Cosmetics, toiletries, fragrances. Enter the aquatic environment primarily via wastewater discharges (municipal and from passenger vessels)
Illicit drugs	Cocaine, methamphetamine, lysergic acid diethylamide (LSD)	Recreational human use. Enter the aquatic environment primarily via wastewater discharges (municipal and from vessels)
Food additives, preservatives	Monosodium glutamate (MSG), sodium nitrite, artificial sweeteners	Consumed by humans in processed food. Enter the aquatic environment primarily via wastewater discharges (municipal and from vessels)
Dioxins/furans	Chlorinated dibenzo-p-dioxins	
chlorinated dibenzofurans	Industrial by-products, incomplete combustion of waste, natural fires, volcanoes. Enter the environment as air-borne particles	
Flame retardants	Polybrominated biphenyl ethers (PBDEs), perfluorinated compounds (e.g. PFOS), organo-phosphorous compounds	Fire-fighting foams, disposal of furniture, electronics, clothing, etc
Disinfection by-products	Trihalomethanes (THMs), haloacetic acids (HAAs), haloketones, haloacetonitriles, bromoform	Disinfection of drinking water, swimming pools, treated wastewater
Polychlorinated biphenyls (PCBs)	Arochlors	Electrical equipment (e.g. capacitors), hydraulic fluids, lubricants, paint. Enter environment from improper disposal
Nanoparticles (NPs)	Fullerenes, metal NPs, semiconductor NPs, ceramic NPs, polymeric NPs	Biomedical applications (e.g. drug delivery), sunscreens, nanotechnology, electronics, energy harvesting (e.g. electrochemical water splitting)
Radioactive isotopes	Naturally occurring (e.g. Pb-210, Cl-36), artificially produced (e.g. Co-60, Cs-137)	Radiopharmaceuticals (e.g. nuclear imaging), industrial radiography (e.g. stress testing), scientific research, weapons manufacture, waste from nuclear energy production
Plasticisers	Phthalates, epoxies, aliphatics, bisphenol A	Promote flexibility in plastic resins. Released and/or leached from plastics and microplastics
Natural toxins	Domoic acid, saxitoxins, brevetoxins, yessotoxins	Defence mechanisms of dinoflagellates, diatoms

Appendix 2.
Legislation pertaining to chemical use and management within the Great Barrier Reef World Heritage Area.

The primary legislation related to the management of the GBR are: 1) the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), which legalises Australia's obligations to protect the GBR under the World Heritage Convention; and 2) the Great Barrier Reef Marine Park Act 1975, which established the Great Barrier Marine Park Authority as the primary managing body of the GBR, and the Queensland Marine Parks Act 2004

There are several other Federal and state (Queensland) Acts that are also related to managing and protecting the GBR (see graphic below from the Reef 2050 Long-Term Sustainability Plan).

Land use and management in GRB catchments is regulated under the Environmental Protection Act 1994 (Qld) and the Sustainable Planning Act 2009 (Qld). In addition, the Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Act 2019 (Qld) was recently passed with the aim of improving the quality of the water entering the GBR. This law primarily focussed on fine sediments and dissolved inorganic nitrogen.

Federal legislation regarding the control and use of chemicals in Australia include the Agricultural and Veterinary Chemicals Act 1994, the Therapeutic Goods Act 1989 and the Industrial Chemicals Act 2019. However, it has been recently documented that there are flaws in the federal regulation of pesticides.[69] In Queensland, the Health Act 1937, the Health (Drugs and Poisons) Regulation 1996, Health Regulation 1996, and the Pest Management Act 2001 are the primary legislative instruments responsible for regulation of chemicals. These are to be replaced in 2020 by the Medicines and Poisons Act, designed to be a single overarching substance management scheme.

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