Water quality

Something in the water

Drugs have been finding their way into our water supplies for as long as they have been in use, so should we worry? Maria Burke reports

In short

- Researchers first detected drugs in groundwater and surface water in the 1990s
- More recently, very low concentrations of commonly-used drugs have been found in drinking water supplies
- Traditional water treatment plants are not equipped to remove small, soluble pharmaceuticals
- Although advanced water treatment could remove these contaminants from water, such technology is very expensive and it remains unclear whether these low concentrations have any effect on people

We take a huge number of drugs. So it's not surprising that the drugs that most people take most liberally – painkillers, antibiotics, antiseptics, contraceptive pills and beta-blockers – find their way into water supplies. It was back in the early 1990s that researchers first identified trace amounts of therapeutic drugs in surface waters and groundwater. This sounded alarm bells and, since then, surveys in Europe and the US have found traces of around 100 of these compounds in surface waters, groundwater, sewage, effluent from wastewater treatment plants, and, more worryingly, tap water.

Pharmaceuticals are usually non-volatile, water-soluble, and often charged molecules, and many of them pass through treatment plants designed to get rid of traditional pollutants. They have been lurking in the environment for as long as they have been in use, but it's only in the past decade or so that analytical methods have advanced enough to detect them at the low levels – less than 1μg/litre – typically found in the environment.

Although these levels are becoming easier to quantify, exactly how much of a risk they pose is a more complex issue. Active pharmaceutical ingredients (APIs) appear to affect aquatic species. This phenomenon hit the headlines in the 1990s when research led by John Sumpter, an ecotoxicologist at Brunel University in London, UK, linked the feminisation of male fish downstream of wastewater treatment plants with the presence of oestrogenic compounds, such as the synthetic birth control compound 17α-ethinylestradiol.

In our drinking water, these drugs are found at extremely low levels – a miniscule fraction of the amount in a medical dose. Yet there is emerging concern about the potential human health effects arising from complex drug mixtures.

Last month, the US Environmental Protection Agency (EPA) asked the National Academy of Sciences (NAS) to provide scientific advice on the potential risk to human health caused by the low levels of these pharmaceutical residues in drinking water. The NAS will convene a workshop of experts to advise the EPA at the end of the year.

What's in your tap?

When people take a drug, only a fraction is absorbed. The rest is often excreted in unmetabolised form, where it enters raw sewage. The flushing of unused or expired medication down the toilet, and drug-containing waste from manufacturing facilities are other routes by which pharmaceuticals find their way into wastewater. The methods of disposal of unused drugs, from hospitals and other care facilities, is an area that the EPA recently stated its intention to investigate.

Many studies have confirmed that some APIs pass through waste treatment plants and enter the environment. A wide variety of organic compounds, including pharmaceuticals, have been found in waterways across the US that receive agricultural, domestic or industrial wastewater effluent.

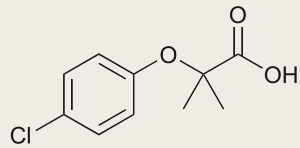
In 2002, in the first nationwide study in the US, Dana Kolpin a hydrologist from the US Geological Survey (USGS) in Iowa, found contaminants in 80 per cent of sampled streams.[1] Among the most frequently detected compounds were the steroids coprostanol and cholesterol, the insect repellant *N*,*N*-diethyltoluamide (DEET), caffeine and triclosan, an antimicrobial disinfectant. The average number of compounds in a given sample was seven, but the researchers found as many as 38 (out of the 95 targeted) compounds in one sample.

And as research delves deeper, new or 'emerging' contaminants come onto the radar of environmental scientists. In one recent study Ed Furlong's team from the USGS selected 54 target compounds, using drugs sales data as a conservative estimate of their likely concentrations, and by estimating the potential of these predicted concentrations to cause biological effects. They detected 38 of the ingredients in at least one sample of wastewater effluents and surface water.[2]

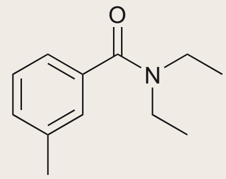
The problem is that wastewater treatment plants in the US are not specifically designed to remove many classes of trace level contaminants, such as pharmaceuticals, explains Furlong. And this is the case for the majority of wastewater treatment plants throughout the world. So pharmaceuticals are discharged into lakes and rivers and aquatic wildlife is continuously exposed (*see box p50*). From here APIs can leach into groundwater aquifers, which are a major source of drinking water. In some areas, treated municipal wastewater – often laced with yet more pharmaceuticals – is also used to top up raw water supplies.

This means that major urban conurbations are likely to get the biggest and most varied doses, and many studies across heavily populated areas of Europe have identified APIs in drinking water at trace levels. A number of reservoirs used for drinking water along the Lergue River in Southern France were found to contain drugs including paracetamol, the anti-inflammatory diclofenac, and the epilepsy drug carbamazepine.[3] Clofibric acid – an active metabolite of many drugs used to lower cholesterol – and diazepam, which is often prescribed for anxiety, were detected in treated drinking water in Milan, Italy;[4] and clofibric acid, propylphenazone, and diclofenac were found in the drinking water of Berlin, Germany.[5]

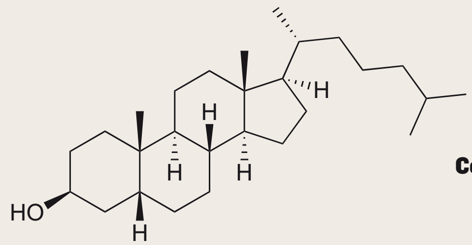
In the US, a team from the Southern Nevada Water Authority



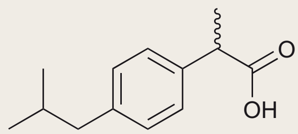
Clofibric acid



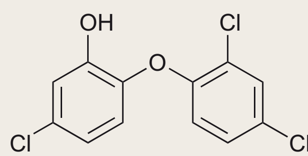
DEET



Coprostanol



Ibuprofen



Triclosan

Mixtures of some of the most commonly-used drugs have been found in drinking water

'Traditional wastewater treatment plants are not designed to remove drugs'

STEFAN BAUM / STOCKPHOTOS

APIs have been found in drinking water at trace levels in many heavily populated areas of Europe – including Berlin, Germany (above)

(SNWA) published a report last November that analysed raw and treated drinking water from 20 full-scale drinking-water utilities and six water-reuse plants.[6] Several pharmaceuticals, including the tranquiliser meprobamate, the anti-epileptic phenytoin, the anti-inflammatory ibuprofen, and the x-ray contrast medium iopromide, occurred in more than 65 per cent of the treated water samples, although rarely at concentrations greater than 10ng/l. The insect repellent DEET appeared in 90 per cent of treated water samples.

Slipping through the pipes

Conventional treatments for drinking water are simply not designed to remove APIs. The report by the SNWA also evaluated the effectiveness of current drinking water treatment technologies and found that no single process was able to remove every chemical.

'Conventional plants were capable of removing about half of the compounds we evaluated, while advanced processes could eliminate nearly all of our target compounds,' says Shane Snyder, an environmental toxicologist at the SNWA and the report's lead author. 'The vast majority of US utilities do not use advanced treatment processes. The bottom line is that while some of these processes are extremely effective, they are also energy-intensive and expensive to install. It would be unwise to move towards energy-intensive processes if there is not an actual [problem] to be solved.' Whether there is a problem, or a real risk, remains debatable.

The conventional process for drinking water treatment plants consists of: coagulation (adding coagulant salts and polymers to

Antidepressants as environmental contaminants

Ed Furlong's team at the US Geological Survey in Iowa is particularly interested in antidepressants. There is huge potential for ever-increasing amounts of these drugs to find their way into water supplies as they are so widely prescribed. The team looked at wastewater effluent and samples collected from a stream containing wastewater.[10] Typical concentrations of individual antidepressants were in the ng/litre range except for venlafaxine (Effexor), which was found in μg/l concentrations.

A major concern is that many antidepressants work in similar ways, explains Furlong. 'If multiple pharmaceuticals with the same modes of action are present in an ecosystem, the additive environmental effect could be substantial.'

And research has already shown how antidepressants can affect fish. In one study, fish living in a stream containing municipal effluent were found to contain concentrations of four antidepressants in their muscle, liver, and brain tissues. These levels are high enough to possibly affect physiological systems, says Furlong. Another study reported that certain antidepressants induced spawning in some crustaceans and bivalves. More recently, three antidepressants were found to be toxic to algae in laboratory experiments.

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destabilise colloidal particles); flocculation (agitating coagulated water to promote the aggregation of suspended materials); and sedimentation (where flocculated water is stilled to promote settling of suspended solids and floccules). The water is then usually chlorinated.

The SNWA team found that conventional coagulation, flocculation, and filtration removed few of the target compounds when used at full scale. Other standard treatments such as disinfection with ultraviolet light, at typical drinking-water dosages, and ion exchange are also largely ineffective.

Chlorine disinfection, on the other hand, removed around half of the compounds. Advanced treatments such as ozonation – oxidation using ozone – proved extremely effective, removing most of the compounds even at relatively low ozone doses. And UV combined with hydrogen peroxide was as effective as ozone. Similarly, activated carbon (AC) – where pure carbon is heated to promote 'active' sites which can adsorb pollutants – worked well as long as it was replaced or regenerated regularly.

But even these tried, tested (and expensive) advanced methods might not be all they seem. As Snyder points out, whether a chemical is detected in a wastewater effluent depends on the detection capability of the analytical methods used. 'In the US, there are no standard methods for analysing pharmaceuticals in water. So, we can't be certain that our compounds are really eliminated, or simply reduced to a concentration that is less than the current detection limits,' he says. 'If our detection limits had been parts per billion rather than per trillion, we would not have detected any pharmaceuticals in drinking water.'

So as long as analytical procedures and bioassay techniques become more sensitive and more readily available, new contaminants will be discovered. This poses a unique challenge for drinking water treatment plants intent on removing organic contaminants. Complete removal is merely a reflection of reporting limits, Snyder adds.

Many pharmaceuticals can be removed with advanced water treatments such as ozonation

Stubborn drugs

Another factor in removal efficiency is the API itself. How effective these treatments are seems to vary widely depending on the type of compound, says Furlong. For example, some hydrophobic compounds are strongly oxidised by free chlorine, and some hydrophilic compounds are partly removed through adsorption processes.

In the US, only a handful of drinking water utilities use advanced oxidation or membrane treatment processes. Advanced treatments such as AC and ozonation are more common in Europe, particularly in Germany and Switzerland, although they don't tend to be used in countries where drinking water is extracted from groundwater, according to Marc Böhler of the Swiss Federal Institute of Aquatic Science and Technology (Eawag).

In England and Wales, ozone and carbon treatment processes are now installed at many waterworks. The Drinking Water Inspectorate (DWI) of England and Wales published a study in June 2008 that found that most of the pharmaceuticals studied were removed by drinking water treatment systems when these included ozonation and activated carbon. 'This combination, together with the more conventional processes, can result in removal rates of more than 90 per cent for a wide variety of pharmaceuticals,' says Sue Pennison, principal investigator at the DWI.

Technologies applied to treat water sources contaminated with agricultural runoff containing pesticides are often equipped with AC, ozone or tight membrane filtration (nanofiltration or reverse osmosis), says Adriano Joss, an engineering sciences researcher from Eawag. 'Plants equipped for removing pesticides will inevitably also remove APIs to a big extent.'

'The little we know about the impacts of human exposure gives cause for concern'

The use of advanced treatment for wastewater is still under discussion in Europe for those plants discharging either into ecologically sensitive aquatic ecosystems or where there is significant water reuse, says Joss. His team has calculated that the additional costs of installing end-of-pipe treatment in wastewater plants would cost between €5 and €30 per person per year. In addition, advanced treatment requires 10–25 per cent more energy than conventional wastewater treatment. But according to an ongoing full-scale study at Eawag, the energy requirement for ozonation per person equivalent corresponds to less than three watts of power. And, as Joss points out, many electronic devices on standby,

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such as video recorders or coffee machines, consume more than that. 'It is a matter for public debate whether society wants to spend the money necessary to put in advanced treatments. The amounts are feasible if the public persuade politicians that they want it,' he believes.

At what cost?

Is there a case to be made for this investment? APIs have been associated with worrying developmental effects in aquatic wildlife, not just in the relatively API-rich environment downstream of treatment plants, but at concentrations usually considered to be harmless, according to Sushil Khetan and Terrence Collins, chemists from Carnegie Mellon University in Pittsburgh, US. 'We know almost nothing about the impacts of human exposure to low-dose mixtures of pharmaceuticals, or of low-dose pharmaceuticals mixed with other low-dose synthetic pollutants, but the little we do know gives reason for serious concern,' they wrote in a 2007 review article.[7]

But while there is no clear evidence of any threat to human health from such low levels of pharmaceuticals, the complex mixtures present in water are new challenges for toxicologists. Italian researchers were among the first to examine the effects of a drug mixture at environmental levels on human cells. They reported in 2006 that a combination of pharmaceutical compounds inhibits the growth of embryonic kidney cells in laboratory tests. Francesco Pomati's team at the University of Insubria in Varese, Italy, designed a cocktail of 13 drugs – including several antibiotics, ibuprofen, and a cancer medicine – to mimic the mixtures found in several Northern Italian rivers and in wastewater.[8] Although the results did not prove conclusively that synergistic or additive effects exist between drugs in the mixture, they fuelled speculation that such interactions are present.

Some drugs have been associated with worrying developmental effects in aquatic wildlife

'The complex mixtures of drugs present in water are a new challenge for toxicologists'

Another concern is how long these compounds could last in the environment and water supplies. Some drugs, such as antiepileptics, are persistent; others are pseudopersistent, meaning that, while they degrade at reasonable rates, they are continuously being replaced. And around 30 per cent have high fat solubility, according to Khetan and Collins, which means they can bioaccumulate – entering cells and moving up food chains, becoming more concentrated in the process.

Snyder's team recently showed that even advanced removal methods like ozonation may not completely remove some highly resilient chemicals.[9] However, he believes that there is 'no appreciable human health risk' at the concentrations found in US drinking waters. For Snyder, the important point is that there are always unknowns in addressing the threshold for risk of any contaminant in water. 'This is why we add safety factors to any regulatory determination,' he says. 'If there are significant concerns regarding synergy, the most logical decision is to add another safety factor. The World Health Organization recently addressed this exact topic and stated that the safety factors already in place are largely adequate to address potential synergies.'

However, Khetan and Collins aren't alone in their view that presence of APIs in water is 'an urgent issue for short- and long-term action.' And while these tiny traces present far more of a risk to aquatic wildlife than to humans, there is still cause for concern. As yet, the tricky toxicology required to answer all of the questions about these very dilute but complex drug mixtures has yet to begin.

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Further reading

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