"Off with their heads!"

How UK water quality regulators redefined the maximum in 2004

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This paper highlights the deliberate exclusion of high contaminant readings from regulatory drinking water quality reporting in England, Wales, Scotland and Northern Ireland.

The inappropriateness of rebranding 99th centile data as the maximum is explored by reviewing regulatory test data (from tests of lead in kitchen tap water) from 2000 to 2009 from Northern Ireland. This period spans orthophospate dosing to reduce lead leaching and the 2004 change in regulatory reporting.

Examination of the 100th centile data (which includes the actual maximum test results) underlines a need for action and awareness on lead in tap water. It confirms the Glasgow 93 Lead Study's recommendation that bottled water is a sensible choice when making up infant formula in properties built before the 1970s. Yet UK National Health Service (NHS) guidance on making up infant formula omits any precautions against lead in tap water, and makes outdated claims that bottled water (which is now tightly regulated to drinking water standards in the EU) is usually too high in salt for infants.

Moreover, while high values for lead samples identify point sources of contamination, low values can offer false reassurance where plumbing materials cannot be directly verified. This means that simply advising parents to have their water tested is not the way forward, as recognised by Toronto Health. Its approach since 2011 is to advise bottled water and filter installation in all older buildings where water is for the use of pregnant women, infants and young children, as lead contamination cannot be firmly excluded.

The World Health Organisation (WHO) sees drinking water testing as an independent check on water providers to safeguard the health of

water users. Transferring regulatory testing from water companies to local health organisations is the best way to secure this goal, especially as health issues from premise plumbing and privately owned supply pipes need to be tackled.

How UK tap water statistics lost their heads (and tails)

In 2004, the minimum and maximum values previously reported for drinking water quality compliance purposes were replaced by 1st and 99th centile values during, but in no way required by, the UK implementation of the 1998 EC Drinking Water Directive. From 2004, 99th centile values are described by water quality regulators "as representing a maximum," a change in statistical practice documented by the UK Drinking Water Inspectorate's Statistical Advisor in Annex 4 to the annual report for England in 2004.

For the UK and Northern Ireland, there are three competing agendas for the regulatory sampling and public reporting of drinking water analyses. These are (a) to support water company performance narratives, whereby regulators demonstrate their own effectiveness over time in securing an improving trend in water quality; (b) operational compliance with regulations based on what is currently technically achievable and/or assumed affordable and (c) the health protection agenda.

The World Health Organisation's Drinking Water Guidelines (4th Edition, page 64, section 4.3) describe regulatory testing as part of a verification process to ensure that shortcomings in water quality are identified and addressed, to protect the health of the people drinking the water.

> "Verification [that the system as a whole is operating safely] may be undertaken by the supplier, or by an independent authority, or by a combination of these..."

The performance narrative - comparing plants or suppliers - is of limited relevance to the health agenda, as supplier choice is not the mechanism by which water quality is safeguarded. Operational compliance can be fully achieved whilst supplying water adversely affecting health (see p383ff of the WHO guidelines above).

Returning to Annex 4 of the 2004 report, the performance narrative agenda is most evident in the two reasons given for redefining the maximum as the 99th centile:

> "if works A is sampled 100 times and an identical works B is sampled 1000 times, the maximum for B is likely to be substantially greater than for A – and this would give the **spurious message** [bold added] that B was worse than A.
>
> …even if the numbers of samples are the same for all works being compared, the minimum and maximum become increasingly remote from the main body of the data…the maximum measures the single most abnormal event encountered…and this will give less and less [sic] insight into what happen at the works for the great majority of the time….
>
> Both these problems are avoided by instead reporting extreme percentiles of the data…."

The report does not present confidence intervals, deferring to an "ongoing consultation". Contacting the DWI for the conclusions of this 2004 consultation, they replied (5 October 2012) that they are unaware as to whether or not this work was completed and hold no output from it.

Logically a modal value gives insight " into what happens … for the great majority of the time." The maximum tell us whether contamination has occurred at levels which link to illness.

The 2011 WHO guidance is explicit that verification testing is to "ensure the best possible chance of detecting contamination" as even brief episodes of microbial contamination can lead directly to illness. This means actively seeking out and reporting the maximum levels of contamination occurring, however briefly, or, by extension, at however few properties. Modal data is not the goal of regulatory testing.

The strange doctrine in which the 99th centile "represents the maximum" and the true maximum disappears from view, is a Humpty Dumpty approach ("When I use a word…it means just what I choose it to mean." *Alice in Wonderland*)

It is also worth noting that the 1998 EU drinking water directive objective is for more testing at taps. This ensures contamination in distribution systems and premise plumbing is addressed. Given this, the need to protect readers from "spurious messages" using a thought experiment at the water plant level is surprising.

What can we learn about the change in reporting practice by looking at Northern Ireland water's regulatory lead data?

Tap water lead contamination in Northern Ireland typically arises as the water passes through plumbing materials connecting a lead free water main via an underground "line" made or contaminated with lead to a property built before the 1970s. Ownership of a lead line is split between the water company and the property owner at the property boundary.

The data considered below is from an Excel file supplied by Northern Ireland Water in response to a request for regulatory test results for lead (and manganese) in tap water for 2000 to 2009 including sample ID, date and water zone.

When the data is ordered (figures 1 and 2), it is clear that its distribution is discontinuous. The discontinuity can only to a limited extent be explained by the proportions of properties tested built before and after lead pipe work - and much later lead solder on drinking water pipes – was banned. It is clear from work for the NHS in Scotland and an incident in Wales that new homes can also record very high lead in water levels, as lead solder is often misused on drinking water pipes. As discussed below, a low test result cannot provide assurance that no lead pipes are present.

A detailed discussion of how the samples are taken and how this limits further analysis is given below. The figures attempt to represent test results before and after the introduction of orthophosphate dosing to reduce lead leaching in December 2003. Note that the sample sizes are very small in relation to the 802,000 properties connected, even when taking two years of data together.

The position of the 99th centile is sensitive to how values reported to the regulator as <x or >x are handled (for example some samples are reported as <50 or >200). Annex 4 mandates an approach of discarding all of this data. For 2009, for example, the NI lead test data indicates that 143 out of 460 results would be discarded before calculating percentiles. For 2007, one test is reported as >200 and 268 values have the < symbol, from a total of 463 reported values.

Figure 1 and 2: Tap Lead Test Data 2000/2001 and 2008/2009

Figure 1: Lead in tap water, 2000 and 2001 (1,732 data points, 99th centile 108)

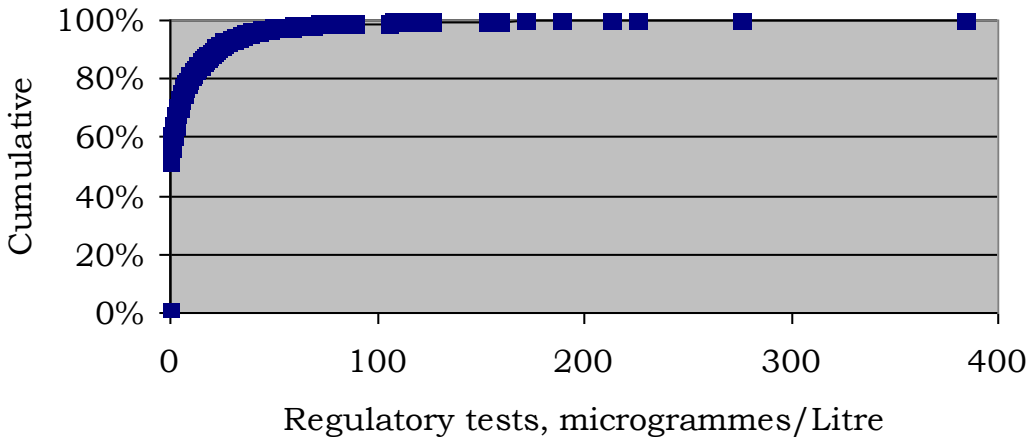
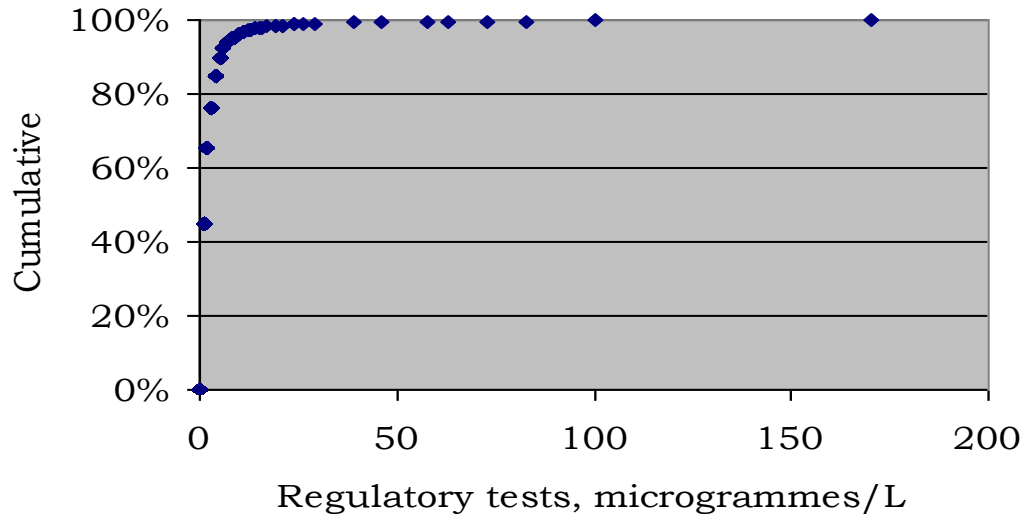


Figure 2: Lead in tap water, 2008 and 2009 (928 data points, 99th centile 26)



In figure 2, results stated as <2, <1, <0.0, <0.8 and <0.7 are replaced (artificially) with the values 0.5, 0.49 and 0.35. Data for 2000 and 2001 did not include < or > symbols.

It is clear from figures 1 and 2 that there is no natural break in the data around the 99th centile and hence no evident basis to say this point "represents" the maximum.

Note that these are regulatory samples preserved for retesting, so laboratory error should not be a reason to exclude high results.

How data is presented in regulatory reports using the 99th centile rule

The 2011 company look up table for Thames Water notes 6 failures of a standard of 25 microgrammes Pb/L from 1,908 tests, with the "99 percentile representing a maximum" of 12.991. It is striking that the "representing a maximum" number is 13 but the standard, breached 6 times, is 25. Looking at our lead test distribution curves from Northern Ireland, we can see it is impossible to predict the actual magnitude of the test failures from the 99th centile. So it is easy to miss real health threats.

The Thames Water company look up table data is replicated in the 2011 regional reports by the Chief Inspector for England and Wales. In her reports, the number of breaches, but not their magnitudes, is discussed.

The regulator for Scotland follows a similar approach. In 2011 the fact that 9% of tests breach the standard for lead is clearly flagged, but nowhere is the magnitude of the breaches mentioned. This is to leave the health impact unaddressed.

A closer look at regulatory water samples

A water zone is an annually designated geographical area served by water from a single water treatment plant or water blended from more than one treatment plant. A designated zone in 2000 could serve no more than 50,000 people.

Performance monitoring counts the number of designated water zones in which failures against standards occur. Regulations in 2007 prohibit the re-designation of water supply zones during the course of the year, evidencing previous gaming of performance through rezoning (Guidance on the Water Supply (Water Quality) Regulations (Northern Ireland) 2007).

In 3 of the 103 zones designated by the end of 2000, just 3 tests for lead were taken and for 65 zones, just 4 samples are reported. Breda 4

(Belfast) has the highest number of lead tests reported, at 37. There were 63 water treatment works and 372 supply reservoirs. The total number of tests for lead in 2000 is 827.

By 2009, there were 5 zones in which 4 tests for lead at tap were performed, and 55 larger zones in which 8 tests were performed. That gives just 460 lead tests from 802,000 possible tests (this is the number of connected buildings – figure from Drinking Water Inspectorate for Northern Ireland's 2009 annual report). The number of treatment works is down to 36, with a smaller reduction in supply reservoirs to 340 (annual report data).

At the water zone level kitchen taps are picked using "a sampling programme that selects sample points at random from a comprehensive list of its consumers, including public buildings."[1]Areas of doubtful personal security are, however, avoided (Guidance, p20). As childhood lead exposure has been linked to violent crime (Wright, JP, Dietrich KN et al (2008), and Kim M Cecil et al (2008)) the omission of testing in unsafe neighbourhoods is very regrettable. As can be seen by the tortuous way in which the dataset is built up and manipulated, the random sampling process does not provide an equal probability of choosing each tap from the 802,000 connected buildings.

If access can be obtained in normal business hours, the first litre of water poured from the kitchen tap (or other tap used for drinking) is collected for metals testing. This is known as a "first draw" sample. If access is not available, as must often occur at homes in business hours, the nearest property (of any type) is substituted. First draw samples disproportionately reflect the presence or absence of contamination from the plumbing materials nearest the tap (typically copper) missing the lead contamination associated with water which has sat in old underground pipes. The issues are vividly discussed in engineer Prof Marc Edwards 2004 Written Testimony to the US House of Representatives Committee.

The number of samples where significant lead contamination is missed by random first draw sampling is put at 20% in a 2008 EC

[1] Separate legislation made publication of results for public buildings necessary, and in England and Wales water companies now have a new duty to ensure that, when they test water in public buildings and it fails the test, their water customer sorts out any problem that relates to a premise plumbing issue.

JRC technical report to which Whitehall's Drinking Water Inspectorate contributed. The Scottish New Homes Lead Survey Stage 2, 2003 estimated that first draw sampling misses 50% of homes where illegal lead solder contaminates drinking water, by checking occupants blood samples and isotope matching the lead found to samples of solder, and by directly testing solder.

A further barrier to drawing logical conclusions from the manipulated and poorly randomised sample data about the population (in statistical terminology) as a whole, is the slippery concept of what that population is. It cannot be the 802,000 connections, as resampling the same property gives inconsistent results, nor is even the total litres of water supplied in a period, as these are not discrete litres. It is important therefore not to over analyse data collected in such an unsatisfactory manner.

Placing lead test results in an infant health context

A 2012 paper by Simoni Triantafyllidou and Marc Edwards allows Northern Ireland's lead in water results to be placed in a context where the health implications are clear. At a property where a child's lead poisoning was firmly linked to tap water, they show that test results ranged from a low of 11 to a high of 583 microgrammes/L (Table 9, page 1325).

Looking at tap water lead in infant feeds shown to have caused lead poisoning: 130 ppb lead (approx 130microgrammes Pb/L) in first draw water was linked by Shannon (1992) to a 13 month infant in Boston. Shannon warned that prolonged boiling of water - boiling tap water is the first step in preparing formula – actually raises lead concentrations. He recommended that all taps used for infant feeding be tested, and bottled water preferred when lead is found. The Glasgow 93 study is careful to test lead levels in kettle water and reiterates the bottled water advice. Note also that bottles are most cheaply sterilised by long boiling in tap water and could themselves become contaminated in this way.

Looking 8 years on from Shannon's letter at Breda 4, the Belfast water zone in which 37 regulatory tests for lead were conducted in 2000, the highest results - 276, 189, 124, 121 and 106 - all have alarming implications for formula fed babies. The corresponding results for 2009 cannot be identified because of the way that the data are reported.

Table 1: Summary of regulatory tests for lead in tap water (N. Ireland)

Year:	2002	2003	2004	2005	2006	2007	2008	2009
results > 130[a], number	12	10	3	0	1	2	1	0
as % of tests in year	*2*	*1.5*	*0.1*	*0*	*0.2*	*0.2*	*0.2*	*0*
results>= 11[b], number	117	164	50	17	11	7	22	10
as % of tests in year	*17.3*	*24.2*	*9.6*	*3.4*	*2.3*	*1.5*	*4.7*	*2.17*
results > 10[c], number	123	170	52	18	16	10	25	12
as % of tests in year	*18.2*	*25.1*	*10.1*	*3.6*	*3.3*	*2.2*	*5.3*	*2.6*
results > 2[d], number	259	346	131	66	73	75	71	150
as % of tests in year	*38.3*	*51.1*	*25.1*	*13.0*	*15.2*	*16.2*	*15.2*	*32.6*
results < 2, number	418	331	390	440	407	389	397	310
as % of tests in year	*62.0*	*49.0*	*75.0*	*87.0*	*85.0*	*84.0*	*85.0*	*67*
Total tests	677	677	521	506	480	464	468	460

[a]130 = infant formula leading to clinically diagnosed plumbism (Shannon)
[b]11 = lowest result at home of child with lead poisoning from tap water (Triantafyllidou)
[c]10 = limit associated with decline in child IQ of at least 3 points, adult rise in (systolic) blood pressure of 3mmHg (see WHO Guidelines for Drinking Water 4th Edition)
[d]2 = results above 2 indicate some source of lead contamination is present

It is striking, however, that the high test results in 2000 failed to trigger wider testing and advice. The Drinking Water Quality Inspectorate treated each failure against the standard as an issue only for the "consumer" of the property tested (eg page 32 of the 2000 report), although properties are rarely built individually.

After orthophosphate dosing (in 2008/9) lead in tap water still occurs at hazardous levels, as the true maximum data emphasize. Moreover, Table 1 (above) shows that, in all years (2000-2009) levels of lead contamination potentially hazardous for infant health were present in a substantial proportion of properties. Yet health service guidance on the preparation of infant feeds continues to omit this issue entirely.

Toronto, Canada

In Canada, drinking water regulation sits in public health, states make their own laws and guidance to consumers is notably more cautious than that from the UK and Northern Ireland water quality regulators. Ontario in 2007 required annual testing for lead in tap water by schools built before 1990. The legislature building, Queen's Park, was also thoroughly tested and 7 out of 20 samples exceeded the legal limit (source CBC News coverage by Sabrina Sacoccio, June 11, 2007).

Acting without waiting for a national consensus has pushed standards faster and higher. For example Prabjit Barn and Tom Kosatsky (2011) can use data from Ontario's school testing to urge the rest of the country to follow suit.

This is Toronto Health's 2011 advice for families living in homes built before lead pipes were banned:

> Actions for people who live in houses built before the mid-1950s
>
> If you are pregnant and/or have a child under six years old: Install an end-of-tap water filter. Look for filters certified by the National Sanitation Foundation that have "NSF-53 for lead removal/reduction" on the label. For information on good filters, call 1-800-673-8010 or visit the NSF website.
>
> If you are feeding your baby formula, begin with cold filtered tap water, boil it, and then let it cool. Use within 30 minutes. Until you have a filter, consider using bottled water for drinking and making baby formula. You can also consider using ready-to-feed formula. [Accessed 8 October 2012, www.toronto.ca/health/lead/drinking_water.htm]

Note that Canada banned lead pipes in the 1950s, but the UK and Northern Ireland did not act until the 1970s.

Advocating the use of lead removal/reduction filters for everyone in a vulnerable group in an older property is a logical response to low rates of testing and biased sampling, the high false negative rates of tap water lead tests and the inadequate documentation by water companies of the materials used in pipe-work buried underground.

Advice and research in the UK and Northern Ireland comes from Whitehall's Drinking Water Inspectorate, and reflects priorities other than the health agenda. This reflects its position in a department committed to reducing per capita water usage. This is at odds with advising flushing out pipes and plumbed in filters.

Lead in water and health and social inequalities

The accepted 2012 US report *Recommendations of the Advisory Committee for Childhood Lead Poisoning Prevention* evaluates the most recent science supporting the elimination of all point sources of lead exposure to children. As early lead exposure inhibits educational achievement and employabiliy, exposure keeps poor families poor, destroying social mobility.

Survey's such as Statistics Canada's 2010 report *Lead and bisphenol A concentrations in the Canadian population* consistently associate low household incomes with higher blood lead levels.

General explanations include hunger and malnutrition promoting lead adsorption and dirtier environments with more sources of lead exposure. More sources of other types of exposure may compound lead's harmful effects.

In the case of tap water lead, difference in housing types between those with lead pipes may mean poorer families face higher exposures. In her 2004 Congressional Testimony (March 5th), Ellen Silbergeld drew attention to Sir Abraham Goldberg's success in tracing a cluster of mentally retarded children in Glasgow to the storage of drinking water in lead lined tanks in 1967.

Citizen's Advice leaflets for Scotland and Scottish Water's "Your Water" leaflet (Scottish Water website) both mention lead cisterns as a contemporary source of lead in water. Cisterns are used to ensure adequate water pressure in the tall tenement blocks typical of urban housing for poorer families.

Other types of high density housing also have more lead pipe between a kitchen tap and the lead free main. Lead levels will be higher and running the tap a counterproductive precaution. A report for Galway City Council of 26 Sept 2008, *Lead in City Water Supply*, includes pipe-work diagrams for Old Mervue revealing very extensive lead pipe-work for this council built estate.

Recommendations

NHS guidance on preparing infant formula feeds and drinks for children should be updated to include precautions to reduce lead, including running the tap, using a filter or choosing bottled water.

To achieve the World Health Organisation's goal that regulatory drinking water testing functions as an independent check on water providers and is for water users, responsibility for commissioning these tests should transfer from water companies to local health groups. In England, GP consortia may be the best option.

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