DRINKING WATER AND WASTE WATER: A PRIMER

Harry Swain

Canada's record regarding drinking water is, on the whole, not a bad one, writes Harry Swayne, but it could surely be improved. While the technology for drinking water treatment has been standardized for over a century and is likely "the greatest single advance in public health in the history of mankind", there are still two important problems with it: it works cheaply only for big systems and it does not challenge many of the new chemicals discarded into the environment. Here he provides a quick primer of drinking water treatment and suggests three further reforms to improve our record: consolidation of small systems into larger ones, creation of financially competent water and wastewater utilities and increased R&D effort on the new threats to aquatic environments.

Le bilan du Canada en matière d'eau potable n'est pas si mauvais, estime Harry Swain, mais on pourrait certainement l'améliorer. Vieille de plus d'un siècle, la standardisation des techniques de traitement de l'eau potable a sans doute constitué « la plus grande avancée en santé publique de l'histoire de l'humanité », mais elle rencontre aujourd'hui deux problèmes majeurs : elle fonctionne à bon prix uniquement pour les gros systèmes et elle laisse passer un grand nombre des nouveaux produits chimiques qui sont rejetés dans l'environnement. L'auteur explique les rudiments du traitement de l'eau potable et propose trois mesures pour améliorer notre bilan : regrouper les petits systèmes en systèmes plus importants, créer des services publics de traitement de l'eau et des eaux usées qui sont sains sur le plan financier, et accroître les efforts de R-D pour ce qui est des nouvelles menaces aux environnements aquatiques.

Safe drinking water starts with good-quality source water, requires treatment to remove microbes and impurities, needs to be distributed through invisible infrastructure and, once used, has to be collected, treated and returned to the environment, where it becomes source water once again. It is so cheap to do this in quantity that we can afford to water our lawns and wash our cars with water pure enough to drink. So what's the problem?

From the point of view of an adequacy of source water, in most parts of Canada there is no problem. Yes, in the Palliser Triangle and the Okanagan, shortages of water are beginning to bite, the more so as climate change makes issues of the variability and seasonality of precipitation. But the real problem is waste and its evil twin, mal-pricing. There are a wide range of demand management tools available for use, and the kinds of water scarcity problems experienced in the dry southwest of the United States or through the desert areas of the world are simply not ours. Elsewhere in Canada, we have both stocks and flows of high-quality natural water that would make a sheikh weep. Southern Ontario, for instance, is a *tarte Tatin* of saturated limestones and other sedimentary rocks, surrounded by the Great Lakes, on which a metre of rain falls every year. Most of this flows on to water the great cities of Quebec.

Some observers view with alarm the prospect of US appropriation of Canadian water, through either grand schemes like the North American Water and Power Alliance (NAWAPA) or the cupidity of companies eager for short-term profit. These fears are largely illusory if only because both we and the Americans price water so cheaply that it cannot bear the cost of shipping or pumping. Gravity is the only agency that can move large quantities, and only Chicago's historic transfer from Lake Michigan to the Mississippi can do this. Even at local scales, more than a third of the operating costs for piped water goes to electricity. Large-scale exports — beyond the vast flows in natural river systems — would require in addition the collaboration of Canadian governments in licensing large new dams and impoundments.

Difficulties with the availability of source water are not so much dictated by nature as they are a consequence of human mismanagement. For example, we pollute our groundwater, fail to study it and are surprised when wells start to produce contaminated water. We price the finished product so cheaply as not to be able to keep up with infrastructural requirements.

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At a deeper level, Canadians have been brainwashed into thinking that we have all but infinite stores of water, that in "Super Natural BC" (to quote the tourist ad) bears do not poop in the woods and that we need to devote no care and attention to stewardship. These are easily fixable problems, and a reasonable degree of progress is being made on them.

Likewise, the technology for drinking water treatment has been standardized for a century now. In the years before the first World War, engineers focused on "chemically assisted filtration and disinfection" as the way to avoid the miasmic plagues of all previous centuries. What does this mean?

It starts from the view that water can kill you fast if polluted with the wrong sort of microbes, or much more slowly if the contaminants are the ordinary chemical solutes and physical particles that are found in nature. One has to kill the bugs first.

There are three types — bacteria, viruses and protozoa — the first two of which are easily overcome by very small doses of chlorine. Protozoa are trickier, in that in their dormant phase, between periods of riotous reproduction in mammalian intestines, they cover themselves with a fairly tough coat that limits the effect of chlorine. Fortunately, however, like bacteria they are mostly larger than two microns in diameter, so that if you have a very fine filter — or can encourage them to stick together in clumps — you can separate them.

That's where the "chemically assisted" part of standard drinking water treatment comes in. A flocculant like alum is added to the source water and forms large, sticky flakes, something the size of wet snow. Slow stirring in a large tank will cause almost all of the microbes, as well as particulates (though not solutes), to stick to the flocculant. The filtration part is equally simple: the floc-filled water is passed through a fine sand filter, which catches these now rather large particles, and what comes out the other end is quite pure. To be sure, a small dose of chlorine is added — not so much to kill any remaining microbes, though it will do that, but more to act as a warning signal farther down the line. Chlorine is consumed in the disinfection process, which means that a measured absence of chlorine is a sign that it may have been used up before all the bugs are inactivated.

There are many variants on this standard treatment, such as the use of chloramines instead of chlorine as the treatment chemical, or the introduction of ozone or ultraviolet radiation in the disinfection chain, but this is the essence. This straightforward method was the greatest single advance in public health in the history of mankind and has contributed in no small measure to the world's burgeoning population.

Broadly speaking, there are two problems with this old standard. First, it works cheaply only for big systems. The economies of scale are great, but the cost of treating the first gallon is astronomical.

As a rough guide, it does not make much economic sense unless there are on the order of 10,000 households — say 30,000 people — for each plant. There are many parts of Canada where this is not attainable. There are some work-arounds, such as having a single management organization look after a number of smaller plants, but there is no getting around the fact that unit costs increase as the size of plant gets smaller.

The second problem is that the standard method does not challenge many of the new chemicals we have discarded into the environment in the industrial age. Many persistent organic pollutants and endocrine-disrupting substances, such as the synthetic estrogens that are the active ingredients in birth control pills, pass unchallenged through both sewage and water treatment plants and are now part of our surface source water. Chlorine itself may produce by-products — trihalomethanes, haloacetic acids and others — that in quantity may be carcinogenic. These chemicals have potentially great effect on the fauna that breathe water. The estrogens, for instance, seem to have dramatic effects on the sex lives of fishes, even in very small quantities.

Fortunetely, there are reasonably economical engineering solutions to the scale problem now. Membrane filtration can remove particles much smaller than microbes, and resin treatment can remove some but not all of the nastier chemicals. At the very least, reverse osmosis or fractional distillation can produce chemically pure water at not unreasonable cost at small scale.

The next step in providing safe drinking water is distribution. The critical characteristics of distribution systems are, first, that their economies of scale are modest and can become diseconomies in larger systems: designers have to take account of the joint effect of treatment plant and distribution system size and geometry to produce optimally low costs. Second, system design needs to avoid dead ends and slow-circulation regions to the degree possible in order that microbe regrowth is precluded.

Of course all of this has to be done in the context of risk, cost and standards. In Canada, standards for treatment are set by a federal-provincial committee of officials, assisted by scientific assessments by Health Canada, and applied by provincial governments. Historically these standards have been highly conservative with respect to chemical and physical pollutants, with extra orders of magnitude stuck in for possible effects of model systems and possible unknowns.

For many the level is set at a wholly theological level: the amount that, when consumed by a human at two litres of water a day for 70 years, could be expected to produce one extra neoplasm in a population of 10,000. Of course such an effect is unmeasurable in practice, but it shows how far the authorities have bent over backwards to reduce risk to a level where it is negligible. The standard for microbes is set indirectly. One wants to get to zero, or very near to it, but since measurement of the result usually takes several days of culturing in a testing lab, by which time the water may well have been consumed, the approach is to specify one of a number of acceptable treatment trains.

This is fine, as far as it goes, but there has been a tendency to make certain steps advisable rather than mandatory when provincial financial officials look at the costs implied by the standards. Thus the important sand filtration part has not historically been part of the mandatory Canadian system, and turbidity standards have been somewhat lax compared to those of other advanced countries. One consequence has been very large numbers of boil-water orders in small communities, and even in a few large ones. Most of Greater Vancouver, for example, was under a boil-water advisory for two weeks in 2007 when heavy rainfall caused mudslides in its north shore reservoir before its filtration plant, then under construction, was completed.

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In Canada, there are four recognized levels of plant operator for each of the water and sewage systems, as well as for distribution and collection, distinguished by level of training, complexity of plant and on-the-job experience. For some time there has been a national shortage of operators certified at or above the level of the plants they run, a shortage that has narrowed since Walkerton but that still persists owing to the time it takes to train senior operators. Small systems have difficulty paying competitive rates and are particularly at risk.

The scandalous state of water and waste-water treatment on First Nations reserves has improved markedly since 1996, when the federal government effectively doubled its allocations to capital and made training a focus of its efforts. It would appear that reserve communities are now, broadly speaking, as well served as non-Indian communities of similar size: a substantial achievement, but one that should not mask the fact that small communities all across Canada bear higher risks of microbial contamination than do cities. A 15-year catch-up investment will be largely complete by 2011, testimony both to the quality of First Nations water operators and to the sustained attention of three federal governments.

The regulatory system overseeing the production of drinking water has, or should have, three major components. First is a set of quantitative standards for contaminants, microbes, turbidity and the like. In Canada, the system that produces these standards is cumbersome and slow, producing highly conservative (and thus more costly than absolutely necessary) numbers, but it works. It can be improved but it is not seriously problematic.

Second, there is a need for enforcement of these standards: by expert provincial inspectors with the power to order remediation, improvements in operations and training, boil-water orders and even plant shut-downs or the imposition of third-party management in extreme cases.

Third, and well short of the necessarily hard hand of law enforcement, there is a need for ongoing advice, usually offered through professional associations, peer review, visits to other systems, continuing education, formal quality control systems and the like. Some provinces used to offer informal visits by trained engineers, but most such services fell to budget-cutters in the 1990s. The First Nations Technical Institute offers a "circuit rider" program, a considerable success that is currently being expanded. And the federal government has promised legislation to extend provincial water quality standards to reserves, but so far without a solution to the enforcement issue.

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This is, on the whole, not a bad record. Where might it be improved? The answers arise from the heavily capital-oriented nature of water services, and their great economies of scale.

Getting scale into the business is the key to keeping costs affordable. Both sewage treatment and water purification can be done economically at the smallest scales — one or a few households — especially, in the case of sewage treatment, when population densities are low. Septic fields for sewage and ultraviolet or membrane filter treatment for potable water are, respectively, old and new methods for the smallest scale.

There is no reason why towns large and small should not pay for their own water services. The relief of taxes at the provincial and federal levels would in most places allow room for cost-based pricing, with all its attendant positive externalities, at the local level. And it would remove the incentive for periodic overspending, while making the utility much more closely attentive to the interests of its customers.

But once settlements and smaller towns require service, the newer technologies fall short of the mark: they can be expensive and require a high skill level to operate safely. Thus the consolidation of small systems into larger ones, either by physically joining several systems where feasible or by putting many small systems under the management of a single organization, is the *sine qua non* of affordable and safe water treatment.

Unfortunately, this flies in the face of municipal *amour-propre*. Recent experience in Ontario demonstrates the power of local particularism: despite the promise of large cost savings, the present government has declined even to offer incentives to consolidate to rural municipalities jealous of their small powers. In so doing it perpetuates the common practice of grant-funding small systems with unnecessarily high per capita costs.

Grants from senior levels of government also distort local decision making. Capital improvements are delayed longer than risks to public health would dictate as municipalities wait for the infrequent cloudbursts of "opium" — other people's money — and then over-invest. The strange consequence is that in an infrastructure-short world, municipalities frequently have much more deteriorating pipe in the ground than they actually need.

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Much has been made of the unsatisfied need for investment in water and waste-water services across the country. The numbers are large but manageable if properly distributed over the long lifetimes of the systems in question. Part of our present difficulty arises from a backlog of capital for treatment — not collection and distribution — in recent decades; part of it stems from an odd technological coincidence on the distribution side.

When piped water first started to become common a century or more ago, the material of choice was cast iron. Such pipes have proven to be good for a century or more. After the First World War, somewhat less durable ductile iron came into widespread use, with an expected lifetime of around three-quarters of a century. After the Second World War, Canada's enormously expanded steel industry started turning out lightweight steel piping — which has a life expectancy of perhaps half a century, depending on groundwater acidity, stray electrical currents and the like. Only recently have highly durable plastics come into use.

The consequence is that an unusually large percentage of the nation's underground piping is starting to leak at the same time. Breaches are expensive to repair, pose the possibility of nasty stuff getting into the distribution system and require ever greater capacity at the treatment plant level to make up for losses.

Thus the second large reform that ought to be considered is the creation of financially competent water and waste-water utilities. There are a few situations where senior government help may be necessary, such as in the case of declining resource towns that no longer have the customer base to finance their legacy systems, never mind their replacement, but these are few. There is no reason why towns large and small should not pay for their own water services. The relief of taxes at the provincial and federal levels would in most places allow room for cost-based pricing, with all its attendant positive externalities, at the local level. And it would remove the incentive for periodic overspending, while making the utility much more closely attentive to the interests of its customers.

These utilities need to be large enough to command expert services in engineering, testing and microbiology, as well as in financial management and customer relations. Their charges should be based on their cost of services, and revenues ought to flow to them rather than pass through the hands of local politicians who may require some of the funds for other local projects.

Revenues, in other words, need to pay capital charges and operating costs first and foremost. If by accident or design there is a surplus, a (multi-) municipal owner could then allocate the amounts for other local purposes. Only if utilities appropriate some of the disciplines of independent businesses can efficient operations be expected over the long term. Note that this statement does not imply the necessity of private ownership.

Finally, sewage treatment. Here especially the country has not kept up with the large investments of the postwar period, and in consequence faces requirements for replacing worn-out systems as well as accommodating population growth. The last few cities without sewage treatment of any kind, like Halifax and Victoria, are either building or under orders to build new treatment plants. The experience of Victoria, however, highlights some problems with current technology.

Standard ("secondary") sewage treatment is fairly good at using bacteria to reduce nutrient loads (nitrogen, phosphorus) and oxygen demand in the effluent. Disinfection with chlorine or ultraviolet is sometimes added. But, as noted, standard treatment does little to eliminate small quantities of the dangerous chemicals from industrial and pharmaceutical sources.

Thus Victoria's untreated sewage, 99.97 percent water and currently dumped untreated into the Strait of Juan de Fuca, has little measurable biological impact more than 100 metres from the outfalls. Within that small circumference a principal observation is that mussels are bigger and fatter. Spending $1.2 billion, the current estimate, to reduce nutrient and oxygen loadings will have negligible effect on the oceanic environment but will require on-land disposal of concentrated biosolids. And nothing will be done to reduce the increasing levels of exotic chemicals.

So the final argument favours an increased R&D effort on the new (or newly recognized) threats to aquatic environments posed by the new materials that we consign to our sewers. Obviously, positive results would apply everywhere and not just to coastal locations. After all, "What Edmonton has for breakfast, Prince Albert gets for dinner."

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