# Sustainable Distributed Drinking Water Treatment for Small Water Systems

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# SUSTAINABLE DISTRIBUTED DRINKING WATER TREATMENT FOR SMALL WATER SYSTEMS

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## ABSTRACT

The provision of safe drinking water for small communities is an inherently challenging task. Instead of focusing on centralized treatment for contaminant removal, some studies favour the development of distributed systems for optimal utilization of resources. However, the question remains whether these systems are sustainable in the more integrated sense. This paper focuses on point-of-use (POU) and point-of-entry (POE) water treatment as an increasingly considered distributed treatment alternative for ensuring the safety of drinking water in small water systems. New technologies have emerged with high removal efficiencies of contaminants that can be implemented on a smaller scale to suit the needs of a small community. With the commercialization of these devices, however, the task of selecting a suitable process and/or device for treatment has become cumbersome. An extensive overview of the drivers for the adoption of POU and POE water treatment is given. The selection procedure was designed based on careful consideration of the various aspects of a treatment technology including regulatory, economical, social, and technical elements. Finally, the use of an algorithm for screening a database of available POU/POE treatment devices in the selection of sustainable treatment alternatives is demonstrated.

## INTRODUCTION

Although the evolution of centralized water treatment has helped in enhancing its sustainability and robustness, decentralized and small water systems still linger in achieving an equivalent level (Anderson and Sakaji, 2007). The reasons are numerous, and perhaps the least of which are financial constraints faced by small systems. For decades the compliance of small water systems to increasingly stricter regulations seemed to be an impossible task, especially in remote and rural areas where the necessary expertise and financial resources are often unavailable. This has led to numerous incidences of outbreaks caused by waterborne pathogens and other adverse health effects resulting from water contaminants in small communities (Dupont, 2005; AquaVic, 2007).

The smallest scale at which drinking water treatment can be implemented is at the point-of-use (POU) level. POU devices usually only treat water intended for direct consumption (drinking and cooking), and are typically installed at a single outlet or limited number of water outlets in a building. A slightly larger scale is the point-of-entry (POE) treatment level, where devices are typically installed at the inlet to treat all water entering a single home, business, school, or facility (USEPA, 2006a, 2006b; AquaVic, 2007).

The growing interest in POU/POE devices has led to an overwhelming increase in the number of commercial devices that are marketed as potential solutions to drinking water problems. This leaves consumers and community water suppliers with the difficult task of choosing from these devices. This paper outlines some of the drivers for the increase in the use of POU/POE systems; the issues associated with implementing such systems, and then finally a framework to help in selecting sustainable POU/POE systems is proposed.

## RISE OF POINT-OF-USE AND POINT-OF-ENTRY TREATMENT

Regulation 170/03 under the Ontario Safe Drinking Water Act (SDWA) defines a POE system as one that: provides primary disinfection (but no chlorination), is installed at or near where water enters a building, and is connected to the plumbing (OMOE, 2002). NSF/ANSI standards add to this definition the condition that flow (Q) of a POE system should be greater than 15 L/min at pressure difference 103 kPa and temperature 18 +/-5 °C (NSF/ANSI standard 53, 2007). A POU system, on the other hand, is one that is installed at or near where water is directly used (faucet or showerhead) and may be connected to plumbing or not (Figure 1).

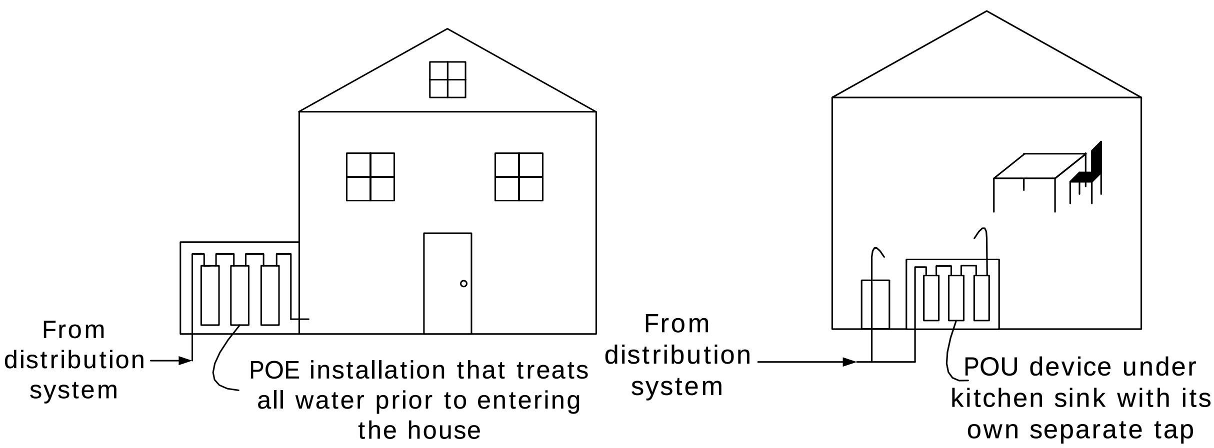


**Figure 1. Typical Installment of POU and POE Systems**

POU/POE devices are typically designed to reduce specific contaminants in drinking water, including heavy metals, pesticides, particulates, and pathogens (Chaidez and Gerba, 2004). Most treatment technologies can be implemented on a POU/POE scale including: activated carbon and other adsorption resins, distillation, membrane filtration, and others. Some treatment packages consist of several processes in series depending on the level of treatment needed and the quality of the feed water. Both types are increasingly spreading in the developing world. This section discusses the drivers behind the increase in POU/POE water treatment.

### Consumer Awareness and Concerns

The most important factor for the rise in the use of POU/POE treatment is the increase in consumer awareness about water issues and their concerns about the safety of centrally treated water. Many studies show that although Canadians rate their water quality highly, a considerable percentage also have concerns with its safety (Odoi et al., 2003; Turgeon et al., 2004; Dupont, 2005; Jones and Joy, 2006). Alternative water sources are often sought due to perceived improvements in quality and safety over regular tap water; in addition convenience is an important factor with respect to bottled water use (Souter et al., 2003; Dupont, 2005). These perceptions are exacerbated when a water supply is from a private source rather than a public source (municipality).

Approximately 56% and 61% of survey respondents used in-home treatment devices and bottled water within their homes, respectively (Jones and Joy, 2006). Dupont (2005) notes that even before the Walkerton incident, cross-Canada surveys reported that 50% of the respondents rated their tap water as presenting a moderate to high health risk. Statistics Canada in its latest report confirms that almost 3 in 10 households drank primarily bottled water as opposed to tap water (Statistics Canada, 2006). Several studies reported a general trend of increasing use of bottled water across Canada, often as an alternative to tap water (43% of respondents) (Levallois et al., 1999; Turgeon et al., 2004; Jones and Joy, 2006). In the same report, household water treatment was noted to be used by 4 out of 10 households that consumed their tap water. Households connected to a municipal supply were more apt to use a stand-alone filter (POU-type of device), while those on a well or other non-municipal source were more likely to use a filter on the tap or supply line (POE-type of device) (Statistics Canada, 2006).

**Distribution System Contaminants**

Realizing the risks from distribution system contaminants has prompted the embracement of the "multiple barrier" approach in drinking water treatment. This approach includes the protection of source water quality, multi-level treatment applied at the water treatment plant, distribution system monitoring and protection, and finally using POU/POE systems as the last barrier for consumer protection (Abbaszadegan et al., 1997; Baker et al., 2006; McEncroe, 2007).

In cases where the contaminants enter in the distribution system through cross-connection, back flow, or contamination of reservoirs; POU and POE alternatives may be the only feasible option to respond to such contamination. Examples of distribution system contaminants are disinfection byproducts (DBPs), copper, aluminum, and lead (Williams et al., 1997; Srinivasan et al., 1999; Smith et al., 2001). Moreover, with increasingly stringent drinking water quality standards, municipalities are faced with two options, either to modify water treatment plants to comply with the new standards or to adopt a decentralized water treatment strategy where some contaminants can be removed at the small scale or point-of-use level (Cotruvo and Cotruvo, 2003). The choice is to some extent based on a comparative benefit analysis mainly governed by the cost of each alternative.

**Remote Areas and Small Water Systems**

In addition to the increasing use of POU/POE devices for water treated by central treatment systems, they have also been proposed as a direct water treatment alternative for small, rural, or remote communities especially where groundwater is the source (Cotruvo and Cotruvo, 2003; Anderson and Sakaji, 2007; McEncroe, 2007). In the latter case the level of control and monitoring required on these devices is far stricter. POU/POE represent an alternative for small water systems with limited financial resources and expertise to comply to increasingly stricter regulations (Jones and Joy, 2006). Furthermore, small and rural water systems are distributed by nature where houses are too far apart to be connected with water networks thus making a decentralized or distributed water treatment system more feasible (Dupont, 2005).

**Security and Risk**

Apart from the use of POU/POE devices for targeting the removal of specific contaminants, there has been a growing interest in these devices as means of reducing risk and providing a sense of security. These devices are often referred to as the final barrier or the last line of defense from a security perspective (McEncroe, 2007). They have been considered as means of alleviating risks cause by the intentional contamination of drinking water (USEPA, 2006a).

The incidental effect of installing a POU/POE device can have a serendipitous security benefit if the device happens to be effective against a contaminant that was introduced into the distribution system. For immuno-compromised consumers POU and POE treatment is of particular importance to ensure protection from pathogens. This case is evident in hospitals that require microbiologically safe water for immunosuppressed patients (Daeschlein et al., 2007).

**Acceptance as Means for Compliance with Regulations**

In general, regulatory agencies have a stronger position against POU than POE systems. Nevertheless, recent changes in drinking water regulations have included acceptance of POU and POE treatment as alternatives to comply with maximum contaminant levels set by legislation. The Ontario Safe Drinking Water Act Regulation 170/03 (Drinking-water Systems) Schedule (3) identifies POE as compliance technology for small municipal residential systems (defined as systems serving less than 101 private residences). In addition, in most cases, water systems with fewer than 15 connections are exempt from regulation thus giving them the freedom to select, install, operate, and maintain their treatment systems (OMOE, 2002).

The British Columbia Drinking Water Protection Act (DWPA) defines a small system as one that serves less than 501 individuals. Section 3.1 stipulates that a small water system in which each recipient of the water has POE or POU treatment that makes the water potable is exempt from section 6 of the DWPA requiring a water supply system to provide potable water (BCMOH, 2003). It is notable the BC DWPA is the only regulation that does not set limitations on the use of POU devices for compliance.

However, in the above mentioned regulations there are many strict requirements for water purveyors to ensure the safety of drinking water, including:

- POU devices cannot be listed as a compliance technology for a microbial contaminant; however, POE devices can be used except for chlorine units;
- Units have to be owned, controlled and maintained by a water purveyor; responsibility cannot be delegated to homeowners as part of a compliance strategy;
- Mechanical warnings should be present (alarm, light, auto-shutoff, etc.); and
- Only certified units can be used.

**Certification of Point-Of-Use and Point-Of-Entry Devices**

In response to the increase in the adoption of POU/POE treatment devices, the Canadian government established a certification mechanism whereby these devices can be tested to prove their claim to remove certain contaminants. Generally, there are two aspects to certification in Canada (AquaVic, 2007):

- The development of standards for drinking water treatment materials (devices, systems, components and additives, both intentional and unintentional e.g., leaching),

- The testing of these drinking water materials to the standards.

Standards are developed by consensus through organizations such as NSF International (NSF) (Table 1) and the Canadian Standards Association (CSA). NSF certification process requires a water treatment system to meet the following requirements:

1. Verification of the contaminant reduction claims
2. Materials and components of the system must not add anything harmful to the water
3. The system must be structurally sound
4. The advertising, literature, and product labeling must not be misleading
5. The materials and manufacturing processes used cannot change

Health Canada does not recommend specific treatment devices or components but strongly recommends that all products that come into contact with drinking water be certified to the appropriate health-based performance standard developed by NSF/American National Standards Institute (ANSI). In Canada, the following organizations have been accredited by the Standards Council of Canada to certify drinking water materials as meeting NSF/ANSI standards (AquaVic, 2007):

- Canadian Standards Association International (www.csa-international.org);
- NSF International (www.nsf.org);
- Underwriters Laboratories (www.ul.com);
- Quality Auditing Institute (www.qai.org); and,
- International Association of Plumbing and Mechanical Officials (www.iapmo.org).

**Table 1. POU and POE Treatment Units' Certification Standards**

| Standard | Title | POE | POU |
|---|---|---|---|
| NSF/ANSI 42 | Drinking water treatment units—aesthetic effects | Yes | Yes |
| NSF/ANSI 44 | Residential cation exchange water softeners | Yes | No |
| NSF/ANSI 53 | Drinking water treatment units—health effects | Yes | Yes |
| NSF/ANSI 55 | Ultraviolet microbiological water treatment systems<br>Class A: systems (40,000 uwsec/cm2) designed to disinfect and/or remove microorganisms from contaminated water, including bacteria and viruses, to a safe level<br>Class B: systems (16,000 uw-sec/cm2) designed for supplemental bactericidal treatment of public drinking water or other drinking water, which has been deemed acceptable by a local health agency | Yes | Yes |
| NSF/ANSI 58 | Reverse osmosis drinking water treatment systems | No | Yes |
| NSF/ANSI 61 | Drinking Water System Components - Health Effects | | |
| NSF/ANSI 62 | Drinking water distillation systems | Yes | Yes |
| NSF/ANSI 177 | Shower filtration systems—aesthetic effects | No | Yes |
| NSF/ANSI P231 | Microbiological water purifiers | Yes | Yes |

A standard relating to POE / POU systems was issued recently by the Canadian Standards Association (CSA) -- Standard B483.1. This standard is intended to complement, but not duplicate, existing NSF/ANSI standards. Its purpose is to address complete systems, to ensure that the sum of their parts meets the existing standards for performance and structural integrity from plumbing, electrical, mechanical, and material toxicity perspectives. Only 2 provinces

(Alberta and Quebec) have made compliance with CSA International Standards for drinking water mandatory, through their Building Codes.

Water treatment devices certified according to NSF/ANSI standards include: softeners, distillation systems, filtration systems, reverse osmosis systems, microbial purifiers, and UV systems. A quick look at the distribution of certified drinking water treatment units among the various standards shows that the majority of the certified products are for aesthetic effects only (NSF, 2008).

## POINT-OF-USE AND POINT-OF-ENTRY TREATMENT ISSUES

Worldwide, there are about 377 manufacturers of certified POU/POE devices listed by NSF producing around 5,685 drinking water treatment products. Only 2,356 of these products are treatment devices, the remaining products are accessories and replacement elements such as: faucets, filter cartridges, housing adapters, membranes, media, valves, pumps, and tanks. Table 2 shows the various configurations of POU treatment devices available on NSF's list of certified treatment devices. It is clear from figure 2 that certified plumbed-in devices represent around 75% of the total certified products (NSF, 2008).

These numbers are for certified products, a survey carried out in 1999 on drinking water units in Canada showed that certified products account for only 34% of the POU/POE market (Lavoie, 2000). Furthermore, often to treat water to adequate quality more than one process is needed. The task of selecting the proper sequence of processes is important since it affects the overall removal efficiency of the treatment train (Craun and Goodrich, 1999; AquaVic, 2007).

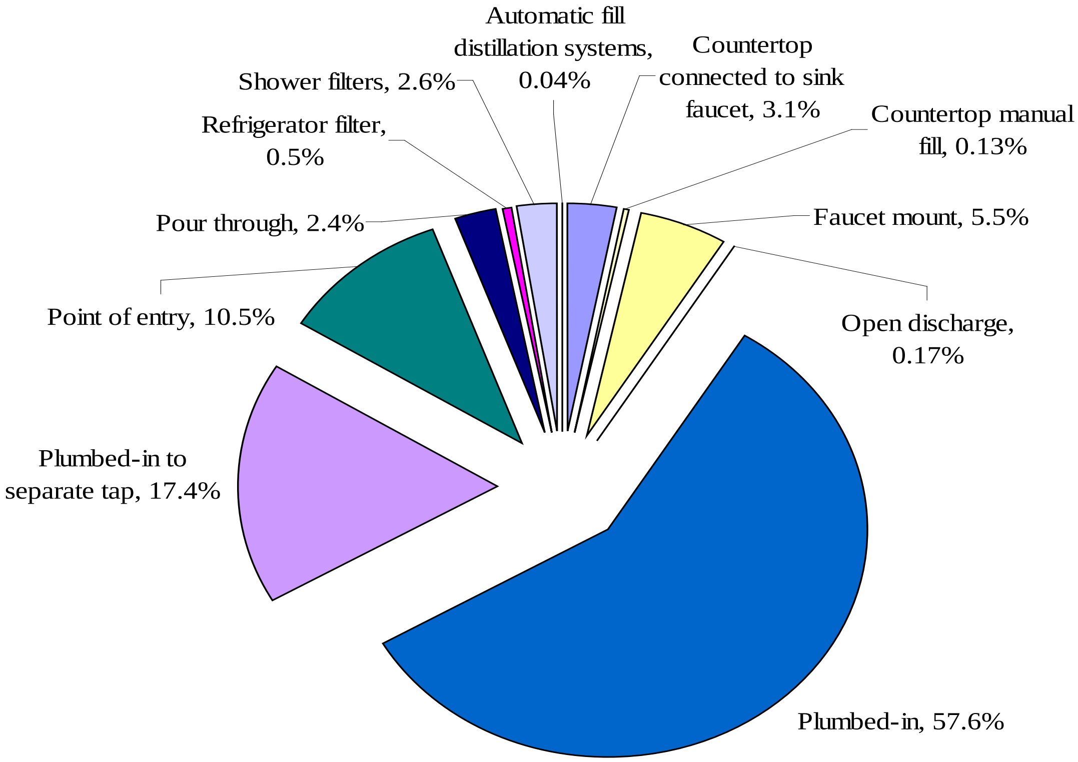


**Figure 2. Percentage Distribution for NSF Certified Water Treatment Products' Configurations**

**Table 2. Main Configurations of POU Treatment Devices**

| Configuration | Description | Advantages | Disadvantages |
| --- | --- | --- | --- |
| Countertop manual fill | Placed on a counter, filled by pouring water into the system and activating it for a batch of water | Easy to install<br>Longer filter capacity<br>No plumbing | Uses up counter space |
| Countertop connected to sink faucet | Placed on a counter and connected by tubing to an existing kitchen faucet | Easy to install<br>Longer filter capacity | Uses up counter space |
| Faucet mount | Mounts on kitchen faucet. Uses diverter to direct water through filter | Easy to install | Frequent filter changes |
| Built-in faucet filters | Replacement kitchen faucet that comes with a built-in filter | Does not require separate faucet | May require professional installation |
| Plumbed-in | Installs on cold water line under sink. Filtered water is dispensed through existing faucets | Longer filter capacity | May require professional installation |
| Plumbed-in to separate tap | Installs on cold water line under sink. Filtered water is dispensed through an auxiliary faucet | Longer filter capacity | May require professional installation |
| Pour through | Water drips through by gravity through a filter | Easy to install<br>No plumbing | Frequent filter changes |
| Shower filters | Install directly to the existing pipe before the homeowner's showerhead | Easy to install | Limited contaminant reduction |

As with any decentralized approach the main challenges in implementing a POU/POE system are of logistic nature. The distribution of responsibilities among interested parties is a difficult task. As mentioned earlier, regulations assign most of the responsibilities to the water purveyor. Nevertheless, educating all the interested parties on their roles and responsibilities is a crucial factor for the success of POU/POE treatment systems (USEPA, 2002). Although operating a small system is less demanding and easier to operate; the issue of the availability of trained operators remains a critical one. Improper operation or maintenance can have an impact on public health (Anderson and Sakaji, 2007). Devices vary considerably in their efficiency, and operation and maintenance requirements.

POU and POE treatment not only vary in their efficiencies but they will also vary considerably in how much they cost depending on the level of treatment required and the quantity of water treated (Table 3). The prices range from less then US$100 for tabletop units, to several hundreds of dollars for under the sink units, to over a US$1000 for POE units (Craun and Goodrich, 1999; USEPA, 2007).

Regulations, standards and guidelines that are complex and expensive to implement will discourage the use of any technology. As mentioned earlier, several recent regulations and standards related to the use of POU and POE systems in Canada have been issued, the most recent of which is CSA's Standard B483.1 which is perceived by manufacturers to potentially escalate the expense and perhaps reduce the availability of necessary POU/POE parts (WQA, 2006). Certification programs are either limited in scope leading to a lack of information needed to choose among a multiplicity of devices, or too complicated and detailed leading to confusion (Craun and Goodrich, 1999). Lack of information on the device capability to remove a target contaminant, its life cycle, operation and maintenance requirements, or other efficiency related information complicates the selection process.

**Table 3. Summary of POU/POE Treatment Technologies and Their Costs**

| Technology | Contaminants Removed | Initial Cost | Operating Cost | Operation & Maintenance Skills |
|---|---|---|---|---|
| Chlorine / Iodine | Pathogens | + | + | + |
| UV / Ozone | Pathogens | ++ | + | ++ |
| Submicron cartridge filter | Protozoa, bacteria | + | + to ++ | + |
| Reverse osmosis | Pathogens, inorganic chemicals and metals, radium, minerals, some organic chemicals | ++ | +++ | +++ |
| Distillation | Pathogens, inorganic chemicals and metals, radium, uranium, minerals, some organic chemicals | ++ | ++ | + |
| Activated carbon | Organic chemicals, radon, odors (carbon block can filter protozoa and some bacteria) | ++ | ++ to +++ | + |
| Ion exchange | Inorganic chemicals, (e.g. radium, nitrate) | ++ | ++ to +++ | ++ |
| Activated alumina | Arsenic, selenium, fluoride | +++ | +++ | +++ |

+ Low ++ Moderate +++ High Source: (Craun and Goodrich, 1999)

Furthermore, just as a central treatment facility generates waste residuals, systems that implement a POU or POE treatment strategy must dispose of the wastes generated by these units. Spent cartridges, media, membranes, bulbs, and filters must all be disposed of at the end of their useful life. In addition, waste brines from the use of POU and POE reverse osmosis systems and POE ion exchange systems, and backwash water from POE activated alumina and granular activated carbon systems must also be disposed of (USEPA, 2002). Therefore, prior to selecting a treatment technology considering the potential difficulties associated with the disposal of these wastes is a must.

Depending on the technology applied in a POU/POE device the expected performance and removal efficiency of the device can be estimated. The process of certification can help in preparing a database of the available POU/POE devices and their treatment claims. Such a database can help in selecting suitable treatment systems tailored to remove certain contaminants. However, further investigation will be needed to develop a comprehensive knowledgebase that includes other non-technical aspects of sustainability for each treatment device. Furthermore, treatment trains rather than individual treatment units need to be considered in a more comprehensive framework of the selection process. Building a database of treatment alternatives is only a preliminary step towards treatment train selection. A selection process for sustainable POU/POE treatment trains needs to be designed, validated and implemented.

## DEVELOPING A FRAMEWORK FOR SELECTING SUSTAINABLE POU/POE SYSTEMS

The framework presented herein is intended to be an integrated process that analyses and shortlists a number of point-of-use and point-of-entry water treatment systems as a potential sustainable water treatment alternative for a particular water source. The framework is to serve as a pre-feasibility decision aid tool to limit the treatment alternatives based on the characteristics of the case under analysis. Objectives of sustainability vary depending on the context, in this case for a water system to be sustainable it has to strive to achieve: (a) a nontoxic environment; (b) better health and hygiene; (c) better use of human, natural, and financial resources; (d) a high degree of functional robustness and flexibility; and (e) cultural acceptance thus encouraging responsible behavior by the users (Hellstrom et al., 2000). The developed framework comprises the five stages outlined in Figure 3 and described below in details.

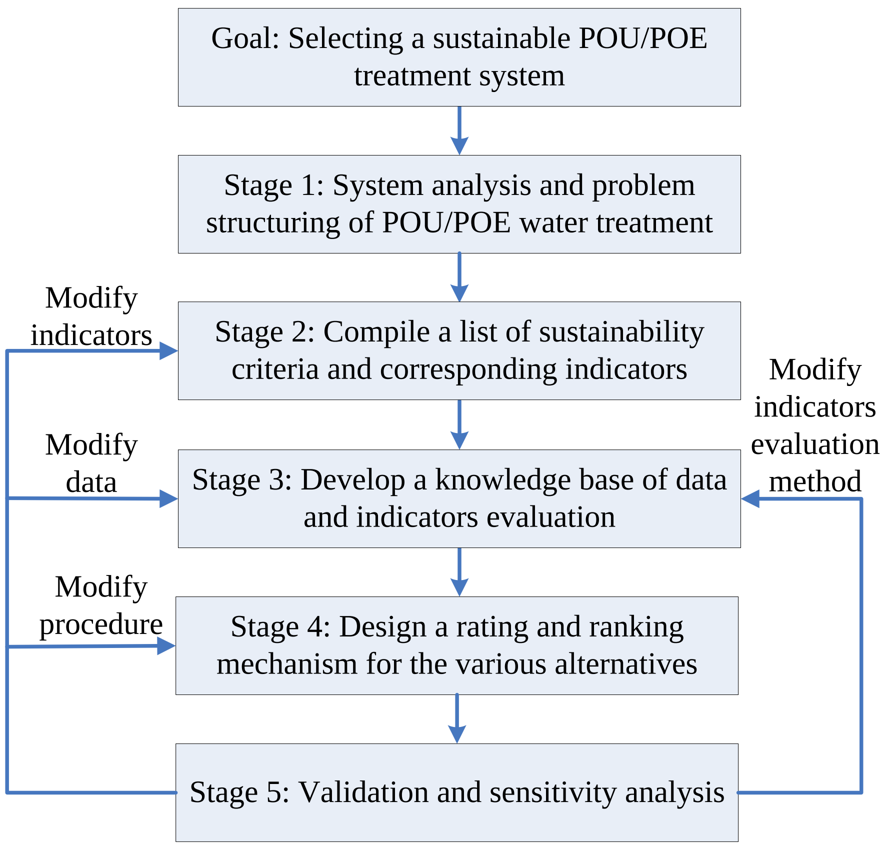


**Figure 3. A Framework for Selecting Sustainable POU/POE Water Treatment Systems**

## Problem Structuring and System Analysis

Problem structuring involves the identification of stakeholders in POU/POE water treatment, the definition of issues, and the identification of objectives. Preferences, constraints, and limitations of various POU/POE treatment alternatives and interests of the various stakeholders involved in the decision making process are considered during problem analysis (Flores et al., 2007). Identifying the components of a systems analysis for the considered problem and understanding the relevant information is important. Table 4 outlines the relative information needed in selecting a POU/POE system. Ideally, all relevant information should be considered in the developed selection framework; however in many cases this is not attainable.

**Table 4 Relative Information (RI) to the Problem of Selecting POU/POE Systems**

| | |
|---|---|
| **Influent water characterization** | |
| RI1 | The type of influent water: surface water, rainwater, groundwater, or centrally treated water |
| RI2 | Influent target contaminants: a list of contaminants of concern and their concentrations, and chemical, biological, or physical characteristics |
| RI3 | General influent characterization: these are characteristics that may not represent a health threat but may influence the performance of a treatment process, or consumer acceptance of the treated water |
| **Canadian drinking water regulations** | |
| RI4 | Drinking water quality standards: maximum acceptable concentrations and interim maximum acceptable concentration for the various contaminants will constitute a main constraint for screening out treatment alternatives |
| RI5 | POU/POE compliance restrictions, required permits, and guidelines |
| **Canadian POU/POE market** | |
| RI6 | POU/POE systems installation, operation and maintenance market costs and availability |
| **POU/POE standards and certification** | |
| RI7 | Technology characterization and performance: certified products are tested for certain performance levels, knowledge of the performance of the various technologies is important to be able to select among them |
| **Residuals disposal** | |
| RI8 | Residuals generated and strategies for disposal |
| **Consumer capacity and interest** | |
| RI9 | Consumer capacity: some characteristics of the intended consumer influence the choice of a POU/POE system |
| RI10 | Consumer needs and preferences: in many cases some consumers have certain preferences that override the common selection procedure; this is valid unless it violates any of the constraints set by regulations |

## Sustainability Criteria for Selecting Among POU/POE Alternatives

The sustainability rating model is meant to be simple and general rather than detailed and precise since it is developed for a pre-feasibility selection stage. The criteria used to rate the various systems include: 1) *Technical criteria* that define the technical performance, implementability, and operability of an alternative; 2) *Economic criteria* that usually are a major constraint when choosing a particular treatment train, this includes purchase and installation costs (capital cost), and operation and maintenance costs; 3) *Environmental criteria* which are often overlooked on such a small scale, nevertheless, the environmental impact can be evaluated by assessing resource use and possible residuals resulting from the treatment train; 4) *Sociocultural and institutional criteria* are rarely considered in water treatment; however, since they play an important role, indirect measures of consumer acceptability of treatment alternatives and their availability can be used.

**Table 5. Examples of Sustainability Criteria and Proxy Indicators**

| **Criteria** | **Subcriteria** | **Example Proxy Indicator** |
|---|---|---|
| Technical | System performance | Removal efficiency matrix for a spectrum of water contaminants |
| Economic | Cost | Capital cost can be presented as a cost category or cost function |
| Environmental | Resource consumption | Energy consumed by the treatment kWh/$m^3$ of treated water |
| Socio-cultural | Cultural acceptance | Market share of a device compared to devices of similar performance |

**POU/POE Knowledgebase Outline**

To estimate the values for technology characteristics, a simple strategy was used whereby technical, economic, environmental, and socio-cultural assessments of the various technologies can be gathered from literature (reports, guidelines, and products listings). Using this data a knowledge base of the available POU/POE devices and their characteristics was compiled and categorized. The knowledge base provides decision makers with a complete overview and enables adaptation of the data. The knowledge base will potentially include:

1. Treatment unit type and description
2. Reduction claims and target contaminants
3. Incidental effects (other contaminants removed, variation in pH, etc.)
4. Maximum and minimum feasible flow
5. Conditions that increase/decrease efficiency e.g. presence of a specific contaminant that impedes the efficient performance of the device
6. Service life (in volume of treated water)
7. A document that includes:
    a. Installation instructions
    b. Required permits for construction, operation and pilot study
    c. Water quality monitoring and reporting procedures

**Alternatives Rating and Ranking**

In POU/POE treatment there are a number of typically used treatment trains. In the course of generating treatment alternatives the first step taken is preparing a set of predefined topologies of treatment trains (Figure 4). These topologies take into consideration the restrictions of sequencing treatment processes. A knowledgebase of the various topologies of treatment train includes:

1. Topology code: used to represent its structure and characteristics;
2. The treatment train scheme, the type(s) and number of processes included;
3. Technical constraints for each treatment train topology

To avoid comparing a large number of treatment alternatives, constraints can be used to screen out non-feasible alternatives. A screening algorithm was developed by superimposing a number of known case-specific constraints. The constraints used can be user defined (e.g. eliminating POU treatment as an alternative) or a technology characteristic. These technical constraints include limits on: system's capacity, influent turbidity, influent hardness, influent pH, etc. Once the treatment trains are defined, the certified devices in the knowledgebase can fill in their respective slots in the topology to generate treatment train alternatives. An alternative train can consist of a stand alone device or a series of devices.

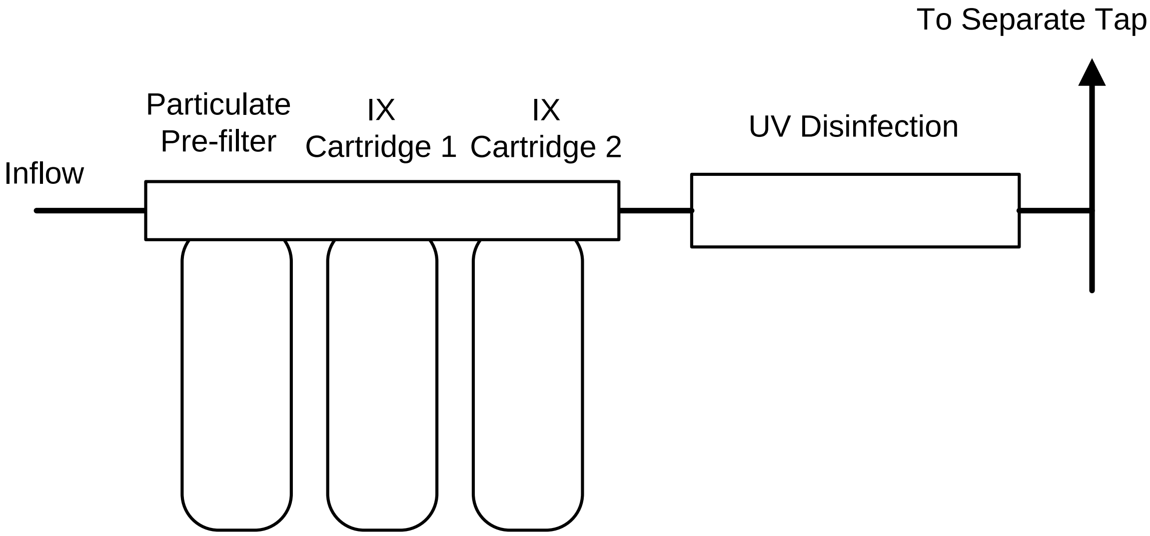


**Figure 4 Sample Topology of a Potential POU Ion Exchange Treatment Train**

Rating and ranking the various treatment alternatives in order of their level of sustainability is the main goal of this framework. At this stage the framework employs a multicriteria decision analysis technique to elicit users' preferences regarding relative importance of sustainability criteria and associated indicators. Preference is incorporated using normalization and weighting of indicators of the objective function. It is important in this case to determine the decisive indicators, trade-offs, and the sensitivity to the individual weighting factors. An optimization method can then be used to rate and rank the alternatives.

The output provided by the framework will rank the best systems from the alternatives knowledgebase, and will give a detailed overview of the sustainability assessment of these alternatives. The output is anticipated to include:

1. List of ranked treatment alternatives with the following:
    a. Their respective scores and sustainability rating
    b. Technical fact sheet for each alternative
    c. A cost estimate for each alternative
2. A summary sheet of the case under analysis: water quality, quantity, etc.
3. A list of companies producing the top five devices on the list.

A sensitivity analysis will then be preformed by varying the inputs, the solution space, and the weighting factors. This provides insight into the sensitivity of the solutions and the trade-offs made by choosing different combinations of technology characteristics, different technologies, or different weights on the sustainability indicators.

## CONCLUSION AND FUTURE RESEARCH

To enable consumers and decision makers to choose sustainable point-of-use and point-of- entry drinking water treatment systems, an insight into the multi-disciplinary nature of sustainability is needed. This necessitates the comparison between alternative treatment topologies and devices on technical, economic, environmental, and socio-cultural grounds. The developed framework provides a reliable approach for identifying alternative treatment trains when provided with the source water characteristics, various requirements and constraints of a particular case.

It is important to rely on objective and professional resources to make an educated decision on which treatment system to use. This is a clear goal especially in a market based industry such as that of point-of-use and point-of- entry devices where advertising seems to dominate the decision making process. This framework is intended to be further developed into and interactive, user friendly, updatable decision support system to select sustainable certified point-of-use and point-of- entry systems.

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## REFERENCES

Abbaszadegan, M., Hasan, M.N., Gerba, C.P., Roessler, P.F., Wilson, B.R., Kuennen, R. and Van Dellen, E. (1997). Disinfection efficacy of a point-of-use water treatment system against bacterial, viral and protozoan waterborne pathogens. *Water Research*, **31**(3), 574-582.

Anderson, A.C. and Sakaji, R.H. (2007). Small systems helpdesk -- Who's looking after alternative filtration technologies for small water systems? *Journal American Water Works Association*, **99**(4), 46-50.

AquaVic. (2007). *Application of point of entry and point of use water treatment technology in British Columbia*, Draft report sybmitted by AquaVic Water Solutions Inc. to British Columbia Ministry of Health on March (2007). [accessed online Aug. 15th 2008: http://www.health.gov.bc.ca/protect/poureport_main.pdf].

Baker, L.A., Westerhoff, P. and Sommerfeld, M. (2006). Adaptive management using multiple barriers to control tastes and odors. *Journal American Water Works Association*, **98**(6), 113-126.

BCMOH. (2003). Drinking Water Protection Act, Drinking Water Protection Regulation. B.C. Reg. 200/2003 includes amendments up to B.C. Reg. 5/2007, August 3, 2007. British Columbia Ministry of Health, Queen's Printer, Victoria, British Columbia, Canada.

Chaidez, C. and Gerba, C.P. (2004). Comparison of the microbiologic quality of point-of-use (POU)-treated water and tap water. *International Journal of Environmental Health Research*, **14**(4), 253-260.
Cotruvo, J.A. and Cotruvo, J.A.J. (2003). Nontraditional approaches for providing potable water in small systems: part 1. *Journal American Water Works Association*, **95**(3), 69-76.
Craun, G.F. and Goodrich, J.A. (1999). Selecting residential or personal water treatment systems. In: *Providing safe drinking water in small systems*, J.A. Cotruvo, G.F. Craun, and N. Hearne (eds), Lewis Publishers.
Daeschlein, G., Kruger, W.H., Selepko, C., Rochow, M., Dolken, G. and Kramer, A. (2007). Hygienic safety of reusable tap water filters (Germlyser ®) with an operating time of 4 or 8 weeks in a haematological oncology transplantation unit. *BMC Infectious Diseases*, **7**(45).
Dupont, D.P. (2005). Tapping into consumers' perceptions of drinking water quality in Canada: Capturing customer demand to assist in better management of water resources. *Canadian Water Resources Journal*, **30**(1), 11-20.
Flores, X., Rodriguez-Roda, I., Poch, M. and Jiménez, L. (2007). Systematic Procedure to Handle Critical Decisions during the Conceptual Design of Activated Sludge Plants. *Industrial & engineering chemistry research*, **46**(17), 5600-5613.
Hellstrom, D., Jeppsson, U. and Karrman, E. (2000). A framework for systems analysis of sustainable urban water management. *Environmental Impact Assessment Review*, **20**(3), 311-321.
Jones, S.A. and Joy, N. (2006). The inequity of the Revised Arsenic Rule for very small community drinking water systems. *Environmental Science and Policy*, **9**(6), 555-562.
Lavoie, M. (2000). *Survey of drinking water treatment devices available on the canadian retail market in 1999*, Water Quality Programme, Healthy Environments and Consumer Safety Branch, Health Canada. [accessed online Aug. 15th 2008: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/water-eau/devices-dispositifs/devices-dispositifs_e.pdf].
Levallois, P., Grondin, J. and Gingras, S. (1999). Evaluation of consumer attitudes on taste and tap water alternatives in Quebec. *Water Science and Technology*, **40**(6), 135-139.
McEncroe, J. (2007). Point of use: The final barrier. *Journal American Water Works Association*, **99**(3), 32-34.
NSF. (2008). *NSF Listings and Consumer Guide: Drinking water treatment products and related components and materials*, NSF International.
NSF/ANSI standard 53. (2007). Drinking water treatment units - Health effects. NSF International, first edition 1981.
Odoi, A., Aramini, J., Majowicz, S., Meyers, R., Martin, W.S., Sockett, P., Michel, P., Holt, J. and Wilson, J. (2003). The status of drinking water in Ontario, Canada (1992-1999). *Canadian Journal of Public Health-Revue Canadienne De Sante Publique*, **94**(6), 417-421.
OMOE. (2002). Ontario Safe Drinking Water Act, O. Reg. 170/03 Drinking Water Systems. Ontario Ministry of the Environment. Statutes of Ontario 2002, Chapter 32.
Smith, D.W., Mavinic, D.S. and Zytner, R.G. (2001). Future directions of environmental engineering in Canada. *Canadian Journal of Civil Engineering*, **28**, 18-25.
Souter, P.F., Cruickshank, G.D., Tankerville, M.Z., Keswick, B.H., Ellis, B.D., Langworthy, D.E., Metz, K.A., Appleby, M.R., Hamilton, N., Jones, A.L. and D.Perry, J. (2003).

Evaluation of a new water treatment for point-of-use household applications to remove microorganisms and arsenic from drinking water. *Journal of Water and Health*, **01**(2), 73-84.

Srinivasan, P.T., Viraraghavan, T. and Subramanian, K.S. (1999). Aluminium in drinking water: an overview. *WATER SA*, **25**(1), 47-55.

Statistics Canada. (2006). Households and the environment. Environment accounts and statistics division, Statistics Canada, Ottawa. Rep. # Cat. 11-526-XIE. [accessed online on Aug. 15th 2008 at http://www.statcan.ca/english/freepub/11-526-XIE/11-526-XIE2007001.pdf].

Turgeon, S., Rodriguez, M.J., Theriault, M. and Levallois, P. (2004). Perception of drinking water in the Quebec City region (Canada): the influence of water quality and consumer location in the distribution system. *Journal of Environmental Management*, **70**(4), 363-373.

USEPA. (2002). *Guidance for implementing a point-of-use or point-of-entry treatment strategy for compliance with the safe drinking water act*, United States Environmental Protection Agency, Office of Water draft report [accessed Aug. 15th 2008 http://www.epa.gov/safewater/standard/draftguid_pou_poe.pdf].

USEPA. (2006a). *Investigation of the capability of point-of-use/point-of-entry treatment devices as a means of providing water security*, *EPA/600/R-06/012*, United States Environmental Protection Agency, Office of Water [accessed Aug. 15th 2008: www.epa.gov/NHSRC/pubs/600r06012.pdf].

USEPA. (2006b). *Point-of-use or point-of-entry treatment options for small drinking water systems*, *815R06010*, United States Environmental Protection Agency, Office of Water, [accessed Aug. 15th 2008: www.epa.gov/OGWDW/smallsystems/pdfs/guide_smallsystems_pou-poe_june6-2006.pdf].

USEPA. (2007). *Cost evaluation of point-of-use and point-of-entry treatment units for small systems cost estimating tool and users guide*, *815-B-07-001*, United States Environmental Protection Agency, Office of Water, [accessed Aug. 15th 2008: http://www.epa.gov/ogwdw000/smallsystems/pdfs/tool_smallystems_cost-tool-usersguidepdf.pdf].

Williams, D.T., LeBel, G.L. and Benoit, F.M. (1997). Disinfection by-products in Canadian drinking water. *Chemosphere*, **34**(2), 299-316.

WQA. (2006). Proposed requirements would force mandatory testing for all POU/POE products sold in Canada. Water Quality Association News Fax, April, 2006.