





COSTS AND THE CHOICE OF DRINKING WATER TREATMENT TECHNOLOGY IN SMALL AND RURAL SYSTEMS

By:

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Introduction/Overview:

The outline of this presentation is as follows:

- In Part 1, we review historical costs of disinfection by chlorine and UV.
- In Part 2, we present costs estimates from Environment Canada Survey data
- In Part 3 we present manufacturer rated cost for UV
- In Part 4 we compare the results of our non linear model with actual plant level costs from small communities in BC
- Finally in Part 5 we summarize our findings
- Our main conclusion is that cost data of small UV systems demonstrate that UV is cheaper than chlorine for disinfection.
- The dominant use of chlorine in small water systems may be due to historical reasons and a failure to modernize after the wide-spread availability of electricity in small and rural communities.

Costs of UV, Chlorination and Ozonation treatments



Source: EPA (1996)

PART 1: REVIEW OF PREVIOUS DISINFECTION COST ESTIMATES: CHLORINE AND UV

- The EPA (1996) has shown that costs for UV treatment are lower than costs for chlorination treatment
- We observe a weak linear upward trend in UV as capacity decreases and an increasing exponential trend in Chlorine as capacity decreases. This indicate a that UV is cheaper at smaller scales
- Chlorine is fairly competitive at large scales: chlorine costs are \$0.02 per cubic metre for a 5mg/L dose for a plants which produces 6814 cubic metres per day
- UV costs can be as low as \$0.03 and \$0.01 per cubic metre for 140mJ/cm2 and 40mJ/cm2 doses for the same sized plant.
- For smaller scales, however, chlorination costs tend to be higher while UV costs tend to be low.
- Chlorine treatment would cost \$0.75 per cubic metre for a plant that produces 91 cubic metres of water per day while UV would cost are \$0.07 and \$0.05 for 140mJ/cm2 and 40mJ/cm2 doses respectively.

Estimated cost function for UV, Chlorination and Ozone based on EPA (1996)

Disinfection Type	Average Cost function	Predicted cost(US \$) for a plant with capacity 100 m ³
UV Dose 40 mJ/cm ²	$y = 0.4228x^{-0.4821}$	0.046
Chlorination Dose 5mg/L	$y = 82.3219x^{1.0427}$	0.676
Ozonation Dose 1mg/L	$y = 74.7949x^{0.9737}$	0.844
UV Dose 140 mJ/cm ²	$y = 0.2033x^{-0.2322}$	0.0698

•Based on cost functions we fitted to EPA data:

•UV costs for a 100 cubic metre plant is on average 63 cents per cubic metre lower than chlorination costs.

• Ozone treatment on average is 16 cents per cubic metre more expensive than chlorine for a 100 cubic metre plant but would provide higher quality drinking water assuming there were no bromates.

Comparison of the efficacy of Chlorine & UV, our preliminary estimations are:

Assuming a temperature of 25C and pH between 6-8:

- UV dose of 40mJ/cm² can have greater than 3 log reduction of Crypto, Giardia lamblia & between 0.5-1.0 log reduction in viruses. At this dose a 1 log reduction of adenovirus type 2 can be achieved
- UV dose of 140mJ/cm² can have greater than 3 log reduction of Crypto, Giardia and up to 3 log reduction in viruses. At this dose a 3 log reduction of adenovirus type 2 can be achieved
- Chlorine at 5 mg/L can kill Giardia with a contact time of 10 minutes and close to 4 log reduction in viruses
- Ozone at 1 mg-min/L can have greater than 4-log reduction in viruses, 3 log reduction in Giardia & up to 0.5 log reduction in Crypto

- Based on the above assumptions on temperature & pH, the dosages in EPA (1996) are fairly comparable.
- UV at 140mJ/cm² seems to achieve the greatest log reductions in viruses & pathogens including adenovirus type 2 while it is more cost effective than chlorine at 5mg/L. UV at 40mJ/cm² can achieve a 1 log reduction in adenovirus type 2 & is more cost effective than chlorine although chlorine will achieve a higher log reduction in the adenovirus type 2
- However, chlorine will not inactivate Crypto but UV at both doses will do so.

Other findings:

 An earlier paper by Wolfe (1990) showed a similar cost profile between chlorine, UV and Ozone treatments to that observed in the EPA (1996) study.

Total Production Costs in 1989 US\$ for UV, Chlorination, Chlorine dioxide and Ozone disinfection based on Wolfe (1990)



- Again we observe, from Wolfe (1990), that chlorine is fairly competitive at larger scales but not at smaller scales.
- UV is slightly more expensive than chlorine disinfection for a plant which produces 3785 cubic metres per day.
- However, the expected cost of UV treatment for a 100 cubic metre plant is \$0.08 per cubic metre in 1989 US dollars holding all else constant which is about 4 cents per cubic meter cheaper than chlorine treatment for the same sized plant.
- Differences between estimates from Wolfe (1990) and EPA(1996) were due to increased inflation/producer price indexes between 1989 and 1996, the method applied towards the calculation of capital costs between Wolfe (1990) and EPA (1996), difference in chlorine dosage and improvements in UV technology over that time period.

Other findings:

- Parotta and Bekdosh (1998) reviewed UV disinfection of small groundwater supplies for US communities of less than 3000 persons.
- They present cost comparisons of UV disinfection with ozonation and chlorination for a range of system sizes (from 9–7000 m3/day) and concluded that UV disinfection is effective and affordable relative to conventional disinfectants assuming US labor costs and infrastructure.

Part 2: NEW COST ESTIMATES

- The costs presented in this section are strictly the *comparative* costs of disinfection only.
- In this estimation procedure, the database includes site specific costs such as the costs of land, administration and distribution. The dummy variable model attempts to separate out those costs that can be attributed to disinfection only.
- Costs from MWWS (2004) include capital, O&M cost including treatment material, replacement and labour.
- Regulations require that some chlorine residual is left in the distribution systems regardless of the primary disinfection method used.
- We assume that systems using UV disinfection do not use chlorine as an additional disinfection but only for residual chlorine.
- The same applies for Chloramines, Chlorine dioxide, Ozone and Other treatment.

NEW COST ESTIMATES: CHLORINE

- First we examine the disinfection types and the number of systems in the Environment Canada survey of Municipal Water and Wastewater (2004).
- The survey has 2402 drinking water systems, of which 1513 reported a population of less than 3000.
- Of these 1513 drinking water plants, 136 gave information on the type of disinfection they use.
- We present information based on the 136 reporting systems.

Disinfection types for drinking water systems with population less than 3000 for 2004



• The figure above shows at least one type of disinfection used by treatment plants which serve less than 3000 people

• It is clear that the dominant disinfection type is chlorination. Chlorine is used in 127 of 136 systems (i.e., 93.38%)

 UV and Ozone together account for only 5.9% of the disinfection types used by small systems





Specific information for DSS development: Questionnaire





Econometric estimation of a nonlinear model

- We estimate econometrically the total average costs at plants that use different disinfection methods.
- We use data from the Environment Canada Survey of 2004 by merging information on disinfection types found in the 2004 MWWS water use Report and information on costs found in the Municipal Water Pricing Data for 2004 by using the jurisdiction/census identification codes.

Each individual disinfection equation presented in the following table will therefore have:



Interpretation of the elasticity or β component: Assuming β is negative, the higher value the greater the reduction in cost per cubic metre as flow increases i.e. the greater the economies of scale

RESULTS:

	MULTIPLICATIVE COMPONENT (A _i)			EXPONENT COMPONENT (β _i)		
Variable	Coefficient	p-value	Robust std errors p-value	Coefficient	p-value	Robust std errors p- value
Chlorine	2.867***	0.002	0.005	-0.154***	0.003	0.000
UV	5.361*	0.094	0.165	-0.105*	0.074	0.092
Chloramines	-1.526**	0.023	0.039	0.0990**	0.023	0.003
Chlorine dioxide	2.525	0.601	0.439	-0.0513	0.484	0.377
Ozone	20.73	0.757	0.777	-0.215	0.499	0.454
Other	-0.283	0.215	0.749	0.0225	0.261	0.588
Small systems	49.76***	0.000	0.329	-0.457***	0.000	0.005

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- Regressions above are based on non-linear least squares estimation procedure.
- Pooled regression (both large & small systems taken into account at the same time) results are shown above.
- We expect the variation in water treatment costs to be smaller for small water plants and to be large for big water plants. In our survey data, this can violate the assumption of error terms being independent or identically distributed.
- We correct for Heteroscedasticity in two ways:

(1) Standard errors are based on clusters representing flow per day for the following categories in cubic metres: 0≤flow per day <1,500, 1,500≤flow per day <3,000, 3,000≤flow per day <15,000, 15,000≤flow per day <150,000, flow per day ≥150,000

(2) Standard errors based on White's robust error method.

 Both methods to correct for heteroscedasticity yield similar pvalues and therefore are robust with respect to the correction method used.

- The results above indicate that a 1% increase in the volume of treated water in a small system will reduce the cost per cubic meter by 0.457% compared to a large system (overall elasticity).
- Controlling for the size of the plant, a 1% increase in the volume of treated water in a plant that uses UV results in 0.105 % lower cost per unit compared to chlorine only, chlorine dioxide and ozone treatments, and 0.204% lower cost per unit compared to chloramines.
- Small systems have higher unit costs compared to large systems.

Estimated average cost functions for disinfection treatment types for small systems:

Disinfection Type	Average Cost function	Predicted cost (\$) for a plant with capacity 100 m ³ per day	Predicted cost (\$) for a plant with capacity 100 m ³ in 2008 dollars
Chlorine Only	$y = 52.627x^{-0.611}$	3.14	3.60
UV plus residual chlorine	$y = 57.988x^{-0.716}$	2.19	2.44
Chloramine plus residual chlorine	$y = 51.101x^{-0.512}$	5.23	5.51
Chlorine dioxide plus residual chlorine	$y = 55.512x^{-0.6623}$	3.12*	3.00
Ozone plus residual chlorine	$y = 73.357x^{-0.826}$	1.59*	1.86

Costs shown above assume all other "non-disinfection costs" are held constant. Costs are long run average total costs at Chlorine only plants, UV only plants, chloramine only plants, Chlorine dioxide plants, and Ozone plants. * Reliable estimates were not found for Chlorine dioxide and ozone disinfection (insignificant p-values from pooled regression). Cost per cubic meter of processed water for chlorine and UVradiation by using NLS results (in 2004 dollars) -

Small Systems

Population	Cubic meter per day (0.3 cubic meter per person)	Cost per cubic meter Disinfectant: Chlorine alone	Cost per cubic meter Disinfectant: UV plus Chlorine residual	Percentage difference UV from Chlorine	
Small plants					
10	3	26.90	26.41	-1.82	
50	15	10.06	8.34	-17.08	
100	30	6.59	5.08	-22.9	
200	60	4.31	3.09	-28.32	
500	150	2.46	1.60	-34.89	
1000	300	1.61	0.98	-39.46	
2000	600	1.06	0.59	-43.71	
3000	900	0.82	0.44	-46.06	

- The results above indicate the competitiveness of UV over Chlorine disinfection for small plant sizes
- For smaller capacities, UV (plus chlorine residual) disinfection is cheaper than Chlorine alone.
- Our econometric estimates of costs are consistent with the results of EPA (1996), Wolfe (1990) and other researchers.
- Chlorine exhibits stronger economies of scale than UV.

- The following 4 slides illustrates the cost functions for small and large systems.
- We present (first small systems then large systems) cost functions for Chlorine and UV plus Chlorine first for comparison, and then the cost functions for all disinfection types based on the NLS results.







Dashed lines indicate insignificant coefficients at the 1, 5 and 10% levels

Limitations of the Environment Canada data:

- Statistically significant estimates were obtained for only Chlorine, UV and Chloramines
- Estimates for Ozone and Chlorine dioxide were not statistically significant due to small sample size.
- While we know the differences in costs of different disinfection types, we do not have costs for *disinfection alone*. But for UV alone, we can get an idea of the disinfection costs alone from the Trojan data– see below.

PART 3: MANUFACTURER RATED PRODUCTION COSTS OF DISINFECTION BY UV ALONE

UV SWIFT SC Technology :

- Trojan UV Swift SC was developed by Trojanuv technologies in Canada and utilizes the ability of ultra violet rays to deactivate microorganisms.
- Water is pushed through a reactor which consists of a series of lamps. When turned on, these lamps emit powerful UV rays which kill micro organisms; the UV level will depend on the amount of water being treated per day.
- UV Swift has a maximum flow rate of 6,300 m3 per hour.
- According to the manufacturer, the hydrodynamic design has been rigorously tested and ensures a high level of efficiency and performance; the UV transmittance rate is between 70 to 98%. This system on its own is chemical free.
- However, it can also be used in conjunction with other treatment processes forming a "multi-barrier" approach for treating water for drinking purposes. See: <u>http://www.trojanuv.com</u>)

- UV Swift will inactivate bacteria, viruses and protozoa, including Giardia and Cryptosporidium with a dose of 40mJ/cm2.
- For some high quality source waters, UV alone may be sufficient. Or if higher quality drinking water is desired then settling and/or filtration and coagulation may also be needed.
- The cost of this addition is not included as we are concentrating on disinfection alone.

• We estimated the following NLLS model based on data received from TrojanUV for small systems.



Costs shown above are cost of disinfection alone and exclude delivery & administration costs.

PART 4 : ACTUAL PLANT LEVEL COST ESTIMATES

- In this section we present actual costs and capacities at various small water treatment plants in British Columbia, Canada which supply drinking water to small populations.
- The names of the water systems have been omitted.
- We present a table showing the disinfection type and capacity level as well as its associated unit operating cost per cubic metre per day.

Some examples of existing small water treatment facilities for 2008

Disinfection type	Name of facility	Scale (m ³ /day)	Operating Cost per year (\$)	Unit Operating cost (\$ per m ³ /day)
Chlorination Only	Plant 1	38	30,202	2.16
Chlorination plus removal of suspended solids	Plant 2	46	46,247	2.72
Chlorination Only	Plant 3	50	23, 536	1.28
Chlorination Only	Plant 4	92	41,128	1.23
Chlorination Only	Plant 5	126	40,496	0.88
Chlorination plus removal of suspended solids, protozoa and dissolved organic content	Plant 6	640	100,000	0.59
Chlorination Only	Plant 7	778	111,641	0.39

Differential disinfection costs (Chlorine=100)

Disinfection Type	Average Cost function	Predicted cost (\$) for a plant with capacity 100 m ³ in 2008 dollars	Relative costs (indexed to Chlorine)
Chlorine Only	$y = 52.627x^{-0.611}$	3.60	100.0
UV plus residual chlorine	$y = 57.988x^{-0.716}$	2.44	67.8
Chloramine plus residual chlorine	$y = 51.101x^{-0.512}$	5.51	153.1
Chlorine dioxide plus residual chlorine	$y = 55.512x^{-0.6623}$	3.00*	83.3*
Ozone plus residual chlorine	$y = 73.357x^{-0.826}$	1.86*	51.7*

* Not significant at 1, 5 & 10% levels

PART 5: CONCLUSIONS

- Our NLS model based on data from Environment Canada Survey for 2004 indicate that for a 100 cubic metre plant which disinfects with chlorine only, the cost per cubic metre is \$3.60 per cubic in 2008 dollars, ceteris paribus.
- For small systems in British Columbia, estimated cost for chlorination for small systems range from 39 cents to \$2.16 per cubic meter per day while capacity ranged from 38 to 778 cubic metres per day.
- Our estimated costs for UV and Chlorine also show UV disinfection is cheaper than chlorine disinfection at small scales.
- Chloramine disinfection was shown to be more expensive than both Chlorine and UV.
- Our manufacturer rated cost for a plant which produces 100m³ per day is approximately \$0.02 per cubic meter per day for UV disinfection.

PART 5: CONCLUSIONS CONT'D

- Previous studies (EPA, 1996 and Wolfe, 1990) have shown that while chlorination costs are fairly competitive at large scales, but at smaller scales chlorination is more expensive than UV.
- UV is cheaper. So Why do small systems rely on chlorine for disinfection?
- It seems clear that the dominant choice of chlorine for disinfection in small systems is due to fact that residual chlorine is required anyway by regulation.
- It is possible that before electricity reached these communities, they had no choice but to rely on chlorine. But electricity has now been widely available to almost all rural areas for the past 150 years.
- Perhaps the use of chlorine simply indicates that these plants have not been modernized over the last 150 years, as there appears to be no regulatory incentive to do so in the public sector. DO YOU AGREE?

We need your feedback!

- Why does your system use chlorine?
- Why not use UV SC, which is cheaper?
- Is it the capital cost of UV?
- Is chlorine easier to use?
- For a small gift, send your feedback to me at: <u>dore@brocku.ca</u>

THANK YOU