

Cost-Benefit Analysis of the Swiss National Policy on Reducing Micropollutants in Treated Wastewater

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S Supporting Information

ABSTRACT: Contamination of freshwater with micropollutants (MPs) is a growing concern worldwide. Even at very low concentrations, MPs can have adverse effects on aquatic ecosystems and possibly also on human health. Switzerland is one of the first countries to start implementing a national policy to reduce MPs in the effluents of municipal sewage treatment plants (STPs). This paper estimates the benefits of upgrading STPs based on public's stated preferences. To assess public demand for the reduction of the environmental and health risks of MPs, we conducted a choice experiment in a national online survey. The results indicate that the average willingness to pay per household is CHF 100 (US\$ 73) annually for reducing the potential environmental risk of MPs to a low level. These benefits, aggregated over households in the catchment of the STPs to be upgraded, generate a total annual economic value of CHF 155 million (US\$ 113 million). This compares with estimated annual costs for upgrading 123 STPs of CHF 133 million (US\$ 97 million) or CHF 86 (US\$ 63) per household connected to these STPs. Hence, a cost-benefit analysis justifies the investment decision from an economic point of view and supports the implementation of the national policy in the ongoing political discussion.



1. INTRODUCTION

Contamination of freshwater ecosystems and drinking water sources with micropollutants (MPs) is increasingly recognized as a major environmental concern in industrialized countries.¹ The term MP denotes compounds found in water at very low concentrations (ng L^{-1} or $\mu\text{g L}^{-1}$). By definition, MPs also include heavy metals, but our study focuses on organic MPs in accordance with the policy measures discussed in Switzerland.

Numerous products used in households, industry and agriculture contain MPs (e.g., pharmaceuticals, personal-care products, detergents, pesticides, and industrial chemicals).² More than 30 000 MPs have been identified and monitored in Switzerland.³ A substantial amount of them enter rivers and lakes through municipal sewage treatment plants (STPs) because they are not or only partially removed in conventional treatment processes.⁴ As a result, aquatic organisms are permanently exposed to MPs.^{5,6} Since about 20% of the drinking water in Switzerland originates from surface water, and another 25% from groundwater directly affected by surface water, drinking water sources frequently also contain wastewater-borne MPs.³ A worldwide assessment of risks from exposure to chemicals originating from STP effluents shows considerable spatial and temporal variability between and within countries.⁷

The effects of MPs are still highly uncertain, although there is an increasing amount of evidence indicating their adverse impacts on aquatic ecosystems and possibly also on human health. Some studies demonstrate that MPs may lead to the feminization of male fish and decreased fish populations.⁸ They might also damage the nervous systems of aquatic organisms, disrupt their growth and reproduction, and inhibit photosynthesis in algae.³ Their impacts on human health are even more uncertain.^{9,10} Nevertheless, several studies suggest that MPs might lead to a higher incidence rate for certain types of cancers, reduced fertility, and impairment of thyroid and metabolic functioning.^{11–14} Most research so far has focused on the exposure to a single MP, while the effects of complex chemical mixtures are largely unknown.¹

New wastewater treatment technologies, such as ozonation and activated carbon, can substantially (>80%) decrease the loads of many MPs.^{15–17} Following the precautionary principle, the Swiss government has decided to impose legal requirements for reducing MP loads from STPs. The water protection ordinance, which is yet to be discussed in a public consultation,

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will regulate which STPs should be upgraded. The current ordinance draft foresees upgrading 123 out of the total of 750 STPs based on four criteria (see Supporting Information (SI)).¹⁸ The associated costs have been estimated at CHF 133 million annually^{18,19} (US\$ 97 million based on the 2012 purchasing power parity for GDP²⁰). However, the benefits to Swiss society have not yet been investigated. This poses an interesting question: does this precautionary measure enhance social welfare in that the benefits outweigh the costs? We propose to estimate the public's willingness to pay (WTP) for reducing the potential risks of MPs to answer this question given that the costs will ultimately be borne by the Swiss population.

Economic analysis of a reduction in MP loads has so far focused mainly on cost estimates.²¹ There has been only one previous attempt to estimate the benefits of reducing MP loads from wastewater.²² However, the authors recognize that their approach is limited compared to stated preference (SP) methods used in our study.²³ Other earlier work using SPs includes estimating the WTP for establishing a pharmaceutical disposal program in southern California, covering only one group of MPs.²⁴ Several studies estimated the economic values of water quality improvements achieved by reduced sewer outflows or overflows.^{25–27} However, they do not focus specifically on MPs and their uncertain effects.

The main objectives of this study are (1) to investigate public awareness and perception of environmental and health risks of MPs in Switzerland, (2) to estimate the benefits of reducing the MP loads from wastewater based on people's stated WTP, and (3) to perform a cost-benefit analysis (CBA) designed to inform policy makers about the economic desirability of the planned national policy for reducing MPs. For this purpose, we integrate knowledge from natural sciences and engineering into a social science survey.

2. MATERIALS AND METHODS

2.1. Cost-Benefit Analysis. The most commonly used tool to support decision-making focusing on economic trade-offs is a CBA.²⁸ It balances all benefits of a policy against all its costs. In a CBA, all relevant effects are monetised and accounted for. The annual flows of the costs (C_t) and benefits (B_t) at a time t are discounted to their present values using a discount rate r over the period of time T during which the relevant effects of an investment become apparent. The net present value (NPV) is calculated as the difference between discounted gains and discounted losses:

$$NPV = \sum_{t=0}^T B_t(1+r)^{-t} - \sum_{t=0}^T C_t(1+r)^{-t} \quad (1)$$

The decision criterion is that if $NPV > 0$, the investment is economically justified. If multiple investment decisions are compared, the one with the highest NPV is recommended. In this way, a CBA can support decision-making processes about the desirability of an investment or choosing between two or more alternative policy options. This does not mean that a CBA is necessarily the sole decision criterion, as other factors apart from economic efficiency may be important in practice. One of the key challenges in applying a CBA to evaluate environmental policy is the monetary quantification of its nonmarket values (costs and benefits), without which the analysis may be incomplete and, therefore, seriously misleading.^{29,30} This study focuses on estimating such nonmarket

values relating to the reductions in potential environmental and public health risks of MPs. These nonmarket values are then compared with the costs involved. Details on the cost assessment can be found in the SI.

2.2. Benefit Assessment: Integrating Natural Science Knowledge into a Choice Experiment. If benefits are public in nature and their value is not captured in existing markets or pricing mechanisms, either indirectly revealed preference or SP methods can be used. While revealed preferences enable estimating the value derived from the use of a resource (e.g., travel costs to a recreation site), SPs can capture both use and nonuse values (including the option to use a resource in the future). While reducing the load of MPs in surface waters might affect resource use to some extent, nonuse values are also expected to be substantial. Therefore, SPs were considered the most appropriate approach for estimating the total nonmarket benefits of the national policy for reducing MPs. A choice experiment (CE) is a SP method which determines people's preferences based on choices they are asked to make in a survey trading off the costs and benefits related to two or more possible policy alternatives. These alternatives are described to the public participating in the survey based on their characteristics, called attributes, and the levels that these attributes take. One of the policy alternatives is usually a baseline option, representing the status quo situation.

The major criticism of SP methods is their hypothetical nature, which raises concerns about the potential overestimation of SP values compared to real market payments.³¹ This issue, known as a hypothetical bias, has motivated researchers to undertake numerous external validity tests and measure the extent of hypothetical bias for example by comparing stated with actual WTP.^{32,33} Although this bias is not found in all stated preference surveys, hypothetical WTP typically exceeds the actual value.³⁴ Following certain guidelines in designing SP survey helps in minimizing hypothetical bias.³⁵ In our study, we are unable to test the so-called convergent validity since we had no opportunity to actually make respondents pay for the proposed policy changes. However, we try to capture the degree of hypothetical bias by simulating an actual payment situation.

The CE in this study was developed in close collaboration with ecotoxicologists, ecologists, and urban water engineers. The specific challenges were (i) the vague definition of MPs, (ii) quantifying the impact of the proposed measures, e.g. how the MP concentrations will be changed by the technical measures and (iii) quantifying the effects that MPs may have as a function of their amount released into the environment. This required a very careful approach to define attributes and attribute levels. The resulting CE design consists of four attributes and a varying number of attribute levels.

The first attribute was defined as *potential environmental risk*, the word "potential" reflecting the uncertainty of the effects of MPs on the environment. Attribute levels were determined on the basis of the number of MPs that may exceed the environmental quality standards (EQS) in 543 river sections downstream from STPs in Switzerland using an existing substance exposure model.⁶ For this purpose, 15 MPs that are identified as relevant and representative for a larger group of MPs in Swiss surface waters were considered.^{36,37} This implies that the planned upgrading of STPs will not only reduce the loads of these 15 MPs, but also of a large number of other MPs. The selected MPs include: atenolol, azithromycin, benzotriazole, bezafibrate, carbamazepine, clarithromycin, diazinon,

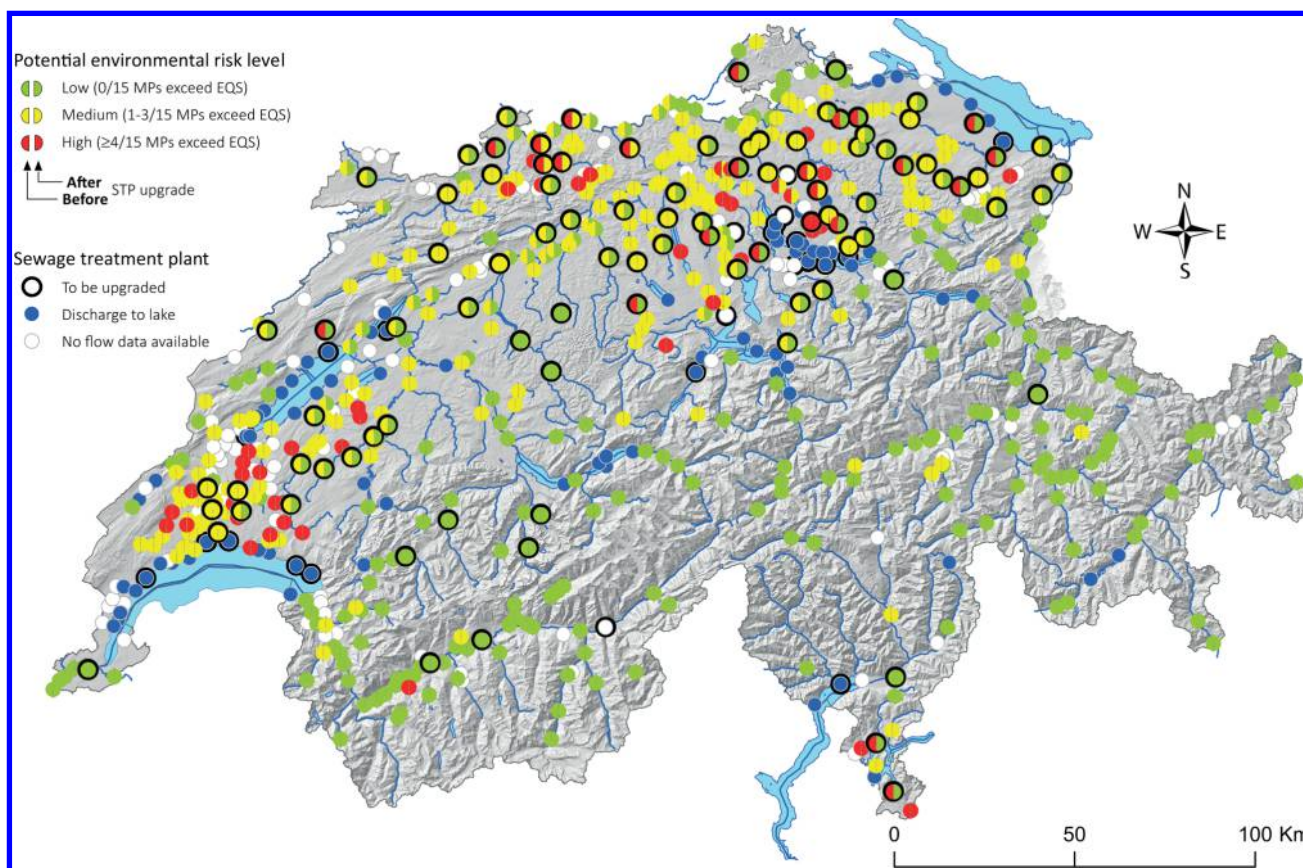


Figure 1. Potential environmental risk levels from micropollutant concentrations in rivers – calculated for base flow conditions (Q95%) – across Switzerland before and after implementing the national policy on reducing micropollutant loads. Map reproduced with approval of Swisstopo.³⁸ Data sources: STPs in Switzerland © 2011, Eawag, updated from Maurer, M.; Herlyn, A.³⁹

diclofenac, ibuprofen, mecoprop, methylbenzotriazole, metoprolol, naproxen, sulfamethoxazole, and trimethoprim. In consultation with ecotoxicologists (personal communication, Robert Kase, Swiss Centre for Applied Ecotoxicology, 23 March 2012), the levels of the potential environmental risk are defined as follows: low if 0/15 MPs exceed their EQS, medium if 1–3/15 MPs exceed their EQS, and high if the overload occurs for $\geq 4/15$ (max. 6/15) MPs. Maps depicting the potential environmental risk levels across Switzerland before and after upgrading 123 STPs were generated based on this definition (see Figure 1).

The second attribute was specified as the spatial scale of the potential environmental risk reduction, distinguishing between national and regional levels. The supply of drinking water and wastewater treatment in Switzerland is largely decentralized.⁴⁰ This attribute therefore aimed to capture the respondents' preferences for the reduction of MPs in the whole of Switzerland or in the canton (state) in which the respondent lives.

Given that there is hardly any scientific evidence about the effects of MPs on human health, the third choice attribute was defined as the availability of new knowledge about the impacts of MPs on human health. This attribute was measured in the number of years that would be needed for such knowledge to be available as a result of additional investment in scientific research. Experts assumed that the time period in which such knowledge would become available in the current situation without additional investments in scientific research was 20

years, while alternative policy scenarios assumed that it would become available in 15, 10, or 5 years.

Finally, a price attribute was included against which the benefits of reduced potential environmental risk and the timely availability of new knowledge had to be traded off. The price was expressed as an increase in the household's current annual water bill, since most people in Switzerland pay it on an annual basis. The price had six different levels, ranging from an annual increase of CHF 10 to CHF 150 per household (US\$ 7.3 and US\$ 110 respectively²⁰).

A mixed multinomial logit model was used for analyzing respondents' choices⁴¹ (for the model specification and more details see the SI). The estimated choice model parameters are used to calculate the marginal WTP (MWTP) for each choice attribute. The mean WTP of households for a specific policy alternative is further calculated by fixing the choice attributes at a certain level and summing the corresponding MWTP estimates.

2.3. Survey Design and Implementation. The questionnaire used in this study consisted of five main parts. The first part included opening questions, such as respondents' general interest in environmental problems or their perception of the current surface water quality. In the second part, the respondents were first informed about how households contribute to the presence of MPs in water bodies and how a wastewater treatment system functions. Next, the effects of MPs on the environment and human health and the uncertainty about those effects were communicated to the respondents. This was followed by questions relating to the respondents'

Table 1. Estimates of the Random Parameters Logit Model and Marginal Willingness to Pay^a

Variable	Coefficient [std. err.]	MWTP ^b [95% CI]
Random Parameters		
Low potential environmental risk	0.737*** [0.047]	CHF 100.21 [84.21–116.20]
National scale	0.378*** [0.041]	CHF 51.26 [40.28–62.24]
Availability of new knowledge about human health impacts	−0.044*** [0.004]	CHF 5.91 [4.82–7.00]
Nonrandom Parameters		
Price	−0.007*** [<0.001]	
Perceived water quality ^c	−1.026*** [0.243]	
Perceived risk of micropollutants ^d	0.819*** [0.213]	
Retired respondents	0.682* [0.390]	
Household income × 1000	0.069** [0.034]	
Households supporting environmental organization	1.250*** [0.315]	
Constant	5.385*** [1.171]	
Standard Deviations of Random Parameters		
Low potential environmental risk	1.471*** [0.097]	
National scale	1.036*** [0.106]	
Availability of new knowledge on human health impacts	0.054*** [0.007]	
Standard Deviation of the Error Component (σ)		3.436*** [0.221]
Log likelihood (restricted)	−6519.165	
Log likelihood (unrestricted)	−4477.344	
LR test (χ^2)	4083.643***	
Pseudo R ²	0.313	
Number of observations	5934	

^aNotes: *, **, and *** denote $p < 0.1$, $p < 0.05$, and $p < 0.01$. Estimations are performed with NLOGIT 5.0. ^bMarginal willingness to pay per household per year. The values in brackets represent 95% confidence intervals around the marginal willingness to pay estimates. ^cThe variable is coded as 1 = very poor, 2 = poor, 3 = moderate, 4 = good, and 5 = very good. ^dThe variable is coded as 1 = not risky at all, 2 = somewhat risky, 3 = risky, and 4 = very risky.

knowledge, awareness and perception of the risks of MPs for the environment and human health. Finally, a map indicating current potential environmental risk levels of MPs in Switzerland, varying from high to low, was shown to respondents (Figure 1, levels before STP upgrade). Respondents were told that these existing potential risk levels cannot deteriorate, and only improvements compared with the current situation are possible in the policy alternatives presented in the CE.

The third part of the questionnaire contained the CE. Since not all 108 possible combinations of the attribute levels could be shown to respondents as separate policy alternatives, a fractional factorial design was generated, consisting of a total of 38 different choice sets, each containing six choice tasks. Choice sets were randomly assigned to respondents. Choice tasks were presented on choice cards, each consisting of two policy alternatives and a status quo alternative. An example of a choice card is presented in Figure 1 in the SI. The status quo represents the option to choose none of the two alternative scenarios, implying that the potential environmental risk will remain at its current level, that new knowledge about the impacts of MPs on human health will become available in 20 years from now, and that household water bills will not increase. In order to identify the degree of hypothetical bias, at the end of the CE respondents were told to memorize their stated WTP amount in the preferred alternative in the last choice card. They were then asked whether they authorize an increase in their annual water bill by this amount of money by selecting the “yes” response to this question. A majority of 78%

clicked the “yes” button in the online survey. Respondents who chose the status quo option in all six choice cards were asked in a follow-up question to give their main reason. Those who gave a reason which indicated a form of protest against the valuation process (1.1%) were excluded from further analysis.⁴²

The fourth part of the questionnaire gathered information about the socio-economic characteristics of the respondents, and the fifth part included follow-up questions about the questionnaire itself.

The questionnaire design underwent careful pretesting to optimize its understandability and length (details can be found in the SI). The final survey was administrated over the Internet in May 2012 in the German-speaking cantons of Switzerland, which represent the majority of the Swiss population. Although there is a discussion about whether or not online surveys entail an additional sample selection bias compared to other survey modes, most studies that have investigated this issue conclude that the online survey mode does not generate significantly different results and confirm its suitability for collecting CE data for the purpose of economic valuation of nonmarket goods.^{43–45} An important advantage of the online compared to face-to-face survey mode is that it reduces socially desirable behavior since respondents have the opportunity to anonymously answer the questions behind their computer. The survey sample consists of respondents above the age of 18 and is representative for the 20 surveyed cantons. Respondents were randomly drawn from the consumer panel obtained from the marketing company ISOPUBLIC and contacted by e-mail. A total of 4011 respondents were invited to participate in the

Table 2. Sensitivity Analysis

Parameter	Annual benefits (10 ⁶ CHF/a)	Annual costs (10 ⁶ CHF/a)	Discounted benefits (10 ⁹ CHF/a)	Discounted costs (10 ⁹ CHF/a)	NPV (10 ⁹ CHF/a)	B/C ratio ^a
Confidence Intervals around the Mean Cost and Benefit Estimates						
Mean benefit estimate; mean cost estimate (baseline scenario)	155	133	3.72	3.32	0.40	1.12
Lower bound of benefit estimate; mean cost estimate	130	133	3.13	3.32	−0.19	0.94
Lower bound of benefit estimate; upper bound of cost estimate	130	166	3.13	4.15	−1.02	0.75
Mean benefit estimate; lower bound of cost estimate	155	100	3.72	2.49	1.23	1.49
Lower bounds of both benefit and cost estimates	130	100	3.13	2.49	0.64	1.26
Upper bound of benefit estimate; mean cost estimate	180	133	4.32	3.32	1.00	1.30
Mean benefit estimate; upper bound of cost estimate	155	166	3.72	4.15	−0.43	0.90
Upper bounds of both benefit and cost estimates	180	166	4.32	4.15	0.16	1.04
STP Upgrading Technology						
100% activated carbon	155	171	3.72	4.27	−0.55	0.87
100% ozonation	155	87	3.72	2.17	1.55	1.71
Mean WTP for Alternative Policy Scenarios^b						
Scenario I	372	133	8.93	3.32	5.60	2.69
Scenario II	326	133	7.83	3.32	4.50	2.36
Scenario III	280	133	6.73	3.32	3.41	2.02
Scenario IV	235	133	5.63	3.32	2.31	1.69
Scenario V	293	133	7.02	3.32	3.70	2.11
Scenario VI	247	133	5.92	3.32	2.60	1.78
Scenario VII	201	133	4.82	3.32	1.50	1.45
Scenario VIII (baseline scenario)	155	133	3.72	3.32	0.40	1.12
Discount Rate						
<i>r</i> = 1%	155	133	4.35	3.86	0.49	1.13
<i>r</i> = 4%	155	133	2.82	2.55	0.27	1.11
<i>r</i> = 10%	155	133	1.49	1.41	0.08	1.06
<i>r</i> = 20%	155	133	0.77	0.79	−0.02	0.97

^aBenefit-cost ratio. ^bFor descriptions of policy scenarios see Table 2 in the SI.

survey, and 1000 completed the questionnaire. This resulted in a response rate of 25%, which is in line with other similar studies.

3. RESULTS

3.1. Sample Characteristics. The sample contains more male (57%) than female respondents. The average respondent is 52 years old and the average household in the sample consists of 2.7 persons. Approximately one-third (34%) of the respondents have at least one child under the age of 18 who lives in the same household. The majority of respondents (61%) have completed high school, 20% have a bachelor's degree and another 12% a master's or PhD degree. This distribution of education levels conforms to that for the general Swiss population.⁴⁶ As regards their employment status, around 71% of the respondents in the sample are employed, 20% are retired, whereas the rest are students, housewives/husbands, or are unemployed. Most respondents reported that their household's monthly income before taxes is in the range between CHF 7501 and 9000. This is slightly less than the average gross household income in Switzerland of CHF 9604.⁴⁷ Over 45% of the households in the sample support an environmental organization through donations or membership fees.

The questions concerning MPs reveal that respondents consider themselves well informed about MPs and their potential risks. Despite this, approximately three-quarters

were not aware of the level of the potential environmental risk of MPs in their area of residence before taking part in this survey. As expected, their perception of the risks of MPs for environmental and human health corresponds with their expressed levels of concern about MPs. Over 80% of the respondents perceive MPs as risky or somewhat risky, and more than 80% of them are concerned or somewhat concerned about MPs. In addition, around 10% of respondents think that MPs are very risky, while only 4% think that they are not risky at all.

Attitudes of respondents toward the economic payment principles applied to water and wastewater services show that a majority agree with the user- and polluter-pays principles. Their standpoint on the principle that households should pay the full costs of water supply and wastewater treatment is less straightforward. Most respondents (40%) agree with this principle, but 35% disagree. There is no strong preference for a specific payment mode. One third of the respondents would prefer to pay the extra costs through an increase in a basic water service fee, 28% by means of a new wastewater charge, and 22% through an increase in their current drinking water charge. Most households (52%) currently pay directly for their water use through their water bill, while 44% pay the water bill as part of their overall utility bill. On average, households in Switzerland pay CHF 512 (US\$ 374²⁰) annually for drinking water and wastewater services.

3.2. Factors Determining Demand for Reducing Micropollutants. Table 1 presents the results of the estimated

choice model. The pseudo- R^2 statistic indicates that the overall fit of this type of cross-section model is good and similar to those reported in other studies using CE. The standard deviation of the error component is statistically significant, implying that the error variance associated with the policy alternatives is considerably greater than that of the status quo alternative. This finding is consistent with other studies, which discuss the implications in more detail.⁴⁸ Across the total of 18 750 choice tasks, the status quo option is chosen in 11% of cases. As one would expect in an unlabeled CE, any of the two policy alternatives is chosen equally often, indicating that respondents do not have a stronger preference for one of the two policy alternatives.

Coefficients of the CE attributes are statistically significant with signs that comply with our expectations. The coefficients indicate that the utility to respondents increases when the potential environmental risk of MPs is reduced from the current high or medium level to a low level and when the risk reduction occurs in the whole country instead of only in their canton. The utility to respondents decreases if it takes longer for new scientific knowledge about the impacts of MPs on human health to become available and if the increase in a household's annual water bill is higher. Standard deviations of the random parameters indicate that preferences for low potential environmental risk, national policy implementation and availability of new knowledge about human health impacts are heterogeneous, that is, that they are significantly different among individual respondents in our survey.

Other significant covariates in the CE model include respondents' perception of the current surface water quality in Switzerland, their perception of the risks of MPs for the environment and human health, and their socio-economic characteristics such as employment status, income, and support of environmental organization. The results show that respondents who perceive the current surface water quality as already rather high attach a lower value to water quality improvement with respect to MPs compared to other respondents. In contrast, a higher perceived risk of MPs has a positive influence on the utility associated with an alternative policy scenario. Retired respondents, those with higher household income levels and those whose household supports an environmental organization value reduction in MPs more than other respondents.

3.3. Benefit Estimates. The estimated MWTP values for nonmonetary choice attributes are reported in the last column in Table 1 for an average respondent in the sample. The 95% confidence intervals around MWTP estimates are obtained with the Krinsky and Robb procedure using 1000 replications.⁴⁹ Results indicate that the MWTP for reducing the potential environmental risk from current high or medium to a low level is CHF 100 $\pm$ 16 annually per household (US\$ 73 $\pm$ 12²⁰, 95% confidence interval). For reducing the potential environmental risk in the whole of Switzerland instead of only in the canton of a respondent's residence, Swiss households are willing to pay CHF 51 $\pm$ 11 annually (US\$ 37 $\pm$ 8²⁰) on top of their current water bill. Finally, their MWTP for having the new knowledge about the effects of MPs on human health available one year sooner is CHF 6 $\pm$ 1 annually (US\$ 4 $\pm$ 0.8²⁰).

Next, we can calculate the WTP for various policy scenarios (see Table 2 in the SI). The most conservative benefit estimate (CHF 100 annually per household) is obtained if (i) it takes 20 years for new knowledge about the impacts of MPs on human health to become available, and (ii) the potential environmental

risk is reduced to a low level only at the regional scale and not in the entire country. This policy scenario corresponds most closely to the real policy measure discussed in Switzerland at present. That is, the planned measure does not foresee additional investment in scientific research to acquire the knowledge about the impacts of MPs on human health sooner, and will ultimately lead to an upgrade of an estimated 123 STPs, which will not reduce the potential environmental risk to a low level in all river sections (see Figure 1, levels after STP upgrade). To estimate the benefits of the proposed policy measure, the WTP for the mentioned policy scenario (scenario VIII in Table 2 in the SI) is multiplied by the number of households in the catchment of the 123 STPs that will be upgraded, corresponding to 42% of the Swiss population. All other households in the country are assumed to have zero WTP. This results in a total annual economic benefit of CHF 155 $\pm$ 25 million (US\$ 113 $\pm$ 18 million²⁰). This estimate is used in the CBA. The underlying assumptions of the benefit aggregation procedure are specified in the SI.

3.4. Cost-Benefit Analysis. In the CBA, the annual benefits of implementing national policy on reducing the loads of MPs from wastewater (CHF 155 million or CHF 100 per household) are compared with the annual costs of upgrading the 123 STPs (CHF 133 million or CHF 86 per household in the catchment of 123 STPs).^{18,19} These costs comprise investment and operating costs, including the increased energy consumption required by the implementation of new technologies. The expected technical life span of the STP upgrade is 33 years. Choosing an appropriate discount rate is a crucial step in the CBA. In this study, a discount rate of 2% was applied, following recommendations for the evaluation of public infrastructure projects in Switzerland.⁵⁰ The results reveal that the discounted benefits over the 33 years life span of the investment equal CHF 3.7 billion, while the discounted costs over the same time period amount to CHF 3.3 billion. The NPV is consequently positive (CHF 401 million or CHF 259 per household), which implies that the investment needed to upgrade STPs with the aim of reducing MPs is justified from an economic point of view. The benefit-cost (B/C) ratio equals 1.12 and the internal rate of return (IRR), that is, the discount rate at which the NPV equals zero, amounts to 16.6% and is considerably higher than the official market interest rate in Switzerland. The CBA results thus support the implementation of the national policy for reducing the loads of MPs from STPs.

3.5. Sensitivity Analysis. A sensitivity analysis of the CBA results is performed with respect to the following key parameters: cost estimates, benefit estimates, and discount rate. Table 2 shows the results of the sensitivity analysis. Lower and upper bounds of the benefit estimate are represented by the 95% confidence interval around the mean WTP estimate for the most realistic policy scenario (CHF 84–116 annually per household). The uncertainty of the estimated costs of upgrading STPs is assessed at $\pm$ 25% for the most likely scenario of ozonation and activated carbon technologies' ratios (see the SI).¹⁸ Performing CBA under all possible combinations of confidence intervals reveals that the NPV remains positive and the B/C ratio higher than one in five out of eight cases.

The sensitivity analysis is also performed for the less likely scenarios of implementing a single upgrading technology in 123 STPs. Compared to the baseline, cost estimates are almost 30% higher if only activated carbon technology is used and 35% lower if solely ozonation technology is applied. The CBA

results indicate that the exclusive use of activated carbon technology would not be economically justified, whereas the use of ozonation in 123 STPs generates a positive NPV and a high B/C ratio.

The CBA outcomes are most sensitive to the estimated mean WTP for the various policy scenarios (Table 2 in the SI). The conclusion about the economic desirability of the investments in the STP upgrades however remains positive under all policy scenarios.

Next, we test the effect of varying the discount rate (between 0% and 20%). Higher discount rates diminish the present value of future benefits, favoring projects with distant costs and immediate benefits. The discount rate at which the NPV becomes negative (IRR) is 16.6%. This is very high in a developed country context, which means that implementing national MP policy is likely to remain economically justifiable under current market conditions and opportunity costs of capital.

The sensitivity analysis demonstrates that the conclusion about the economic desirability of the investment is sensitive to uncertainties underlying the cost and benefit estimates. If the costs are higher than expected (>16%) or the benefit estimate lower (>14%), a negative NPV may result.

4. DISCUSSION

The Swiss government made a legally binding decision on upgrading STPs to reduce the MP loads from wastewater, while the selection of STPs that should be upgraded is still to be discussed. This study presents the first CBA of implementing a national policy to reduce MPs from water bodies as a precautionary measure. It ties in strongly with a series of national and international MP-related studies.¹⁶ The survey used in this study integrates insights on MPs from the natural sciences and engineering into a social science research format. The SP method (CE) is applied because it is the only approach that can estimate the total economic value that would be generated by the reduced potential environmental and health risks of MPs. The estimated nonmarket benefits are compared with the costs of achieving reduced environmental MP contamination in a CBA. This is an important step in the process of supporting all previously gathered knowledge into an effective national policy.

The results show that despite high uncertainty surrounding the impacts of MPs, Swiss households are willing to pay a substantial amount of money on top of their current water bill for their reduction. The mean WTP for reducing the potential environmental risk of MPs to a low level at a cantonal scale (CHF 100 annually per household) equals 20% of the household's current water bill and just over 1% of an average household's income. Swiss households are, moreover, willing to pay 51% extra for the same environmental improvement at the national level. The reliability of the benefit estimate is ensured by thorough pretesting of the questionnaire and is confirmed by a very low rate of protest responses (1.1%).

The CBA results show that investments in upgrading STPs in the country can be justified and they support the implementation of national MP policy from an economic perspective. These results are, however, not entirely robust. The estimated costs and benefits need close future monitoring to ensure that the conclusions drawn in this study are valid. For example, cost estimates could be revised after the first STPs are upgraded and real cost data become available. Policy makers may also consider increasing the share of ozonation technology,

which proves to be cheaper and therefore ensures higher social welfare. On the benefit side, new scientific evidence about either the environmental or human health impacts of MPs could further improve the accuracy of the estimates. At the same time, diminished uncertainty about the effects of MPs might affect the risk preferences of individuals and consequently welfare estimates. Prospect theory, for instance, argues that people tend to overweight outcomes that are considered certain relative to outcomes which are merely probable.⁵¹ The stability of respondent preferences over time should also be taken into consideration to examine the temporal stability of benefit estimates, especially given the possible influence of media coverage of the issue.

This study assumed that only households in the catchment of the 123 STPs that will be upgraded would benefit from the national MP policy. If all households in the cantons in which the 123 STPs will be upgraded are considered beneficiaries, the total economic benefit of implementing the national MP policy would more than double, amounting to CHF 341 ± 54 million annually (US\$ 249 ± 40 million²⁰). Furthermore, the estimated economic benefits of achieving a low potential environmental risk in the whole country amount to CHF 519 million annually. Even though it would be technically unfeasible to achieve this only through STP upgrades, a combination of policy measures (e.g., more stringent environmental standards at pollution sources) might be considered. Of interest for international policy and decision-making is that people value positively additional investments in scientific research aimed at improving knowledge about the effects of MPs on human health. The benefits of identifying these effects one year sooner than currently expected are estimated at CHF 20.3 ± 3.7 million for the Swiss society alone. Since such results are made available globally, the potential number of beneficiaries and the benefits themselves may in fact be considerably higher.

Although a CBA is a useful and commonly applied decision-support tool, it is not the sole decision criterion for public environmental policy. We show that a CBA can evaluate the economic efficiency of policies which have uncertain outcomes, but other decision criteria may also play a role in such cases. Further research is needed to find the most appropriate approach for incorporating the risks and uncertainties associated with precautionary measures into the assessment of nonmarket economic values by means of SP methods.

■ ASSOCIATED CONTENT

§ Supporting Information

Additional information as noted in the text. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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Notes

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