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Additional Information for "Structured Decision-Making for Sustainable Water Infrastructure Planning and Four Future Scenarios"

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Abstract

To support Sustainable Water Infrastructure Planning (SWIP), a participatory decision-making procedure was developed in the SWIP project at Eawag[1]. This procedure is based on Structured Decision Making (SDM)[2], which guides stakeholders through different steps of the decision process: (1) clarify decision context (may include a stakeholder analysis); (2) define objectives and attributes; (3) develop alternatives; (4) estimate consequences; (5) evaluate trade-offs and select alternatives; and (6) implement, monitor and review.

The SDM application to water infrastructure planning was developed in close collaboration with stakeholders in a case study near Zürich, Switzerland. The experienced advantages and disadvantages of the first steps of the proposed procedure were discussed in a scientific publication by Lienert et al. (2014)[3]. We strongly encourage others to apply this SDM procedure for sustainable water infrastructure planning to their specific case. To this end, the approach was developed in a generalized way and we present more material covering the different steps of the SDM procedure in this working paper.

The here presented material includes different steps in the development of a comprehensive objectives hierarchy for water supply and wastewater management. The objectives are operationalized with attributes (indicators/ benchmarks), which are described in detail, including the ranges (best- and worst-possible case) and a description of the status quo. Four future scenarios were developed in a scenario planning workshop together with local stakeholders to capture socio-demographic uncertainty, which are again described in detail. Ten strategic decision alternatives were developed by stakeholders with help of a strategy generation table. These include the current system with central water supply and wastewater treatment plants, but also fully decentralized on-site options and different management strategies. The strategy generation table can be used to tailor decision alternatives for water infrastructure planning to other cases. Finally, we provide detailed feedback from the stakeholders for each step. We evaluate the proposed SDM approach and give recommendations for other applications.

Keywords: decision-making, scenario planning, stakeholder participation, structuring, water infrastructure, water management

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1. Content

2. Step (2) Define objectives and attributes

2.1 Preliminary objectives hierarchy

A preliminary objectives hierarchy was created on the desktop by the project team and discussed with the stakeholders in the 27 face-to-face interviews (Figure 1; also see Lienert et al. 2014). Details concerning this interview series and the stakeholder selection are also given in the stakeholder and social network analysis (Lienert et al. 2013).

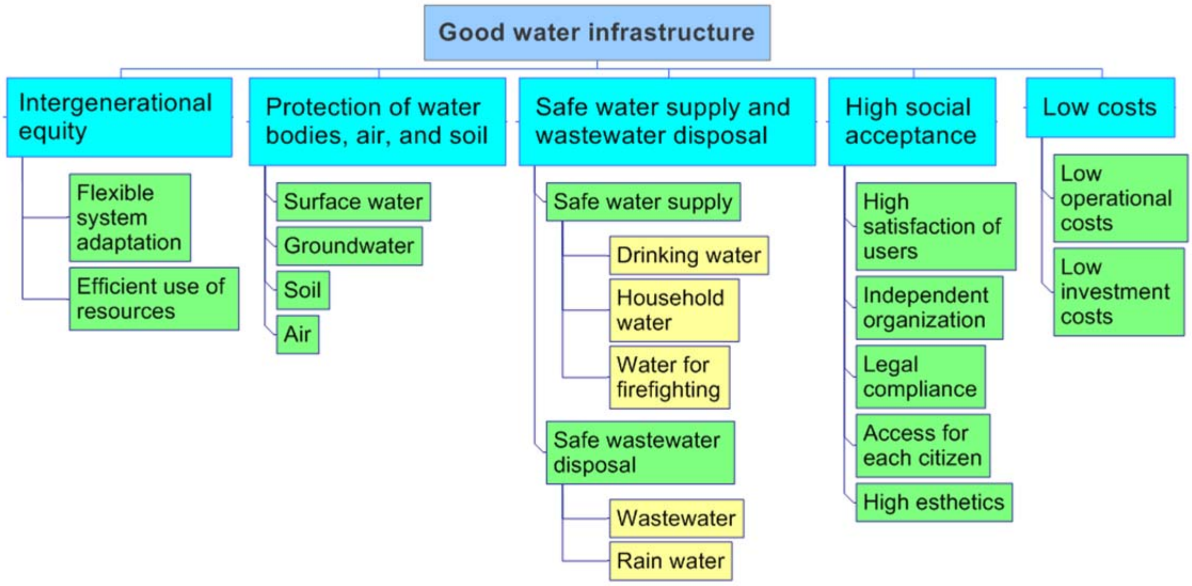

Figure 1. Preliminary objectives hierarchy.

2.2 Face-to-face interviews concerning objectives

In the face-to-face interviews with 27 stakeholders (see Lienert et al. 2014), each stakeholder was asked to classify the objectives into: essential (without this objective I cannot judge whether the fundamental objective is reached), important (without this it would be difficult to judge whether the fundamental objective was reached), and nice to have (attainment of fundamental objective can be judged without). NS = not significant for this stakeholder or missing (e.g. the water supply objectives were not judged by the wastewater stakeholders). The water supply and wastewater objectives were split and only judged by the respective stakeholders (explaining the large number of NS in Tabs. 1 and 2). The results concerning the objectives on the highest-level of the hierarchy are given in Table 1 and for the lower-level fundamental objectives in Table 2.

The objective "low costs" was judged as only "nice to have" by ten interviewees. However, the corresponding two lower-level objectives ("low operational" and "low investment costs") were judged as "nice to have" by only three and four stakeholders, respectively, which seems a bit contradictory. Most of the other 18 lower-level objectives were judged as very important by the large majority, with exception of "protection of air", which was classified as only "nice to have" by seven interviewees.

Based on the input from the interviews and an extensive discussion in the scientific project team, the objectives hierarchy was again revised. The revised version is given in Figure 2. This version was used as input for the stakeholder workshop.

Table 1. Classification of highest-level objectives in interviews. We show the results of face-to-face interviews with 27 stakeholders about the importance of the highest-level fundamental objectives. For each objective, we give the number of stakeholders that chose the respective classification. Details see text.

Objective → Classification ↓	Intergenerational equity	Protection of water, air and soil	Safe water supply	Safe wastewater disposal	High social acceptance	Low costs
Essential	4	17	18	13	4	3
Important	16	7	1	1	17	10
Nice to have	2	0	0	0	3	10
NS or missing	5	3	8	13	3	4

Table 2. Classification of the lower-level objectives in interviews. See Table 1.

Objective	Intergenerational equity		Protection of water, air and soil				Safe water supply			Safe wastewater disposal		High social acceptance					Low costs	
Sub-objective → Classifcation ↓	Flexible system adaptation	Efficient use of resources	Surface water	Ground-water	Soil	Air	Drinking water	House-hold water	Water for firefighting	Waste-water	Rain water	High satisfaction of users	Indepen-dent or-ganization	Legal com-pliance	Access for each citizen	High esthetics	Low operation-al costs	Low investment costs
Essential	7	8	14	17	7	4	18	7	9	13	9	10	1	12	11	4	15	8
Important	15	14	7	4	6	6	1	8	8	1	5	10	4	3	8	8	6	11
Nice to have	1	1	1	1	3	7	0	1	0	0	0	4	5	4	1	4	3	4
NS or missing	4	4	5	5	11	10	8	11	10	13	13	3	17	8	7	11	3	4

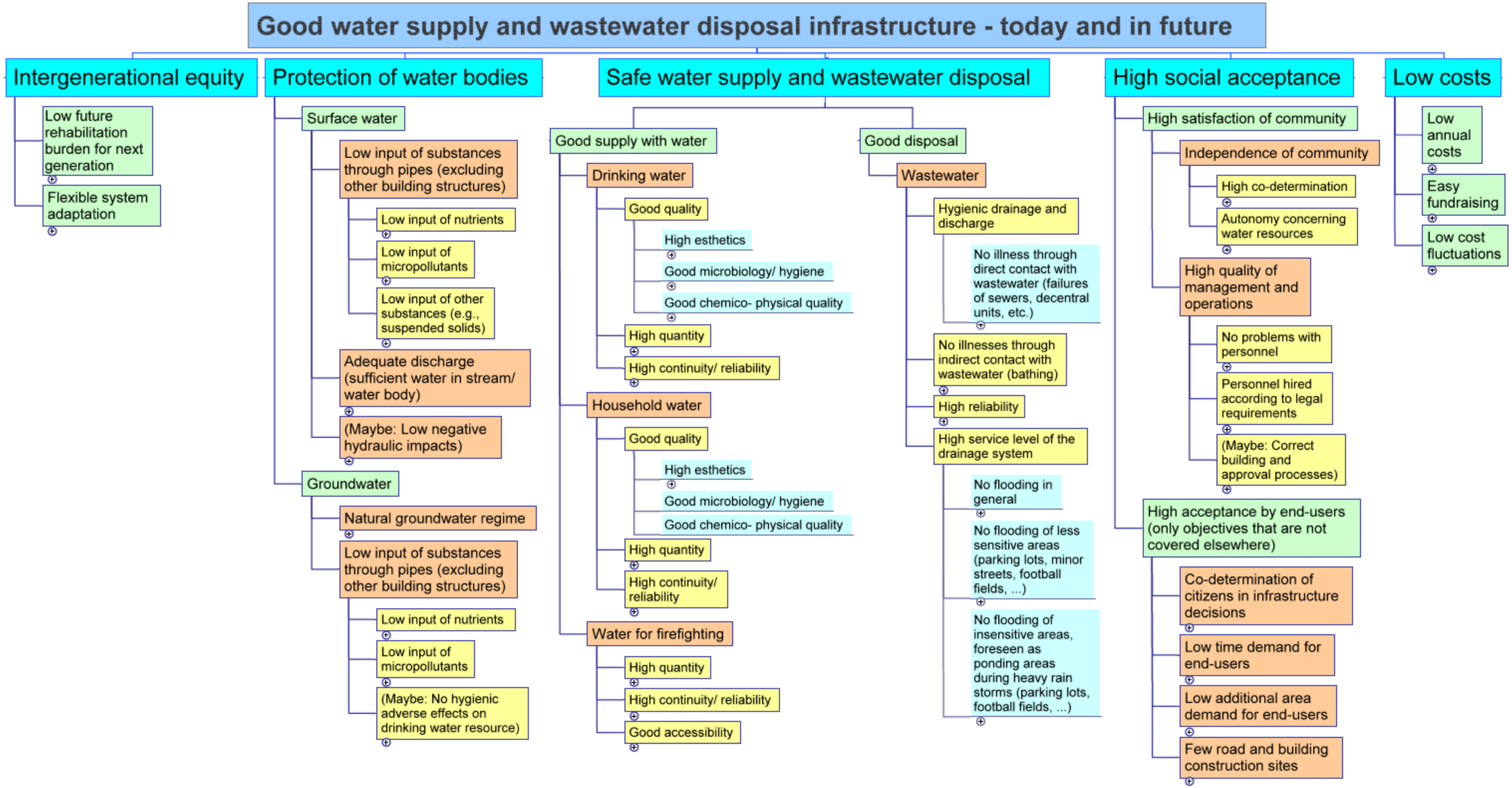

Figure 2. Objectives hierarchy used in workshop, after revision by the project-team. Revision based on input from interviews (Tabs. 1 and 2) and extensive discussions in the scientific project-team. The highest-level (1) fundamental objectives are colored blue, the second-level (2) are green, the third-level (3) are orange, the fourth-level (4) are yellow and the lowest-level fundamental objectives (5) are colored light blue.

2.3 Discussion of objectives in workshop

The objectives hierarchy presented in Figure 2 was extensively discussed in a stakeholder workshop (see Lienert et al. 2014). In Table 3, we show the feedback and group discussions concerning the proposed fundamental objectives.

Table 3. Feedback in workshop concerning fundamental objectives. We show objectives on different levels of an objectives hierarchy (see Fig. 2), where level 1 corresponds to the highest level (in blue, e.g. Intergenerational equity, Protection of water bodies,…), level two to the next-lower level (in green, e.g. Low rehabilitation burden, Flexible system adaptation,…) etc. Furthermore, we present the proposed attributes, the written feedback by workshop participants as discussed in groups of two, the main issues discussed in the plenary in the workshop, and the distribution of points (each of 20 workshop participants received three points which he could distribute to mark those objectives that seemed least relevant). Propositions for new objectives are given at the end of the table. WWTP = wastewater treatment plant; CSO = combined sewer overflows.

Object. (level 1)	Objective (level 2)	Objective (level 3)	Attribute	Written notes from workshop participants	Discussion in workshop	Points
1. Intergenerational equity				One comment that this objective is OK and that long-term investments should be made according to today's already existing concepts; one comment that it can be deleted because it is already contained in "safe water supply and wastewater disposal".		
Low future rehabilitation burden for next generation			Is rehabilitation demand during this generation done in this generation? (e.g. % necessary realization)	One comment that this is not a relevant objective.		1
Flexible system adaptation			Ease of technical extension or deconstruction of infrastructure (expert predictions)	Four comments: flexible adaptation can be deleted; additional comments that the system is very inert and changes are slow; flexibility is expensive; the uncertainties remain; is dependent on technological innovations, which are not foreseeable.		6
2. Protection of water bodies				"Protection of soil and air" was removed before the workshop by project team; they were considered less important by many interview partners and also the project team.		
Surface water	Low input of substances through pipes (excluding other building structures)	Low input of nutrients	g/ m³; kg/ a	Some ("fantastic") alternatives might not have pipes anymore; hence this is not a good objective; several statements that the objective should be less specific, just state that there should be a reduction of the pollution from wastewater.	Discussion that other building structures such as infiltration structures and WWTP should be included since they are relevant for input of substances; discussion about the system boundaries of analysis?	
		Low input micropollutants	µg/ m³; g/ a			1
		Low input other substanc-	µg/ m³; g/ a	Two statements that "other substances" are not im-		

Object. (level 1)	Objective (level 2)	Objective (level 3)	Attribute	Written notes from workshop participants	Discussion in workshop	Points
		es (e.g. suspended solids)		portant, can be deleted.		
	Adequate discharge (sufficient water in stream/ water body)		L/ s; / (s * h)	Two statements that discharge is not relevant because there is only discharge into river during rain events when there is sufficient water in the river / stream anyway.	Controversy between: discharge is not so relevant because of natural variations of river discharge and rainfall and: discharge is relevant because there can be too low dilution of substances from urban areas.	1
	(Maybe: Low negative hydraulic impacts)		Number of bed-moving floods due to CSOs / no. of bed-moving floods without CSOs	Four statements that it can be deleted because natural bed-moving floods are much larger than those from CSOs; two suggestions to change it to "no mechanical negative impacts".	Not so relevant because there are natural variations in discharge due to rainfall.	3
Groundwater	Natural groundwater regime		% Removal / regeneration	One statement that groundwater is not relevant; one that this is critical, but difficult / impossible to measure.		
	Low input of substances through pipes (excluding other building structures)	Low input of nutrients	g/ m³; kg/ a	One comment that "low input of substances" is sufficient, without distinguishing between nutrients and micropollutants; OK to not include details of WWTP; relevant objective if there is a dynamic development of the settlement.		
		Low input micropollutants	µg/ m³; g/ a			
	(Maybe: No hygienic adverse effects on drinking water resource)		Semi-quantitative expert estimate (state of pipes; probability that pumps break, etc.)	Two comments that hygienic effects on groundwater can be deleted; one comment that drinking water protection zones are relevant and should be included.		
3. Safe water supply (good supply with water)						
Drinking water	Good quality	High esthetics	Taste, smell, etc.	Can be subjective, e.g. in USA chloride characterizes safe water.		
		Good microbiology / hygiene	*Escherichia coli*, *Pseudomonas aeruginosa*, entero-cocci in colony forming units (CFU/ 100ml)			
			Potential of re-contamination			
		Good chemico-physical quality	Anorganic substances (N-compounds)			
			Turbidity			
			Pesticides, micropollutants			
			Dinitrophenols			

Object. (level 1)	Objective (level 2)	Objective (level 3)	Attribute	Written notes from workshop participants	Discussion in workshop	Points
			Corrosion potential of metals			
	High quantity		L/ (person * d)	Comment that it can be deleted/ that it is relevant and that the quantity should be multiplied by three to include water for industry.		
	High continuity / reliability		Customer minutes lost (length of outage * number of people affected/ 1,000 people)			
			Hours with outage			
Household water						4
	Good quality	High esthetics	Taste, smell, etc.	Three comments that high esthetics of household water can be deleted, because it is not relevant, e.g. for the washing machine.		2
		Good microbiology / hygiene	*Escherichia coli, Pseudomonas aeruginosa*, entero-cocci in CFU/ 100ml	Two comments that good microbiology / hygiene is irrelevant for household water.		1
			Potential of re-contamination			
		Good chemico-physical quality	Anorganic substances (N-compounds)			
			Turbidity			
			Pesticides, micropollutants			
			Dinitrophenols			
			Corrosion potential of metals			
	High quantity		L/ (person * d)	Could be changed to "sufficient quantity".		
	High continuity/ reliability		Customer minutes lost (length of outage * number of people affected/ 1,000 people)			
			Hours with outage			
Water for fire-fighting						3
	High quantity		l/ min with minimally 3,5 bar flow pressure	One comment that "water for firefighting" can be deleted.	High pressure of water for firefighting is important.	1

Object. (level 1)	Objective (level 2)	Objective (level 3)	Attribute	Written notes from workshop participants	Discussion in workshop	Points
			Water reserve m³ per pressure zone			
			Flow rate l/ s			
	High continuity / reliability		Criticality index			
	Good accessibility		Length of hose to building			
4. Safe wastewater disposal (good disposal)						
Wastewater	Hygienic drainage and discharge	No illness through direct contact with w-water (failures sewers, decentral units, etc.)	e.g. Number of illnesses in population per year	Two comments that double coverage with number of illnesses can be deleted.	Maintenance-friendliness should be included (e.g. easy access to manholes, easy to flush, …)	
		No illnesses through indirect contact with wastewater (bathing)	e.g. Number of illnesses in population per year			
	High reliability		Customer minutes lost (Length of outage * number of people affected)			
	High service level of the drainage system	No back pressure of wastewater (anywhere)	Number of people affected * length of back pressure	One comment: "no back pressure" is unrealistic; several comments: all three sub-objectives needed for non-conventional solutions.	Damages should be included.	
		No back pressure of rain on retention areas (parking lots, football fields, ...)	Number of people affected * length of back pressure	Suggestion to change to "few" or "controlled" back pressures; four comments that it can be deleted.		4
		No uncontrolled back pressure of rain (e.g. streets, non-retention parking lots)	Number of people affected * length of back pressure	Two comments that this can be deleted.		
5. High social acceptance					Social acceptance is not so important; is a soft factor. Can be assessed for today, but difficult for the future.	1
High satisfaction of community						7
	Independence of community	High co-determination	Qualitative: influence of community (differs between organizational forms)	One comment that co-determination of community is too political and should be deleted; one comment that direction is unclear (is more or less better?).	Acceptance by community depends on people working there; independence was so far not important in infrastructure decisions. Currently, no co-determination for telecommunication, but it works well. Discussion whether it can be deleted; but objective is necessary to measure organiza-	

Object. (level 1)	Objective (level 2)	Objective (level 3)	Attribute	Written notes from workshop participants	Discussion in workshop	Points
					tional forms of some alternatives.	
		Autonomy concerning water resources	% Of annual water demand from external providers	Eight comments that autonomy of water resource is not important and can be deleted.		3
	High quality of management and operations	No problems with personnel	Number of working hours per year required from volunteers	Two comments that this can be deleted; one comment that well-trained personnel is important.	Is strongly dependent on personnel, and not on size of the network or professionalism of organization; efficiency is not only measurable in costs. Discussion that it is required to distinguish organizational forms.	3
		Personnel hired according to legal requirements	Number of hours / year that surpass the legally allowed maximal working hours (for stand-by emergency duties)	Two comments that objective is not important; legal requirements should be fulfilled; flexibility of job market is not relevant.		2
		(Maybe: Correct building and approval processes)	% Approvals granted for "correct approval process" / total approvals	Eight comments that this objective can be deleted; legal requirements are boundary condition; instead use objective "simplified processes".		1
High acceptance by end-users	Co-determination of citizens in infrastructure decisions		Degree of co-determination (expert estimate; classes)	Three comments that co-determination of citizens is irrelevant.	In long term (25 – 40 years), acceptance by end-users is more important than acceptance by community.	1
	Low time demand for end-users		hrs/ yr			
	Low additional area demand for end-users		Additional area demand on private property per end user (m^2 or maybe m^3 in buildings)	Six comments that this objective can be deleted; it is unimportant, because 98% is below the ground anyway; public interest is more important than personal interests.		3
	Few road and building construction sites		Number of building sites in community / year weighted with average number? Or length of pipes?	Three comments that this objective can be deleted.		7
6. Low costs				Several comments that the overall annual costs are important; not the details.		1
Low annual costs			Capital costs; CHF/ year (interest rates, depreciation, investment costs)	General comment that details concerning costs are not important; it is dynamic over the decades; the overall costs are important.		
			Personnel cost; CHF/ yr	One comment that personnel costs can be deleted.		
			Material costs; CHF/ year	Two comments: "operational costs" are more important		

Object. (level 1)	Objective (level 2)	Objective (level 3)	Attribute	Written notes from workshop participants	Discussion in workshop	Points
				than material costs.		
Easy fundraising			Qualitative in classes (dependent on size of organization and level of debts)	One comment that it is important that also small organizations receive subventions; general comment that it is not important.		3
Low cost fluctuations			Number of increases >5% (compared with previous year over 40 years)	Several comments that increase of costs is not so important; only the overall annual costs are important.		5
Propositions for other objectives (based on individual written statements in workshop)						
Good supply with drinking water	High water pressure			Mentioned twice.		
Safe wastewater disposal	High water pressure			Mentioned twice.		
High satisfaction of community	Ease of maintenance			Mentioned twice.		
High satisfaction of community	Low additional area demand for community			One comment that this is important, because there can be resistance in the community.		
High satisfaction of community	High quality of managem. and operations	Highly qualified, well-trained personnel		Mentioned once.		
High satisfaction of community	High quality of managem. and operations	Separate politics from operation		Mentioned once.		

2.4 Modification of objectives hierarchy

In the months following the discussion of the objectives hierarchy in the stakeholder workshop, the SWIP project team carefully went through all objectives and attributes again. The resulting objectives hierarchy (Fig. 1 in Lienert et al. 2014) is less complex than the one presented in Figure 2 of this paper. This is a result of our efforts to cut down the number of objectives to those that are absolutely essential to characterize the water infrastructure system. We deleted objectives that are of minor importance (for water supply and wastewater infrastructures), which do not help to discriminate between the strategic decision alternatives, or for which it seemed impossible to generate reasonable predictions (neither could we model or estimate them ourselves, nor could we find experts that were capable of giving estimates). If possible, we used other attributes instead. The major changes are given below (minor changes, e.g. concerning the wording are not listed).

- Protection of water bodies / surface water / low input of substances through pipes / low input of nutrients / … micropollutants / … other substances → changed to: Protection of water and other resources / surface water / **good chemical state of the watercourse**
  Reason: The chemical state of the water bodies is the fundamental objective, while the input of e.g. nutrients is only a means objective. As attribute we use an aggregated measure over a number of indicators (several nutrients and pesticides) in five quality classes. We base our assessment on the procedure developed in the related NRP 61 project iWaQa (Schuwirth et al. 2012; iWaQa 2013), which in turn draws on existing assessment procedures by water authorities in Switzerland and Germany (see Schuwirth et al. 2012 for references). Because it is difficult to elicit preferences from lay people for attributes that characterize a good chemical status of the river, expert valuations of these single indicators are used for our predictions. The valuation scheme is based on the modeled contribution of chemicals from the wastewater infrastructure system to natural water bodies. As reference points we use existing measurement stations of AWEL (2006) with additional reference points added to the model used in iWaQa (2013), basically upstream and downstream of urban areas. We also rely on the iWaQa experts for the aggregation and weighting procedure of these attributes to come to an overall description of the chemical state of the watercourse in one of five classes (very bad to very good; also see Langhans and Reichert 2011; Langhans et al. 2013). However, we do ask all our respondents for trade-offs between this and other objectives (i.e. for the scaling constant or weight of this objective).
- Protection of water bodies / surface water / **adequate discharge** (sufficient water in stream / water body) → deleted
  Reason: Removed after extensive discussion, also with the related project iWaQa (2013). Our project SWIP relies strongly on iWaQa to model and quantify the effects of the urban infrastructure system on surface waters. However, there are no clearly defined criteria (attributes) available to assess this objectives' degree of fulfillment. Since we are not able to quantify different outcomes of this objective for the different decision alternatives based on our own models, nor is it being modeled in iWaQa, we decided to delete it.
- Protection of water bodies / surface water / **low negative hydraulic impacts** → included
  Reason: We had first considered excluding this objective, because the water quality experts from iWaQa (2013) are not using it due to the problem of not being able to translate hydraulic events into negative effects for the water ecosystems. However, there are existing guidelines for wastewater engineers in Switzerland (VSA 2002), which quantify the ratio of bedload movements with or without stormwater discharge. We decided to use these. Our attribute is thus very simple: the % reference points in the river network (of the case study catchment) that fulfill the VSA (2002) guidelines for stormwater handling. The same reference points

as for “good chemical state of watercourse” are used. The status quo levels are elicited together with engineering experts.

- Protection of water bodies / groundwater / low input of substances through pipes → replaced with **low contamination from sewers**
  Reason: Leaky sewers are potential inputs of pollutants into the soil and eventually the groundwater. While this is certainly an important objective, it is very difficult to quantify, since it is dependent on various factors. We decided to use semi-quantitative expert judgments (groundwater specialists at Eawag) to estimate the amount of wastewater exfiltrating from sewer lines, dependent on their physical condition. The assessment of the attribute in terms of water quality classes follow those used for a “good chemical state of watercourses”.
- Protection of water bodies / groundwater / → additional objective **low contamination from infiltration structures**
  Reason: Additionally to leaky sewers, infiltration of stormwater from impervious areas such as roofs increases the risk of contaminating the groundwater. This risk depends, for example, on the location of the infiltration structure and the amount of rain water being infiltrated. As above, the potential for contamination is based on estimates from groundwater experts in five water quality classes.
- Protection of water bodies → changed to protection of water and **other resources**; i.e. including two new objectives: **Recovery of nutrients** and **efficient use of electrical energy**
  Reason: We decided that these are two important fundamental objectives that should be included in a comprehensive objectives hierarchy, which also focuses on ecological sustainability. Moreover, the recovery of nutrients from wastewater (characterized by the indicator “% recovery of phosphate from wastewater”) allows distinguishing between current centralized solutions (where nutrients are normally not recovered) and decentralized options where nutrient recovery is often an explicitly stated objective (e.g. Larsen et al. 2009, 2012).
- Safe water supply and wastewater disposal → split into two fundamental objectives at the highest level: **Good supply with water** and **safe wastewater disposal**
  Reason: In the SWIP project, the wastewater infrastructure systems (C. Egger) are modeled separately from the drinking water infrastructure system (L. Scholten); the same applies to the MCDA for wastewater (J. Zheng) and water supply infrastructures (L. Scholten).
- Good supply with water / water for firefighting / **good accessibility** → deleted
  Reason: This attribute was characterized by the length of the hose to the building, which is obviously dependent on where fire hydrants are placed. We decided to base our dimensioning of the alternatives on the given current legal requirements for the case study utilities in the canton of Zürich, Switzerland (GVZ 2011). The same applies to the current legal requirements for minimum water pressure (3.5 bar in the distribution system).
- Safe wastewater disposal / high reliability and / high service level of the drainage system → combined to one higher-level objective with two fundamental sub-objectives; the sub-objectives concerning no floodings in general / of less sensitive areas / and insensitive areas were deleted: Safe wastewater disposal / **high reliability of the drainage system** / **few structural failures of drainage system** and … / **few overloads of drainage system**
  Reason: The two sub-objectives concern the same objective, namely that one expects high reliability of the drainage system, i.e. that it does not block or collapse due to structural failures (leading to floodings), and that there are only few floodings under heavy storms. We use the following two attributes: For “few structural failures” we use the “weighted (by pipe diameter) number of pipe collapses

and blockages / year / 1,000 inhabitants"; weighting is done with the pipe diameter under the assumption that bigger pipes have a larger impact when they fail because more water is conveyed by them. Pipe failures are condition dependent and hence based on condition states predicted by a sewer deterioration model (Egger et al. 2013). For "few overloads of drainage system", we use the "weighted (by urban land use and number of inhabitants) number of incidents of insufficient drainage capacity per year (e.g. overflowing of manholes)" predicted by a hydraulic model. Here, we assumed that the damage is more severe if more people are affected, more dramatic in historic city centers, and the disturbance is higher if local trade or business is affected. Thus, we weighted this attribute by 1.5 if the area flooded is in a historic town center with mixed living and commercial zones.

- High social acceptance / **high satisfaction of community** and / **high acceptance by end-users** → deleted
  Reason: The hierarchical cluster distinguishing between the satisfaction (acceptance) of the community and the end-user is unnecessary and presumably only complicates elicitation, since it can, for example, also be important for the community to have low disturbance by road works. For similar reasons we removed all hierarchical clusters on the lower levels.
- High social acceptance / high satisfaction of community / **high quality of management and operations** / with three sub-objectives → sub-objectives deleted
  Reason: We decided to use the "% score of the EFQM Excellence model (European Foundation for Quality Management)" as attribute, since it is well-known and covers the relevant management aspects better than the sub-objectives that we invented. "The EFQM Excellence Model is the most popular quality tool in Europe, used by more than 30,000 organizations to improve performance"; EFQM 2013). We asked an expert at Eawag (business economist) to classify our strategic decision alternatives accordingly.
- Low costs / **easy fundraising** → deleted
  Reason: Test-interviews for preference elicitation indicated that there are preferential overlaps between the two objectives "low annual costs" and "easy fundraising" because it proved difficult to get reliable estimates for real interest rates in the different alternatives. Additionally, we decided early in the project to not include financing strategies (e.g. are infrastructures fully financed via tax payers, are there subventions?). For these two reasons, "easy fundraising" was removed. As consequence, the real interest rate is also not considered in the calculation of the annual costs, but the discount rates still apply.
- Low costs / low cost fluctuations → reformulated as **low cost increase**
  Reason: We do not consider it as problematic if the costs decrease sometimes, while (large) increases are rather relevant.

2.5 Short discussion of objectives hierarchy and attributes

The construction of the objectives hierarchy was an extensive and careful process. First, we defined the system and e.g. decided that protecting floodplains is outside the infrastructures' system boundary. We included objectives that are often neglected in engineering practice and were judged less relevant by our stakeholders. These concerned social acceptance, future generations and the environment such as protecting groundwater (see above and Fig. 1, Tab. 1 in Lienert et al. 2014). We justify this to ensure that all pillars of sustainable development are included (Wuelser et al. 2012). Stakeholders tend to value current pressing issues higher than important solved ones from the past. For example, septic tanks were abolished in Switzerland due to groundwater pollution; groundwater quality is now high, and stakeholders judged groundwater protection as low priority. But for other cases and future generations, groundwater remains an important resource.

We need some objectives to distinguish between alternatives: “flexible system adaption” and “low unnecessary construction and road works” help to positively distinguish decentralized alternatives from the conventional central system, whereas “low time demand” and “low additional area demand for end users” are negative characteristics of these. Similarly, “high quality of management and operations” discriminates between organizational aspects. If this is not part of the decision, it can be excluded by giving it a scaling factor (weight) of zero. “Water for firefighting” might not be a requirement of the water supply system elsewhere. Other Switzerland-specific objectives might be “high autonomy concerning water resources” or “co-determination of citizens”, since in many countries people cannot vote about (infrastructure) decisions.

We took great care to construct the attributes in such a way that they are applicable to other cases and that they comply with engineering requirements as well as decision theory. Some attributes may look similar, namely “few gastro-intestinal infections through direct contact with wastewater (due to failures of infrastructures)” and “few structural failures of drainage system” (Tab. 4; also see above and Fig. 1, Tab. 1 in Lienert et al. 2014). In both cases, the cause may be poor maintenance leading to collapses of pipes and back-pressure of wastewater into streets or cellars. However, the first objective refers directly to preserving human health; a fundamental goal of urban sanitation. The second aims at preventing the disturbance of daily business and traffic or the damage of property.

We regard this objectives hierarchy, as presented in Lienert et al. 2014 in Figure 1 and Table 1 to be exhaustive. It covers the main aspects important to water infrastructure planning. In application to other case studies, we recommend that those stakeholders carefully discuss which objectives are required for their specific decision situation and to delete those, which do not add additional insight. The attributes (Tab. 4) were constructed in a generalized way so that they are applicable to other cases. However, the respective ranges must be adapted to the boundaries in the respective application case, i.e. they should cover the worst- and best-possible decision alternative that is considered in that case.

Table 4. Description of the attributes that measure how well each objective is achieved. The short name refers to the objectives hierarchy given in Fig. 1 of Lienert et al. (2014; also see Tab. 1 in Lienert et al. 2014). We give the units, the ranges (worst- and best-possible state), the status quo, a more-detailed description of the attribute, and a narrative of the status quo in the case study region Mönchaltorfer Aa. DW = drinking water, WW = wastewater, WWTP = wastewater treatment plants, CSO = combined sewer overflows (discharge of mixed rain and wastewater without or with only basic treatment in the case of heavy rain events).

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
Intergenerational equity							
rehab	% Realization of the rehabilitation demand	[% reali-zation]	0	DW: not completely realized WW: 80 – 100%	100%	DW: In the short term, purely repair-based rehabilitation strategies are cheaper than renewal or replacement strategies. The consequence is a water infrastructure which not only has a higher average age, but which is also more prone to failure. Undetected leakage leads to high increased water losses. The realization of the rehabilitation demand for the period 2010–2050 is calculated as 1 – [(no. of failures per km) / (no. of failures if nothing – except repair – is done)] * 100%. According to the recommendations of the Swiss Gas and Water Industry Association (SVGW), the failure rate should not exceed 0.1 failures per km. WW: To keep the system as good as it is today, annual investments are needed. These are approximately the reciprocal of the mean lifetime of pipes times the replacement value of the pipe network: Investment demand = (1[a]* replacement value) / (mean lifetime of pipes [a]) As an example, sewers have a lifespan of about 80 years. To keep the system as good as it is today, about 1.25% of the total system have to be rehabilitated every year: 1 / 80 years * 100 = 1.25 For each alternative, the effective investments in rehabilitation measures are summed up over the whole planning horizon and related to the total investment demand over the same period of time (also see Scheidegger et al. 2013).	DW: The rehabilitation demand is not completely realized (objective: <0.1 failures / (km * a), status quo ca. 0.15 – 0.2 failures / (km * a) WW: Currently, 80 to 100% of the total rehabilitation demand are being realized.
adapt	Flexibility of technical extension or deconstruction of infrastructure	[% flexibil-ity]	0	20 – 50%	100%	Expert assessment. All alternatives were judged individually by four engineers according to how easy it is to technically extend or deconstruct the infrastructure. The relevant aspects were: organizational structure, construction and operation of infrastructure, wastewater and drinking water system technology. Each alternative was classified as: "very low (0 – 20%)", "low (20 – 40%)", "medium (40 – 60%)", "high (60 – 80%)", "very high (80 – 100%) system flexibility". Using the mid-points of the intervals (10, 30, 50, 70, 90%), the average and standard deviation were calculated. Alternatives with >10% deviation were discussed, and a final score assigned. Larger interval ranges depict higher uncertainty or higher variance.	Today's wastewater system is not very flexible (20 – 50% flexibility). This is caused, amongst others, by the high path-dependency.
Protection of water and other resources: Surface water							
chem	% Reference points in catchment that fulfill water quality target (nutrients, micropollutants, value > 0.6)	[% > 0.6]	0	50%	100%	Phosphorus in water bodies is an indicator of anthropogenic influences (via WWTP, CSOs, agriculture) and can lead to eutrophication. In Switzerland, nitrogen is usually not a limiting factor for plant growth. Nitrite is strongly toxic for fish. Ammonium indicates pollution from wastewater or agriculture. Dissolved organic carbon can be an indicator for anthropogenic pollution. Total organic carbon includes particulate organic carbon, which reaches water after heavy rain from CSOs or organic fertilizers. The biochemical oxygen demand is a measure for the oxygen used up by biological degradation processes; in severe cases, anaerobic conditions occur. These can produce toxic substances as nitrite, methane, and	Currently, the chemical state of the watercourse is "moderate" in the case study area Mönchaltorfer Aa. 50% of the reference points fulfill the water quality target level, based on a number of indicators for nutrients and pesticides. For example, for three reference points, the concentrations of nitrate (NO_3) are higher than double of the

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
						hydrosulfides. (source: FOEN 2010) The Swiss Modular Concept for stream assessment is a new procedure to assess rivers and streams (Bundi et al. 2000; http://www.modul-stufen-konzept.ch). To assess the chemical state, a set of nutrients are used (FOEN 2010), and three indicators for pesticides that are relevant in the region Mönchaltorfer Aa (AWEL 2006). The nutrients are: total phosphor / (Ptot), total phosphor filtrated (Ptot filtr), orthophosphate (PO4-P), total nitrogen (Ntot), nitrate (NO3-N), nitrite (NO2-N), ammonium (NH4-N), total organic carbon (TOC), dissolved organic carbon (DOC), biochemical oxygen demand (BOD). The micropollutants are: photosynthesis inhibitors, chloroacetanilides, organophosphates. For each substance, a target level is defined (concentration limits). The estimated level (from measurements or models) is compared with the target and classified (FOEN 2010): • "very good": estimated level of substance in watercourse is lower than half of the target level • "good": estimated level is higher than half of target level and lower than target level • "moderate": estimated level is higher than target level but lower than 1.5x target level • "unsatisfactory": estimated level is higher than 1.5x target level but lower than 2x target level • "bad": estimated level is as large as or even higher than 2x the target level. To aggregate the results of each indicator at each reference point, we use an approach first described by Langhans and Reichert (2011) and Langhans et al. 2013, which is further developed in the iWaQa project, based on multi-attribute value theory (Schuwirth et al. 2012). The quality class obtained by each indicator is transferred to a neutral value between 0 and 1 with a value function. The values are mathematically aggregated to give an overall assessment of the state of the watercourse. We use a mix of additive and geometric aggregation, with equal weights for each indicator. The reference points are existing measurement stations of AWEL (2006) with additional reference points added to the model used in iWaQa, basically upstream and downstream of urban areas. To spatially aggregate the values at each reference point, we determine whether the estimated level is above the target. If it is above, the water quality requirement is not reached (i.e. classes "bad", "unsatisfactory", "moderate" = value < 0.6). If the estimated level is below the target, the requirement is fulfilled (i.e. classes "good", "very good"). Over the entire catchment, we give the % reference points that fulfill the quality requirements.	target level, so that these reference points are judged as "very bad" concerning nitrate.
hydr	% Reference points in catchment that fulfill VSA guidelines for stormwater handling	[% yes]	0	44 – 74%	100%	The VSA (2002) guideline for a single discharge point evaluates the following relationship: $V = Q\_347/Q\_E * f_S * f_G$ V = “Einleitverhältnis” = ratio between water amount coming from the river and water amount coming from the discharged rainwater [–] Q_347 = water flow in the river that is surpassed at 347 days a year (similar to the almost minimum water flow in the river) [m^3/ d] Q_E = discharged rainwater flow after a rain event that occurs once a year [m^3/ d]	Currently, 44 to 74% of the discharge points fulfill the requirement of the VSA (2002). This means that in about half of the discharge points, the water that is led into the river can lead to turbulence distraction of the flora and fauna in the river.

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
						f_S and f_G = correction factors to account for the type of river and river bed. Q_347 is derived from the model output of the water quality model of iWaQa and Q_E is determined from the total discharges from the combined and stormwater systems upstream of the individual reference points. The result is evaluated in three classes: • VG > 1: Discharge is allowed, only for very polluted water a treatment is required • 0.1 < VG < 1: Discharge is allowed, but in water protection area, treatment is necessary • VG < 0.1: Discharge is only allowed with prior retention. The reference points are existing measurement stations of AWEL (2006) with additional reference points added to the model used in iWaQa (2013), basically upstream and downstream of urban areas. To spatially aggregate the values at each reference point, we determine whether the VSA guidelines (2002) for stormwater handling are fulfilled or not. Over the entire catchment, we give the % reference points that fulfill the guideline.	
Protection of water and other resources: Groundwater							
gwhh	% Water abstraction / groundwater recharge	[%]	180	6	0	Will be presented in later paper by Lisa Scholten et al. (2014)	
exfiltrsew	Water quality class (of nutrients; based on expert estimates)	5 classes	very bad	good	very good	One expert (Eawag scientist) classified the sewers according to the condition classes of VSA (2007a), and another estimated the % wastewater that exfiltrates into the ground. As indicators, we use the same nutrients as for the "good chemical state of watercourses" (see there), classified into one of five water quality classes (FOEN 2010), but not the pesticides. The concentration of each nutrient in wastewater is estimated based on average values from the literature (AWEL 2006; FOEN 2012; Gujer 2002; Herlyn and Maurer 2007). Then, the groundwater recharge rate is used to calculate the concentration of the nutrient in the groundwater. For the condition classes according to VSA (2007a), following % of wastewater exfiltrated was assessed with the experts: • Class 0 (sewer is untight, has several cracks, is strongly incised, crushed, danger of collapse is given, floor is strongly corroded): 2 – 100% of wastewater exfiltrates into the ground (average: 30%) • Class 1 (sewer is corroded or strongly eroded, has several cracks, has open pipe joints or some that broke off, loses water): 2 – 30% of wastewater exfiltrates • Class 2 (sewer shows damages, pipe joints are broken at the crown, some holes at the crown, has several cracks, that are sometimes strongly calcified, floor is slightly corroded and eroded): 0 – 15% of wastewater exfiltrates • Class 3 (sewer is in an insufficient condition. The floor is slightly eroded, several small calcifications at the crown and the walls): 0 – 8% of wastewater exfiltrates • Class 4 (sewer is in a good condition): 0 – 4% of wastewater exfiltrates. Contrary to surface waters, there is no need to spatially aggregate the water quality classes at different reference points. The groundwater body is regarded as an entity, and the calculations are based on the groundwater recharge rate of the entire system. The influence of the soil (retention, degradation, hydraulic conductivity, height of the groundwater	Currently, the contamination through wastewater, for instance because of leaky sewers, is relatively low in the case study area Mönchaltorfer Aa (expert estimate: 8 – 10%). The groundwater quality regarding nutrients is classified as "good".

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
						table) cannot be taken into account because there is not enough information. This is why the uncertainty of this attribute is very high.	
exfil-trstruct	Water quality class (of biocides; based on expert estimates)	5 classes	very bad	very good	very good	The concentration of each biocide in the infiltration water is estimated based on average values from the literature (AWEL 2006; Staufer and Ort 2012), and with an Eawag-expert. Then, the groundwater recharge rate is used to calculate the concentration of the biocide in the groundwater. Each biocide indicator is classified into a quality class, analogously to the "good chemical state of the watercourses" (see there). There are not a lot of nutrients present in infiltration water, so we did not consider these. We only look at infiltration water from roofs (with Eawag expert). The influence of the soil (retention, degradation, hydraulic conductivity, height of the groundwater table) cannot be taken into account because there is not enough information available. This is why the uncertainty of the attribute is very high. Contrary to surface waters, there is no need to spatially aggregate the water quality classes at different reference points. The groundwater body is regarded as an entity, and the calculations are based on the groundwater recharge rate of the entire system.	Currently, there are no collection systems and infiltration structures to infiltrate water from roofs, parking lots, and streets in the case study area Mönchaltorfer Aa. Thus, hardly any water from such areas that can contain biocides is being infiltrated. Therefore, a "very good" water quality is assumed for infiltrated water.
Protection of water and other resources: Efficient use of resources							
phosph	% Recovery of phosphate from wastewater	[% P recovery]	0	0	100%	Phosphate recovery from urine is only done on laboratory and pilot scale at the moment. With the current treatment it is possible to recover about 90% of the phosphate (Etter and Kohn 2009). Theoretically, it is possible to recover up to 100%.	Currently, no phosphate (as indicator for the recovery of nutrients) is recovered from wastewater.
econs	Net energy consumption for water / wastewater treatment and transport	DW: [kWh / m^3] WW: [kWh / p / yr]	DW: 2 kWh / m^3 WW: 250 kWh / p / yr	DW: ca. 0.5 kWh / m^3 (estimated) WW: 45 – 60 kWh / p / yr	0	The best case (low energy consumption) is assumed to be zero, because of little / no treatment of water and wastewater, and the use of gravity for transport. The status quo was calculated / estimated using data provided by the water supply / wastewater treatment plants in the case study area Mönchaltorfer Aa. The worst case (maximum energy consumption) was calculated assuming very energy-intensive water treatment, and water withdrawal and transport over long distances requiring pumps and tank wagons. To transport bottled water, mineral oil equivalents were converted to energy. For wastewater, we assumed the energy consumption of high tech decentralized treatment units, and added the energy consumption for the removal of micropollutants and the treatment of urine (and a safety factor). With the gas produced during the digestion of the wastewater sludge, electricity can be produced using a gas-powered combined heat and power unit. It is not only possible to produce electricity; heat can also be recovered from the wastewater stream with a heat exchanging device. The heat energy is neglected because it only plays a minor role compared to electrical energy. If inefficient use of electrical energy generates higher costs, these are considered separately in the objective "low costs".	Currently, the energy for treatment and transport of water is estimated to 0.5 kWh/ m^3 (ca. 46 kWh/ person / year) in the case study region. This equals about 0.25% of the energy requirement of a household, given current water usage. For wastewater, the net energy for treatment and transport of wastewater in the central WWTPs of the case study area amounts to 45 to 60 kWh/ person/ year. Compared to the total energy consumption of about 8,000 kWh/ person/ year, this equals about 0.6% of the total energy requirement of a Swiss person (VSE 2012).
Good supply with water: Drinking water: Good quality							
aes_dw	Days per year with esthetic impairment such as taste, smell, etc.	[d / yr]	365	0	0	Each alternative's esthetic water quality is assessed by an expert of the Cantonal Laboratory Zurich. Details will be presented in later paper by Lisa Scholten et al. (2014)	
faecal_dw	Days per year with	[d / yr]	365	0	0	Each alternative's esthetic water quality is assessed by an expert of the Cantonal Lab-	

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
	hygienic concerns (hygiene indicators)					oratory Zurich. Details will be presented in later paper by Lisa Scholten et al. (2014)	
cells_dw	Changes in total cell count as indicator of bacterial re-growth	[log]	2 (hundred-fold increase)	ca. 0.68	0 (stable concentration)	Each alternative's hygienic water quality is assessed by an expert of the Department of Environmental Microbiology at Eawag and an expert of the Cantonal Laboratory Zurich. Details will be presented in a later paper by Lisa Scholten et al. (2014); also see Lautenschlager et al. (2010).	Currently, there is approx. a doubling of the cell counts after overnight stagnation.
no3_dw	Anorganic substances (nitrate concentration)	[mg / L]	20	10	0	Will be presented in later paper by Lisa Scholten et al. (2014)	
pest_dw	Pesticides (sum of pesticide concentration)	[µg / L]	0.15	0.036	0	Will be presented in later paper by Lisa Scholten et al. (2014)	
bta_dw	Micropollutants (indicator: benzotriazole)	[ng / L]	150	105	0	Will be presented in later paper by Lisa Scholten et al. (2014)	
Good supply with water: Drinking water: High quantity							
vol_dw	Days per year with water quantity limitations	[d / yr]	365	0	0	Will be presented in later paper by Lisa Scholten et al. (2014)	
Good supply with water: Drinking water: High reliability							
ci_dw	Criticality index	-	0.25	estimated: 0.01 – 0.03	0	The criticality index is calculated as: criticality of affected pipe x probability of outage / total criticality of all pipes. Will be presented in later paper by Lisa Scholten et al. (2014)	
Good supply with water: Household water							
	Same objectives and attributes as "Drinking water"					Will be presented in later paper by Lisa Scholten et al. (2014)	
Good supply with water: Water for firefighting							
vol_ffw	Available water for fire-fighting in new housing areas	[L / min]	500	ca. 1'500	3'600	Will be presented in later paper by Lisa Scholten et al. (2014)	
ci_ffw	Same as for "Drinking and Household water"					Will be presented in later paper by Lisa Scholten et al. (2014)	
Safe wastewater disposal: Hygienic drainage and discharge							
illn	% Of total population getting infected once per year	[% / yr]	25% / yr	0.001 – 2.3% / yr	0.0002 % / yr	Wastewater contains human pathogens, but also from other sources (e.g. animal manure), if such wastewater drains into the sewer system (e.g. from farms). These pathogens can cause infections, which may lead to illness such as gastrointestinal disorders, especially in sensitive people (e.g. the elderly or children). Note that this risk is rather low. We therefore use the % of the total population getting infected once a year as attribute. If a person gets infected twice a year, he or she counts double in the calculation. The attribute was calculated using the research of Ten Veldhuis et al. (2010). A quantitative microbiological risk assessment is used to estimate the risk of illness due to exposure to micro-organisms after flood events and direct contact with wastewater. For this, a dose response model for a certain infectious organism is required, which is combined with infor-	The inhabitants of the region Mönchaltorfer Aa have direct contact with wastewater once every 10 years. Between one person in four years (0.001% of the population) and 547 people (2.3% of the population) get infected with gastrointestinal pathogens every year (total population in region is 24,180 in 2011). Of those that get infected, ca. 10 to 100% get ill, depending on their body's defenses. For the model, an average intake volume

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
						mation about the exposure frequency. The dose response models link the amount of a certain pathogen with the risk of infection at a single contact (P_single). There are many different models. Ten Veldhuis et al. (2010) use an exponential model for *Cryptosporidium* and *Giardia*, and a Beta Poisson dose-response model for *Campylobacter*. The dose response models lead to very different results for different organisms in the same wastewater sample. The risk of infection is therefore subject to a very high uncertainty. Sampling: In Ten Veldhuis (2010) a series of samples was taken from combined sewers during dry weather flow. *Cryptosporidium, Giardia, Campylobacter, E. coli*, and *Enterococci* concentrations were measured. The E. coli and Enterococci concentrations found were compared with measurements of concentrations in flood water to roughly estimate the dilution during a flood event. Based on this, the concentration of *Cryptosporidium, Giardia,* and *Campylobacter* in flood water could be calculated and then used in the microbial risk assessment (dilution factor: 10). With the exposure frequency (how many times does a person have contact with wastewater per year), an annual risk of infection can be calculated with: P_annual=1 – (1 – P_single) ^ EF where P_annual is the annual risk of infection, P_single is the risk of infection per incident (result of the dose response model) and EF is the exposure frequency. To define the amount of pathogens, a certain intake volume has to be defined. According to the literature it was decided to use an intake volume of 10 to 30 ml per event. The concentrations and the dose response models used were the same as in the work of Ten Veldhuis et al. (2010). Exposure to wastewater may occur due to maintenance activities, failures, and flooding during extreme storms. To estimate the predictions of this attribute for every alternative, the exposure frequency due to flooding will be defined by means of the hydraulic model), exposure due to failures with help of a failure model, and exposure due to maintenance due to literature values.	(20 ml) and an exposure frequency of 0.1 (contact with wastewater once every 10 years) was assumed.
cso	Number of combined sewer overflows (CSOs) per year per receiving water	[no. / yr / receiving water]	60 CSOs / year / receiving water	10 CSOs / year / receiving water	plus-minus 0 (0.001 = 1 in 100 years)	We know that currently up to 4% of the population gets infected once per year with gastro-intestinal pathogens after swimming or bathing in rivers or lakes. This number is estimated with the average *E. coli* concentration at recreational sites in Switzerland and a model of the EPA (US Environment Protection Agency) for *E. coli* and gastrointestinal infection. There is no information about CSOs underlying this approach, and we do not have any information for the case study region Mönchaltorfer Aa. Therefore, we use the number of CSOs directly for this attribute. Pathogens causing gastro-intestinal infections can also reach wastewater from agriculture, e.g. from animal manure. It is usually not possible to distinguish whether the original source of infection is wastewater, or agriculture. The worst case (maximum number of CSOs per year and receiving water) was defined by experience (Eawag scientist). The status quo was defined using the GEP ("genereller Entwässerungsplan"; urban drainage planning in Switzerland) for the town of Mönchaltorf. This describes the number of CSOs into the river Mönchaltorfer Aa. The best case is close to zero (1 overflow in 100 years). To make the predictions of this attribute for each alternative, we will use the number of CSOs per year and receiving water, which are a direct output of the hydraulic models.	In the year 2005, there were about 10 combined sewer overflows (CSOs) from the town Mönchaltorf into the river Mönchaltorfer Aa. Hence, 10 overflows per year and per receiving water is considered to be the status quo.

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
Safe wastewater disposal: High reliability of drainage system							
failure	Weighted (by pipe diameter) number of pipe collapses and blockages per year and 1,000 inhabitants	[no. / yr / 1,000 people]	10 / yr / 1,000 p	0.0005 / yr / 1,000 p	0.0005 / yr / 1,000 p	Although this attribute seems similar to the ones above concerning "no gastrointestinal infections through direct / indirect contact with wastewater", it follows a different objective. The previous ones refer directly to preserving human health. This one refers ("only") to preventing nuisances, the disturbance of daily business, or the damage of property. If a sewer is very large, it carries more rain and wastewater. Consequently, if a larger sewer is damaged, there will also be a larger potential for wastewater being spilled into urban areas, and hence larger potential for damage than if the sewer is small. We account for this by weighting the number of pipe collapses and blockages with the pipe diameter. To estimate the range, the weighted pipe failure f was calculated as: f = l * r_f * g where l is the length of the sewer [km], r_f is the failure rate [/ km/ yr], and g is the weight: g= (D/ D_average) ^ 2, where D is the diameter of a certain pipe, and D_average is the average of all pipes of the sewer systems. For the range, different failure rates were taken from the literature; minimum (for the best case): 0.0001/ km/ yr; maximum (for the worst case): 0.5/ km/ yr. For two communities (Egg and Mönchaltdorf), an inventory of all pipes with their length, diameter, and location is given and used for the calculations. To estimate the predictions of this attribute for each alternative, a model ("proportional hazard function") will be developed. It links the condition class predicted by Egger et. al. (2013) to a failure rate.	Today's drainage system is very reliable, we expect 0.0005 weighted pipe collapses and blockages per year and 1,000 people. This equals one failure every 80 years in the case study region (24,180 inhabitants in 2011). In Mönchaltorf, for example, there are no reported failures. In a bigger system, more failures can be expected. As comparison, also in the city of Zürich there are hardly ever failures (confirmed by Zürich). The Zürich sewers are in very good condition and well maintained.
service	Weighted (by city center and number of inhabitants) number of incidents of insufficient drainage capacity per year (e.g. overflowing of manholes)	[no. / yr]	10 / yr	0.0002 – 0.13 / yr	0 (0.0002) / yr	This attribute may seem similar to the objective above "few structural failures of drainage system", because the final effects to the population might be similar, namely floodings of streets and houses with combined rain and wastewater. However, we separate them, because they describe different types of troubles that are both important to urban drainage and wastewater engineers. The causes for the attribute above are structural failures, and the prevention strategy is better maintenance and rehabilitation. In the case of "sufficient drainage capacity", the causes are a too low hydraulic capacity of the drainage system, which can occur even if the system is very well maintained. In this case, mitigation measures are the reduction of impervious areas (so that rain water drains directly into the ground), or can indirectly be addressed by planning the system differently (e.g. larger pipes and retention tanks, decentralized systems comprising larger retention and infiltration of stormwater). Of course, the nuisance or damage that such floodings cause is higher if more people are affected. We weight the number of incidents by the number of inhabitants per hectare. The damage is also more dramatic in historic city centers, and the disturbance is higher if also local trade or business are affected. To account for this, we give a weight of 1.5 if the area flooded is in a historic town center with mixed living and commercial zones. A 30 year historic rain series measured by a rain gauge located in the vicinity of the catchment area was used to evaluate the capability of the drainage system of properly draining stormwater. For the worst case, it was assumed that no well-designed drainage system is present, so the water is mainly drained on surfaces and in trenches. For the status quo, it was assumed that 20% of the area is flooded every 10 years. For the best case, it was	The drainage service is relatively high. About 20% of the area is flooded every 10 years due to insufficient capacity of the drainage system. This leads to a weighted damage of 0.0002 to 0.13 per year, depending on the vulnerability of the flooded area. (see "calculation attribute")

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
						assumed that the area is almost never flooded. The damage d is then calculated as: d=(flooded area) / (total area) * flooding frequency * g Where g is the weight: g = (population density in flooded area) / (average population density) * 1.5 (for city center and mixed zones). The lowest weight is given to a zone with only single-family houses (a lot of area where water can drain off; e.g. big gardens), and the highest weight is given to residential and commercial zones with four story buildings. To calculate the predictions of this attribute for each alternative, the frequency of overloading of each individual manhole will be calculated with a hydraulic model using historical rainfall series as model input. To each manhole, an area is assigned which might be affected by flooding when overloading of the manhole occurs. The area is characterized by the urban land use as indicator for its vulnerability to urban flooding. The weight for the vulnerability can be by experts.	
High social acceptance							
auton	% of the water coming from the region Mönchaltorfer Aa	[%]	0	55%	100%	The water supply from within and outside the case study region Mönchaltorfer Aa is calculated within the SWIP project, based on the descriptions of each alternative and the water demand under the four future scenarios.	On average, 55% of the water comes from the case study region Mönchaltorfer Aa, and 45% from lake Zürich.
efqm	% Score of EFQM Excellence Model (European Foundation for Quality Management)	[%]	20%	55 – 70%	100%	Each of the SWIP alternatives were assessed concerning their performance according to the EFQM Excellence Model (EFQM 2013) by interviewing a business expert (Eawag scientist). The assessment is based on the organizational form and the geographic extent of our alternatives. Through the nine criteria of the EFQM Excellence Model, the firm can understand and analyze the cause and effect relationships between what the organization does and the results it achieves. Five of these criteria are “Enablers” and four are “Results”. The “Enabler” criteria cover what an organization does and how it does it. The “Results” criteria cover what an organization achieves (EFQM 2013). The nine criteria and their relative weightings are: 1. Leadership [10%], 2. Strategy [10%], 3. People [10%], 4. Partnerships & Resources [10%], 5. Processes, Products & Services [10%], 6. Customer Results [15%], 7. People Results [10%], 8. Society Results [10%], 9. Key Results [15%].	The quality of management and operations under the current structures in the case study area Mönchaltorfer Aa can typically achieve 55% to 70% of the EFQM Excellence Model score, given favorable conditions.
voice	Degree (percent) of co-determination	[%]	0	50 – 90%	100%	Each of the SWIP alternatives was assessed by two experts concerning the co-determination (Eawag scientists). They received documentation prior to the interview with a description of the relevant aspects for this attribute (organizational structure, geographic extent, financial strategy). As classification, the following semantic categories were used, and then translated into %: very low (0 – 20% co-determination); low (20 – 40%); medium (40 – 60%); high (60 – 80%); very high (80 – 100%). In the case of differing estimates, the range was enlarged to cover both expert estimates. This means that the lower % number was decreased, or the upper % increased. As an example: if expert A gave an estimate from 40 – 60% and expert B from 60 – 80%, we used the total range from 40 – 80%.	Currently, the end users have medium to very high co-determination of about 50 – 90%. The system is a mix of responsibilities in the hands of households (household connections), cooperations, and the community. The citizens are often directly involved in decisions by being able to participate in council meetings, or via public vote.
time	Necessary time investment for operation	[h / person	DW / WW: 10 h / p /	0	0	This attribute estimates the time each citizen has to invest per year to operate and maintain their decentralized water supply or wastewater disposal system. This can involve e.g. the	The current situation corresponds to the best-possible case. Currently, there are

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
	and maintenance by end user	/ yr]	yr each			cleaning of filters, reading of meters, or the maintenance of tanks. Also telephone calls to ask for help by a specialist, or complaints to a service hotline require time. Estimates based on (realistic) times for maintenance of currently available decentralized (waste) water treatment units, and a number of telephone calls, based on expert estimates and product information.	practically no decentralized water supply or wastewater systems in the case study area Mönchaltorfer Aa that have to be maintained by the end users. Hence, the time demand is 0 hours per person and year.
area	Additional area demand on private property per end user	[m^2 / person]	DW / WW: 10 m^2 / p each	0	0	The range for this attribute was calculated using the area demand of decentral water or wastewater treatment units found in the literature (product information), and expert estimates. Decentralized water supply systems cover the use of decentralized tanks with or without point-of-entry or point-of-use treatment. In case of centralized supply, additional treatment can be installed in households. One possibility for decentralized wastewater systems is a small treatment plant that works in the same way as a big central WWTP. Another option is for example a septic tank, where the wastewater is stored before it is pumped out again and transported away with a truck. There are also low tech options such as constructed wetlands, which require the most area. Hereby, the sewage water is lead into a planted field. The plants take up the pollutants (e.g. nutrients) in the water and thereby clean it.	Currently, there are practically no decentralized water and wastewater systems in the case study area Mönchaltorfer Aa that have to be installed on the private property of end users. Apart from the installations for the pipes (including water meters and gate valves), the area demand thus corresponds to 0 m^2.
collab	Number of infrastructure sectors that collaborate in planning and construction	–	1	3	6	This attribute judges for each of the decision alternatives in SWIP, how many of six sectors that use the underground collaborate. As an example, if the drainage company is renewing its sewers in a specific section and the gas and water infrastructure could also soon need rehabilitation, these works could be carried out together. Otherwise it could happen that right after the constructions works are closed by one sector, another sector starts its amelioration works, hereby reopening practically the same "hole".	Currently, in the case study area Mönchaltorfer Aa there is usually cooperation between the water supply and wastewater sector with the transportation department; i.e. three sectors collaborate. In the community Gossau, for example, there are two joint meetings / year for planning and coordination. In other communities there are joint meetings of road construction, water supplier, and wastewater utility as needed, i.e. if larger construction works are planned.
Low costs							
costcap	Annual cost / person in % (DW) or in CHF (WW) of mean taxable income	DW: [% / p / yr] WW: [CHF / p / yr]	DW: 5% / p / yr WW: 863 CHF / p / yr	DW: 0.4% / p / yr WW: 289 CHF / p / yr	DW: 0.01% / p / yr WW: 76 CHF / p / yr	For wastewater, the calculations for the range are based on numbers in a report of VSA (2011; the Association of Swiss wastewater and water protection experts). Hereby, all Swiss communities were asked to provide their cost data. In the VSA (2011) report, the total annual costs consist of running and capital costs. The running costs consist of the labor and material costs. The capital costs consist of the imputed depreciation costs and the interest costs. The transport costs for sludge transport is included for decentralized treatment options. The money needed for the water supply and wastewater infrastructure can be collected in numerous forms through taxes, tariffs, and direct payments, which we do not consider. For the water supply sector, we decided to elicit cost-preferences as percentage relative to the mean taxable income (65,000 CHF / p / yr for federal taxes, averaged over the four communities in the area of the case study Mönchaltorfer Aa). For the wastewater sector, we decided to elicit the preferences by using the annual cost in	Currently, the total costs for water supply in the region Mönchaltorfer Aa amount to ca. 0.4% (273 CHF / p / yr) of the average taxable income (ca. 65,000 CHF / p / yr). The total costs for the entire wastewater disposal system amount to 289 CHF per person and year, based on the average total annual costs of wastewater treatment plant and the sewer system for the year 2011.

Short	Attribute	Units	Worst	Status quo	Best	Detailed description attribute and calculation	Status quo
						CHF per person to measure this attribute. The detailed cost calculations for each alternative will be carried out by an engineering company.	
cost-change	Mean annual linear increase of costs in % (DW) / in CHF (WW) per person and year until 2050	DW: [% / p / yr] WW: [CHF / p / yr]	DW: 20% / p / yr WW: 43 CHF / p / yr	DW: 8% / p / yr WW: 1.4 CHF / p / yr	0	To estimate this attribute, the total annual costs will be calculated for every year (see attribute "low annual costs"). The increase of costs from 2010 to 2050 will be divided through 40 and averaged for the cost increase per year.	In the case study area Mönchaltorfer Aa, the total costs for water supply from 2006 to 2010 increased on average by 8% (linear increase). For wastewater disposal, the costs have increased by 1.4 CHF per person per year in the last five years (20,864 CHF higher costs / year at an average running cost of 776,975 CHF / year). For wastewater, we use accounting information about the running costs of the WWTP in the case study area Mönchaltorfer Aa from 2006 to 2010.

3. Future scenarios

3.1 Methods: scenario workshop

Three future socio-demographic scenarios for the case study region for the year 2050 were created in a stakeholder workshop in April 2011. 15 of 22 invited participants from the case study region participated. After a general introduction to the project and the ideas behind scenario planning, we presented three scenarios that differed in six main characteristics: global situation, environment, spatial development, population, working, and transportation. Furthermore, we presented eight factors that characterize the water supply and wastewater system: quantity of water used and wastewater generated by the population, quantity for industry, societal requirements concerning water quality, legal requirements concerning drinking water and wastewater treatment, spatial development of the communities, financial situation of the communities, financial situation of population and industry, and subventions and tax incentives. The factors were discussed in groups of two and then in the plenum to eliminate factors that are not relevant for the region or to include other very important factors.

We then assigned the participants to three groups with mixed stakeholder types and assigned a scenario to each group. Each group discussed what the general development in 2050 could mean for their communities, and they were asked to conjure a vivid, detailed, and coherent picture. In the next step, they were asked to describe in detail how the water supply and wastewater system might look like in the respective future world; they were asked to be as specific as possible and to use numbers (e.g. for population growth or water consumption). The scenario specification was based on the factors that had been previously discussed and modified in the plenum (Tab. 5). They chose a title for their scenario, noted the core characteristics on a flip-chart, and made a sketch to visualize the main ideas. The three scenarios were presented in the plenum.

3.2 Results: scenario workshop

The eight factors that characterize the water supply and wastewater system were discussed in the plenum. One factor was eliminated by merging (financial situation of population and industry merged with financial situation of community), and three were added: coordination among the communities, environmental impacts, and availability of energy (Tab. 5). The factors “availability of resources and materials” and “available technologies” were discussed in the plenum but not included in the list of mandatory factors. However, the groups could include them if they wished.

Three future socio-economic scenarios were created in the groups (details in Tab. 6). Note, that we later modified certain characteristics defined in the scenario workshops; namely the spatial planning in the “Boomtown Zürich Oberland” scenario” and the water demand per person and day (also see Lienert et al. 2014).

Table 5. Factors to construct scenarios. Description of the factors that describe the water supply and wastewater system, which were given to the workshop participants, discussed and adapted in the plenum, and finally used to specify the future scenarios created in three stakeholder groups. WWTP = wastewater treatment plant.

	Factor	Description
A	**Quantity** of water used and wastewater generated by the population	Describes two developments: (i) the demographic development (i.e. population growth) and (ii) the specific water demand of households. Will future lifestyle change the required water quantity? We assume that the wastewater quantity is similar to the supplied water quantity.
B	**Quantity** of water used and wastewater generated by the industry	Describes the requirements of industries that are relevant for water management. The water demand and wastewater production (especially the load of contaminants) should be described separately.
C	Societal requirements concerning water **quality**	What services do the people and consumers ask from the urban water management system? For example, are they very environmentally-friendly and health-conscious and would they also be willing to pay more for water and wastewater treatment than required by law? Would they also pay for the elimination of micropollutants in drinking water or for the hygienization of the wastewater overflows from WWTP?
D	**Legal** requirements concerning drinking water and wastewater treatment	Describes the legal requirements and norms for water supply and wastewater treatment. As an example, is it required by law to monitor a number of micropollutants in drinking water and to remove these? Are there more stringent requirements for wastewater treatment such as the hygienization of wastewater overflows from the WWTP? What are the requirements for firefighting?
E	**Spatial** development of the communities	Describes the type of settlements and the building activities in the communities. Will there be densification or urban sprawl? Will there be mainly apartment houses or single-family houses? Where will there be buildings and where not?
F	**Financial** situation of the communities (and population, industry)	Describes the financial degrees of freedom and the possibilities of the communities, population, and industries in the region. Are these heavily indebted? Is there sufficient public (tax) money available?
G	Financial situation of population and industry	Merged with F after discussion in the plenum.
H	**Subventions** and tax incentives	How is the urban water management system financed (e.g. with public tax)? Are there tax incentives (e.g. wastewater bills, taxes to deal with water shortages or to remove micropollutants)? Are there subventions (e.g. to hygienize the outflow from WWTP for re-use in agriculture)?
I	**Coordination** among the communities	Describes how the communities are organized. Is there a separate political and management system for each community? Do the communities collaborate (and if yes, how)? Are there mergers of communities into one larger entity?
J	**Environmental** impacts	For example, consequences due to depleting water resources. Consequences of activities in the region and the water infrastructures on the quality of water bodies.
K	Availability of **energy**	For example, what are the consequences of energy shortages for the water sector? Is energy generated and/ or stored by the water supply and wastewater system?

Table 6. Scenario description. Description of the three socio-economic scenarios for the case study region near Zürich that were created in a stakeholder workshop: (A): Boom, (B): Doom, (C): Quality of life. WWTP = wastewater treatment plant, CSO = combined sewer overflow (mixed rain and wastewater is discharged directly to rivers and lakes without treatment or only very basic treatment in the case of heavy rain events).

	Scenario	General situation	Spatial development	Transportation	Financial situation	Collaboration	Water supply	Wastewater system	Energy and environment
A	Boom-town Zürich Oberland (Silicon Valley Aabach)	In 2050, Europe belongs to the most prosperous regions worldwide. Region Mönchaltorfer Aa is booming. Massive population growth from today 25,000 inhabitants to ca. 200,000. High-tech industries with high productivity; large trust in technologies.	Region is very densely populated. High land prices; very dense urban development (25-story-buildings). Few villas for the rich. Few agricultural areas and nature protection zones. Recreational areas (river Aabach, Lake Greifensee).	Strong increase in mobility; commuters from E-Switzerland. New transport axes (highway, access roads, magnetic levitation train).	Communities prosper, rising tax revenues. Loans for infrastructure investments needed, but also higher income (more connection fees). No subventions, financing only via fees. Tax incentives foster use of water of different qualities.	Communities are forced to collaborate due to high dynamics in region.	Overall increase of water demand (population growth), but considerably lower per person water demand due to clean-tech. Some areas distribute water of different quality (drinking water, household water, firefighting). No shortages due to access to lake Zürich. High water quality standards promote closed-loop technologies and on-site treatment. Health-consciousness of people leads to high requirements for drinking water quality (at least as good as today).	Central WWTP in industrial zone, mainly for household water (no heavy industries). Much stricter requirements for wastewater treatment to compensate population growth. Remaining nature protection zones (Aabach, lake Greifensee) similarly clean as today (no smell or eutrophication). Additionally, removal of micropollutants is required from society and by law. Climate change leads to heavy rain events and various measures for discharge management and flood control.	Environmental protection and quality of life very important. High costs for fossil fuels: resource stewardship; use of renewables. Per person energy consumption much lower (clean tech).
B	Doom	Increasing gap between Europe and prospering Asia. Switzerland is increasingly unattractive in the global world. This causes strong financial pressure on public provisions, especially of infrastructures in water sector that have high investment costs. Decline of industries. Deregulation.	Spatial development of communities stagnates. Relatively strong urban sprawl. Slight population decline.		Despite high investment needs and rising costs it is politically not possible to raise water fees. No subventions or state finances.	Increased collaboration between communities to make use of synergies and expertise.	Water demand decreases to 80 l / person / day (ca. 2x less than today)[a]. Communities reduce capacities and investments. Very bad state of pipes. Strong dependence on local water sources; highly variable quality (on average only household water). Hence, population has own water sources; e.g. bottled water, rain water collection (garden, membrane filter for kitchen). Control and monitoring by state hardly existent and ineffective. Drinking water quality standards as 2011, but not relevant (bottled water etc.). Minimal requirements for fire water.	Wastewater quantity is lower by ca. 25% than in 2011. Negligible inputs from industries. Separate sewers for wastewater only are abandoned; only mixed sewers (rain and wastewater together). Climate change effects are strongly perceptible in urban drainage: increasing floodings after heavy rain events and more CSOs. WWTP are in a very bad state. They are held together with "spit and tape", with frequent failures. Only mechanical parts are functioning reliably. Lower wastewater quality standards.	Environmental effects (deficient wastewater treatment; climate change (CSOs)). Decreasing concern about micropollutants. Energy is expensive (saved wherever possible).
C	Quality of life	Europe belongs to the most prosperous regions. In Europe, Switzerland is important. Moderate population growth (<5% / year; 20% until 2050). High environmental and health awareness. High productivity in agriculture;	Additionally required residential areas mainly created by more dense urban development, rather than providing more land for buildings. Only 5% additional building areas (= ca.	Public transport is promoted and efficient. Commuting is reduced by actively promoting e-technologies	Financial situation of communities and population is good. Sufficient finances for good maintenance and operation of the water infrastructures available.	Grüningen and Gossau are merged. Mergers with other communities discussed, following general trend in ct. Zürich: 50 communities in	Higher drinking water quality (sensitive analytics; better information about chronic effects). Water demand of households lower than today (140–150 L / person / d)[a]; of industry as 2011; higher in agriculture. Water supply by public network, rain water retention basins combined with advanced treatment ponds. Lower technical requirements for networks. Cost savings due to	Very high quality requirements for wastewater treatment, and protection of the environment and water resources. Discharge from WWTP reaches nearly drinking water quality standards. Depleting resources, high energy prices, and climate change effects have led to constant optimization and new developments. E.g. nutrients are recycled from wastewater and used as fertilizer in	Very high environmental standard; resources recycling. Energy production from biomass; energetic optimization of wastewater

Scenario	General situation	Spatial development	Transportation	Financial situation	Collaboration	Water supply	Wastewater system	Energy and environment
	high ecological standards.	today's reserves of building zones)	(ca. 30% home office).		2050 (2010: 171).	smaller pipe diameters, new laying techniques. Flexible fire water provision, coupled with rain retention measures.	agriculture.	system.

[a] We could not directly use the water demands specified in the workshop; Lienert et al. (2014).

4. Step (3) Develop alternatives

4.1 Methods: workshop to create alternatives

In the 2nd stakeholder workshop in May 2011, the twenty participants created strategic alternatives with help of a strategy generation table. We prepared the 17 factors and their specifications beforehand. The 17 factors concerned the organizational structure (four factors; e.g. cooperation between sectors), geographic extent (two factors; e.g. cooperation between communities), financial strategy (two factors; e.g. rehabilitation strategy), construction and operation of water infrastructure (four factors; e.g. operation & maintenance), wastewater system technology (two factors, e.g. storm water handling), and drinking water system technology (three factors, e.g. central or decentralized water treatment). The strategy generation table is given in Table 7.

The participating stakeholders were split into four groups according to their professional background. We mixed groups to ensure the representation of different perspectives (local, cantonal, and federal stakeholders, and actors from different sectors, i.e. water supply, wastewater, administration). Each group was assigned to one of the four change scenarios specified in the first stakeholder workshop (Boom, Doom, Quality of Life, and status quo; Tab. 6). We asked the participants to create at least two different alternatives per group. First ideas of possible alternatives were collected by each group during a 15 minute brainstorming under the premises of the assigned change scenario. Each group then selected some of the generated alternatives (the favorite one, the most probable one, etc.), which was further systematically characterized by choosing (or generating new) specifications of each factor from the strategy generation table (Tab. 7). Some of the factor specification required a more-detailed definition. As an example, for the funding strategy (factor G, Tab. 7), specifications c) and d) required numbers concerning the % self-financed in the constant budget, or the % increase per year in the progressive budget. The most important characteristics were presented in the plenum. Altogether ten decision alternatives were defined. The project team used these backbones as input to develop more-detailed alternatives to be used in the later MCDA.

Table 7. **Strategy generation table.** Overview of 17 factors (A – Q) and the respective factor specifications (a – h) in six main categories: Organizational structure, geographic extent, financial strategy, construction and operation of the infrastructure system, and system technology of the wastewater and drinking water system. DW = drinking water, WW = wastewater, WWTP = wastewater treatment plant.

Organizational structure				Geographic extent		Financial strategy		Construction, operation of water infrastructure				Wastewater technology		Drinking water system technology		
A Form of organization	**B** [a] Cooperation sectors: DW, WW, others	**C** [a, b] Responsibilities WW sector	**D** [a, c] Responsibilities DW sector	**E** Cooperation communities	**F** Cooperation w. other communities	**G** Funding	**H** Rehabilitation strategy (DW & WW)	**I** Rehabilitation measures	**J** Pipe / sewer laying technique	**K** Operation & maintenance	**L** Inspection & surveillance	**M** Drainage system	**N** Storm water handling	**O** Purpose of use	**P** Distribution system	**Q** Water treatment
a) Community	a) DW / WW / others	a) Private / sewer / WWTP	a) Intake / treatm / distr / private	a) All individually	a) None	a) Constant budget, 100% self-financed	a) Rehabilitation of x% of network	a) Replace	a) In trench	a) Extensive	a) A lot (to be defined)	a) Combined sewer (1 sewer)	a) Discharge	a) Water for food (drinking & cooking)	a) Centralized	a) Centralized (to be defined)
b) Cooperatives	b) [DW + WW] / others	b) Private / [sewer + WWTP]	b) [Intake + treatm] / distr / private	b) 2 together, the others individually	b) Wetzikon	b) Constant budget, 0% self-financed	b) Condition-dependent measures	b) Repair	b) Trenchless	b) Moderate	b) Average (to be defined)	b) Separate (2 or more sewers)	b) Retention	b) Water for hygiene (e.g. shower)	b) Decentralized tanks (e.g. roof)	b) Decentralized (to be defined)
c) Operator model: franchising	c) [DW + others] / WW	c) [Private + sewer] / WWTP	c) Intake / [treatm + distr + private]	c) 3 together, 1 of others individually	c) Uster	c) Constant budget, x% self-financed	c) Rehabilitation basis = prioritization	c) Renovate		c) Minimal	c) Little (to be defined)	c) Decentralized	c) Infiltration	c) Water for cleaning & garden	c) Supermarket (bottles)	c) Combinations
d) Operator model: contracting	d) [WW + others] / DW	d) [Private + sewer + WWTP]	d) [Intake + treatm + distr] / private	d) All 4 together	d) Maur	d) Progress. (x% annual increase)	d) Measures only upon urgent need	d) Do nothing		d) Do nothing	d) None at all	e) Semi-(de-)centralized	d) Combinations	d) Water for fire fighting	d) Delivery service (tanks or bottles)	d) None at all
e) IKA = inter-communal agency	e) [DW + WW + others]		e) [Intake + treatm] / [distr + private]	e) Parts of communities with a) – e)	e) Whole Greifensee area including Pfäffikersee		e) Do nothing					f) Combinations		e) Water for emergency supply	e) Decentralized ponds	
f) Corporation			e) [Intake + treatm + distr + private]		f) Whole Gr.see excl. Pfäffikersee										f) Household delivery from community	
g) Households					g) City of Zürich										g) Combinations	
					h) Region Zürich Oberland											

[a] Interpretation for B, C, and D: as an example, [DW + WW] / others means that the drinking water and wastewater infrastructures are managed together by one entity, while other infrastructures (e.g. electricity, gas supply, telecommunication) are separately operated by another entity.

[b] Here, "private" mean the house drainage sewer pipes on private ground.

[c] Here, "private" means household connections for water supply on private ground; "intake" means retrieving water from a source; "treatm" refers to the drinking water treatment; "distr" refers to the distribution and storage of drinking water.

4.2 Results: strategic decision alternatives

The specifications of each factor for each of the ten decision alternatives that were created in the stakeholder workshop are summarized in Table 8. The alternatives were then processed by the research project team to ensure internal consistency. Moreover, to better describe alternatives, we created following additional factors: water source, water treatment, operations, technical planning, administration and support, leadership, strategy, and partnership and resources. Some factors were necessary to predict the objective "high quality of management and operations", for which we used the attribute "% score of the EFQM model" ("The EFQM Excellence Model is the most popular quality tool in Europe, used by more than 30,000 organizations to improve performance"; EFQM 2013). The more-detailed description developed by the project team, is given in Table 9. In the following we give the narratives for each strategic decision alternative, based on the workshop results. Note that the alternatives were created having a certain future scenario for the year 2050 in mind but that they will be evaluated in the MCDA for their performance under all four future scenarios. Following a recommendation of Gregory et al. (2012a) we re-named the alternatives so that their names are better understandable also to those that did not participate in the workshop.

Alternatives for scenario A, "Boom"

A1a) Centralized, privatization, high environmental protection

All network infrastructures are combined together (water, wastewater, gas, roads, telecommunication, and electricity) and managed by one private single entity that charges fixed fees for its services. Whereas sophisticated contracting is necessary, conflicts of interest arise between the municipalities, the wider public, and the contractor. Maintenance is mostly asset-related. New buildings are mainly equipped by green rooftops for stormwater retention.

A1b) Centralized, IKA

Differs from variant 1a) only in the fact that an intercommunal agency (IKA, "Interkommunale Anstalt") manages the infrastructure, not a contractor.

A2) Centralized, IKA

Although combined, the wastewater, drinking water, and gas infrastructure services remain in the public domain, but private sector principles rule their management. Their maintenance is asset-related and pipe or sewer laying is done in the most economic manner. No dedicated retention of stormwater is foreseen.

A3) Fully decentralized

The water infrastructures are as decentralized and as much reliant on the consumers as possible. The responsibility for the water and wastewater service is privately owned so that the centralized infrastructure is minimal. Storm water is collected, reused, and infiltrated where possible.

Alternatives for scenario B, "Doom"

A4) Decaying infrastructure; decentralized outskirts

Water infrastructures are still centralized, but local sector combinations exist. Outside current residential areas, the communities have transferred the responsibility for sewerage and storm water management to the private consumer. The currently existing wastewater system is still publicly operated, while newly developed areas are not served by a well-designed buried sewer system. Instead, stormwater from these areas is simply drained on the surface of roads and via trenches and sanitary wastewater is treated in septic tanks. The existing central WWTPs decay and provide only mechanical treatment. The quality of the piped water supply is not apt for drinking (no treatment). Consumers buy their water for food in the supermarkets or have their own household treatment. No real budget is available. Whenever funding is available, it is allocated in the most sensible way. Consequently, maintenance and inspections are only performed based on importance classification of the pipes and sewers. Rehabilitation only takes place if at least 100 consumers are affected, otherwise only repairs will be done.

A5) Decaying infrastructure everywhere

Most infrastructure services as well as their funding are in the responsibility of the customers. In general, no public funding is available anymore for the maintenance of the distribution, collection, and treatment systems. Therefore, wastewater is technically managed as in A4. However, sludge from septic tanks is collected privately. There is no centralized water supply, and no more pipes are being built. Consumers are accountable for their own water supply and operate tanks which are intermittently recharged. Water is delivered to the households by a private delivery service and treated in house (e.g. with activated carbon). The municipalities – or parts of them – are partially combined. Operational and maintenance efforts are considerable where affordable, but then again no inspection and surveillance are done.

Alternatives for scenario C, "Quality of life"

A6) Maximal collaboration, centralized

One of the main ideas behind this alternative is to increase the decentralized use of rain water in the households and provide considerable retention volume under intensive rainfalls. Despite this, centralized drinking water supply and drainage remain. Only about 10% of the drinking water (mainly surface water from the lake) is treated. The service provider of the four case study communities and Oetwil am See is a cooperative that combines the water and wastewater services with telecommunication, electricity, gas, and road services. A 100% self-financed constant budget is available for the realization of rehabilitation measures according to the condition of the infrastructure. Efforts for operation and maintenance, as well as inspection intervals are neither low nor high.

A7) Mixed responsibility, fully decentralized with onsite treatment

Public water supply and wastewater services are combined within one cooperative for all four case study communities. However, treatment facilities on private grounds (households, industry) are within the responsibility of the owner. A central wastewater treatment plant and centralized storm water sewers are operated by the cooperative, but no sanitary wastewater sewers will be constructed in new development areas. Stormwater is retained extensively as in A6. The water infrastructure is mostly decentralized, with on-site drinking water treatment and wastewater treatment with urine source separation for nutrient recovery. This fertilizer finds its use in local agriculture. The water demand within households is strongly reduced thanks to modern vacuum toilets. The concentration of wastewater is thus high. Water within the households is reused as far as possible (especially rain water) and is only delivered (with tank trucks) by the municipality upon special demand or in longer dry periods. The firefighting policy is based on fire engines that withdraw firefighting water from central water storage ponds. All residues (e.g. sludge) from on-site treatment installations are transported by truck to central treatment and disposal facilities. Rehabilitation of the infrastructure is 100% self-financed and prioritization is according to condition. Operation and inspection efforts are medium, as in alternative 7. The infrastructure organization, structure, and management in the surrounding urban areas are comparable.

Alternatives for scenario "Status Quo"

A8a–e) Status quo with storm water retention (drinking water only A8a–b)

While the communities remain responsible for a single, integrated wastewater and drinking water sector, some services are contracted out to private enterprises. The water infrastructures of Egg, Gossau, Grüningen, and Mönchaltorf are jointly operated and maintained. Funding is flexible owing to a mix of 50% leverage and 50% self-finance. The quality of construction and maintenance is high and regular inspections lead to a good comprehension of the underground infrastructure. The standards and legal requirements are respected, and the STORM guideline (VSA 2007b) is widely implemented. To prioritize the development of the wastewater system, the Swiss water protection law (article 7, Abs. 2, GSchG) is interpreted as follows: first, infiltration of storm water, second, separate sewer system (storm water is discharged to surface water bodies, if possible following retention or treatment) and third, combined sewer system. While the capacity of the sewer network remains the same as today (2011), optimization in wastewater treatment leads to higher quality of the treated wastewater. Water for food, hygiene, cleaning, and firefighting is distributed through a pipe network from a central treatment facility, as today. Several variants of this alternative were later elaborated comprising decentralized as well as centralized treatment options at different locations and scales of the wastewater system.

A9) Centralized, privatization, minimal maintenance

This alternative reflects how the stakeholders believe that an unfavorable development under current conditions could look like. It differs from alternative 8 (status quo) mainly with regard to organization, finance, and maintenance while the legal framework and technical wastewater and drinking systems are roughly the same. Due to privatization, consumers can choose their water service provider (e.g. water from a supermarket provider; in general all providers seek for revenue-maximization). Funding is 100% leverage-based and despite rising fees, no financial sustainability is obtained. This is partly due to the fact that rehabilitation measures are only undertaken when urgently needed. The efforts for operation, maintenance, and inspection of the water infrastructure network are also minimal. The horizontal (sectoral) as well as vertical (no merging of communities) fragmentation of 2011 remain (see Lienert et al. 2013).

Table 8. Alternatives composition matrix. Factor specifications of the ten (nine and two variants of alternative 1) strategic decision alternatives that were created in the stakeholder workshop. Columns represent factors, rows the chosen factor specifications. Each number (1–9) represents one alternative. Shaded fields indicate factors that were specified beforehand (as in Tab. 7); fields with numbers but without shading indicate that a new specification was created by the workshop participants for the respective alternative. Empty shaded fields were not chosen. Fields with blue shading indicate factor specifications that were removed by the participants. Reading example: Alternative A4 ("Decaying infrastructure; decentralized outskirts") consists of the factor specifications: A a) [or b) or g)], B a), C b), D g), E e), F i), G e), H d), I b), J a), K c), L c), M e), N c), O b [or c)], P g), Q d). DW = drinking water, WW = wastewater.

	A Form organization	B Cooperat. sector	C Respons. WW	D Respons. DW	E Coop. communities	F Cooperat. others	G Funding	H Rehab. strategy	I Rehab. measures	J Pipe / sewer laying	K Operation, maint.	L Inspection	M Drainage syst.	N Storm water	O Purpose use	P Distribution syst.	Q Water treatment
a)	4, 8	3, 4, 7, 9	9	9	(3), 9	2, 3 8, 9	2, 6 7		5, 6	4, 5, 6, 7, 9	1, 5				1,2,5,6, 7, 8, 9	1, 2, 6, 8, 9	1, 2, 3, 6, 8, 9
b)	4, 6, 7	5, 8	4, 5, 6				9	2, 6	1, 2, 3, 4, 6, 9	8	2, 6, 7, 8	1, 2, 6, 7, 8	1, 2, 6, 7, 8, 9	6, 7	3, 4, 5, 6	3, 5, 7	5, 7
c)			7				8	1, 7, 8	7, 8	1, 2	3, 4, 9	3, 4, 9	3, 7	4, 5, 8, 9	4, 5	3	
d)	1a, 9		1, 2, 8	6	1, 2, 6, 7, 8			3, 4, 5, 9				5	5	1, 2, 3, 5		3, 5	4, 6
e)	1b, 2	1, 2, 6	3		4, 5		1, 3, 4, 5						4			3	
f)				1, 2, 7, 8													
g)	3, 4, 5, 7, 9			4, 5												4	
h)						1											
i)						4, 5, 6, 7											

Table 9. Definition of strategic decision alternatives. Overview of nine strategic decision alternatives (and some variants) for water supply and wastewater infrastructures in the study region Mönchaltorfer Aa. The alternatives were initially developed in a stakeholder workshop and thereafter processed by the research project team to ensure internal consistency. For simplicity, we grouped the 17 factors (Tables 7, 8) and provide a general description together for: organizational structure, sector cooperation, and management (factors A–G), rehabilitation strategies, operation and maintenance (factors H–L), and wastewater and water supply system technology (factors M–Q). WW = wastewater, WWTP = wastewater treatment plant.

No.	Alternative name	Organizational structure, sector cooperation, management	Rehabilitation strategies, operation, and maintenance	Wastewater and water supply system technology
A1a	Centralized, privatization, high environmental protection	One private organization manages all sectors [(a)] and all communities [(b)] together (also with entire region Zürich Oberland). Equal partnership with contractor who charges fixed fees. Performance-based leadership that achieves promised service levels at minimal costs.	Rehabilitation is done according to prioritization [(c)]. Decisions about measures (replace, repair) are related to asset. The extensive operation and maintenance is comfortably performed through underground service galleries, but inspection is only average.	The water supply and wastewater system are fully centralized. Large amounts of water are supplied in drinking water quality, and can also be used for firefighting. There is a fourth treatment step at the WWTP to remove micropollutants. New development areas outside existing building zones are drained by separate systems. New houses are equipped with green rooftops for retention of stormwater.
A1b	Centralized, IKA	Differs from A1a only in the fact that an intercommunal agency (IKA) manages the infrastructure, not a contractor. Technocrat leadership (very experienced and qualified, but rather rigid) with focus on maximizing performance.	As A1a	As A1a
A2	Centralized, IKA, rain stored	As A1b, but constant budget, 100% self-financed.	Rehabilitation is done according to condition [(d)]. The decision about measures (replace, repair) is related to asset, and the most economical pipe laying technique is used. Their operation, maintenance, and inspection are only moderate.	The water supply and wastewater system are fully centralized, as A1a. However, water for firefighting is only partially supplied through the network, and is gained as far as possible from rain water, which is retained in underground firefighting tanks. No dedicated retention of stormwater is foreseen.
A3	Fully decentralized	All sectors [(a)] and communities [(b)] work separately. Main responsibility, also concerning funding, is with the consumers (households), who are well-informed. The services are contracted to external organizations that have a long-term relationship with their customers.	Only repairs, but no rehabilitation is undertaken, and only upon urgent need for action. Operation and maintenance are moderate, while there is little inspection.	The water infrastructures are as decentralized as possible, only minimal centralized infrastructure. Storm water is collected in households, decentrally treated and reused for household water and firefighting. Drinking water is bought in the supermarket. Gray water is treated locally and fed into water supply tank, rest is treated centrally. Excess storm water is wherever possible infiltrated.
A4	Decaying infrastructure; decentralized outskirts	Water infrastructures are managed by a mix of communities, cooperatives, and households, and separate from other sectors [(a)]. Outside the core residential areas (area of 2010), the communities have transferred the responsibilities to private consumers, who are also responsible for funding. Specialized services are contracted to external companies. Administrator leadership with focus on maintaining the status quo.	As A3, but operation and maintenance is even worse, i.e. minimal.	The infrastructures are decaying. In the core residential areas (as 2010), water is centrally supplied, but it is not drinking water quality. Households have own POU [(e)] systems to reach drinking water quality, or buy water in the supermarket. The existing wastewater system is publicly operated. In new urban areas, no pipe system is built. Instead storm water is infiltrated, or simply drained via roads and trenches and sanitary wastewater is decentrally treated with cheap technologies, e.g. septic tanks and a municipal collection service. Household water in the outskirts is supplied by municipal trucks once a week.

No.	Alternative name	Organizational structure, sector cooperation, management	Rehabilitation strategies, operation, and maintenance	Wastewater and water supply system technology
A5	Decaying infrastructure everywhere	Most infrastructure services as well as their funding are in the responsibility of the customers (households), who are well-informed. The services are contracted to external organizations that have a long-term relationship with their customers.	Measures are only undertaken upon urgent need for action; the replacement is in trench. Operation and maintenance are minimal (as A4), and inspection is even worse, namely none at all.	As in outskirts of A4: No centralized water supply, and no more pipes are built. The consumers operate tanks for drinking water that are recharged by private delivery service, and treat the water in house. Household water is delivered by municipal trucks. Wastewater is technically managed as in A4. However, sludge from septic tanks is collected privately.
A6	Maximal collaboration, centralized	There is maximal cooperation; the case study communities [(b)] and Oetwil am See are organized in a cooperative. This service provider combines water and wastewater services with telecommunication, electricity, gas, and road services [(a)]. The constant budget is 100% self-financed. Management focuses on minimizing costs and maximizing performance, with strong personal motivation.	Rehabilitation is done according to condition [(d)]. Repair and replacement are done in trench. Their operation, maintenance, and inspection are only moderate.	The water supply and wastewater system are fully centralized, as in A1a, but with a much stronger focus on retention of storm water. Water is supplied in drinking water quality, also for household use. Water for firefighting is only partially supplied; further volumes are stored in underground tanks. There is a fourth treatment step at the WWTP to remove micropollutants. Separate systems and large stormwater retention volumes are installed in new development areas.
A7	Mixed responsibility, fully decentralized with onsite treatment	Public water supply and wastewater services are combined within one cooperative for all four case study communities [(b)], but there is no collaboration between different infrastructure services [(a)]. Treatment facilities on private grounds (households, industry) are within the responsibility of the owner. Management and funding as A6, but additionally well-informed households.	Rehabilitation is done according to prioritization [(c)]. Renovation is done in trench. Their operation, maintenance, and inspection are only moderate (as A6).	The system is nearly fully decentralized. Rainwater is reused in households as far as possible and treated at POE [(f)]. Additional water will only be delivered with trucks by municipality upon special demand or in longer dry periods. Water for firefighting is stored in shared community tanks (eggs). Wastewater is treated on-site, including urine source separation and nutrient recovery, with re-use as fertilizer in local agriculture. The remaining wastewater is drained into the stormwater sewers. As in A6, large stormwater retention volumes will be installed in new development areas.
A8a	Status quo with storm water retention	The communities [(b)] remain responsible for a single, integrated wastewater and drinking water sector that jointly operate the water infrastructures, with some services contracted out to private enterprises. Funding is flexible owing to a mix of 50% leverage and 50% self-finance. Administrator leadership with focus on maintaining status quo.	Rehabilitation is done according to prioritization [(c)]. Renovation is trenchless. Their operation, maintenance, and inspection is only moderate (as A6).	The water supply and wastewater system are fully centralized. Drinking water is centrally supplied in large amounts, and can also be used for firefighting. Stormwater is infiltrated as much as possible. Treatment of wastewater in the central WWTP as today.
A8b–A8f	Status quo technical variants	Organization of all variants as A8a.	As A8a, except A8f where more demanding hydraulic design criteria are applied.	The status quo is modeled with different technical variants of the current water supply and wastewater disposal system. For example, there are separate or combined sewer systems; the system is extended or additional WWTP plants are built (A8b); decentral wastewater treatment with flush toilets (A8c); only one central WWTP for the whole region at different locations (A8d, A8e); water for firefighting is centrally distributed with drinking water, but newly developed housing areas have different dimensioned fire-flows (self-cleaning networks; A8b–A8f).

No.	Alternative name	Organizational structure, sector cooperation, management	Rehabilitation strategies, operation, and maintenance	Wastewater and water supply system technology
A9	Centralized, privatization, minimal maintenance	The water infrastructures are fully privatized, and all sectors work separately [(a)]. Private consumers choose their contracting provider; in general all providers seek for revenue-maximization. The constant budget is 0% self-financed (100% leverage). The well-informed households choose contractors, who have a long-term relationship with their customers.	Measures are only undertaken upon urgent need for action; only repair is done, and in trench. Operation and maintenance are minimal, with little inspection (as A4).	The water supply and wastewater system are fully centralized, as in A8a. Drinking water is centrally supplied in large amounts, but water for firefighting is only partially supplied. Further volumes are stored in underground tanks. Stormwater is infiltrated as much as possible. Treatment of wastewater in the central WWTP as today.

[a] With all sectors we mean transportation, gas supply, energy supply, district heating, telecommunication, as well as water supply and wastewater disposal.
[b] The four communities are: Mönchaltorf, Gossau, Grüningen, Egg.
[c] x % of pipes in priority class y.
[d] x % of pipes in condition y.
[e] POU = Point of use treatment in the households to achieve drinking water quality; can be done e.g. on the tabletop or under the sink.
[f] POE = Point of entry; e.g. water is treated where it enters the household water cycle at the entry point from a centralized water system or after a water storage tank.

5. Stakeholder feedback and recommendations

In all the first steps of Structured Decision Making (SDM, Gregory et al. 2012a) as developed in the SWIP project and described above, we asked the stakeholders (interview partners or workshop participants) for feedback. We present details of this feedback in Table 10 below. We then summarize the advantages and disadvantages of the proposed approach, based on the stakeholder feedback. Finally, we give some recommendations for application the SWIP approach for Structured Decision Making in other settings and applications.

Table 10. Stakeholder Feedback. Overview of the Steps of the SDM process (Structured Decision Making), the types of stakeholder involvement and their feedback, the advantages and disadvantages of the adopted approach and recommendations for other applications. SH = stakeholders, WS = water supply, DW = drinking water, WW = wastewater, WWTP = wastewater treatment plant, CSOs = combined sewer overflows.

Step	Description of process	SH involvement	SH feedback	Advantages	Disadvantages	Recommendations
1	**Clarify decision context**					
1.1	**Case study selection and delimitation of system boundaries**					
	Intensive discussions to choose good case study; criteria: (a) good data ; (b) high pressure; (c) high motivation; (d) collaboration. Detailed evaluation of four case studies. Choice of "Mönchaltorfer Aa", mainly because of very high demand for collaboration in NRP-61 (www.nfp61.ch). Lack of strong pressure was later serious drawback: necessity to convince SH to participate.	Phone, Email, meetings in case study area. Clear definition of required data, time/ type of involvement (workshops, interviews, questionnaires).	Resistance of some communities to participate. Enablers: participation of other communities, acceptance by local politicians, national research programme, good name of Eawag among engineers, support by engineering consultant. Worries about time demands, type of involvement.	Lengthy procedure resulted in good case-study knowledge and later high willingness of SH to collaborate. Main advantage for research: sharing data with other projects in NRP-61 (agriculture, spatial planning of future scenarios, water quality).	Selection of case study clearly driven by request to collaborate and exchange data. Problematic for MCDA, since local SH did not see need to change a system that is functioning well.	Choose a real problem! i.e. SH need solution. Clearly define interactions (type, number, length). Strong personal commitment of research team (e.g. organize attractive meetings). Look for support by important SH as mediators.
1.2	**SH selection; clarify decision problem with SH**					
	Details in Lienert et al. (2013). First stratified sampling: local, cantonal, national level (vertical axis), sectors (e.g. engineering, administration & politics; horizontal axis), all communities, WS & WW sector. Second snowball sampling in 27 SH interviews. Detailed feedback: who plays role in infrastructure planning, who is affected, interests, interactions. Based on SH and network analysis: invitation to workshops; selection of 2 x 10 SH (WS/ WW) for MCDA preference elicitation interviews. Feedback questions at end of interview (see 1.2.a – 1.2.e below).	Face-to-face interviews with 27 SH.		Detailed SH and network analysis to select interview partners presumably only possible in research project. Advantage: high confidence about very good representation of different interests. In-depth knowledge about perspectives, current and future problems, interests, interactions, power relationships etc.	Very time-consuming procedure; hardly feasible in real implementation projects with limited resources. Not possible to cover representative population sample with face-to-face interviews.	In most real applications, it might suffice to select SH with short questionnaire (Email, phone call, internet survey). Important questions: Who is involved in decision? Who is important to make decision on scale of 1 – 10? Who is affected once decision is made on scale of 1 – 10? What are their main interests? Who might have very different perspective?

Step	Description of process	SH involvement	SH feedback	Advantages	Disadvantages	Recommendations
1.2.a What is next step (by whom)?						
	First feedback question in First interview: what would be next step and who should do it? We categorized answers and state how often comments belonging to each category were made (in parentheses).	Face-to-face interviews with 27 SH.	Eawag must do next step (mentioned 6x); include uncertainty in planning (6x); Eawag should show current state/ deficits (4x); increase professionalism of engineers (4x); performance of new alternatives (3x); guidance w.r.t. economic constraints (3x); planning tool (3x); strategy development (by authorities, professional organizations; 2x); support in planning/ enforcement of legislation (by canton; 2x). Mentioned 1x: training course at Eawag; better linked networks; information exchange between communities; end-users interests. Ten of 27 respondents: no spontaneous idea.	Clarification of expectation of SH: strong pressure on Eawag to do next step and concrete expectations about guidance in infrastructure planning, including e.g. planning tool. To a lesser extent: support in strategic planning and enforcement of legislation by authorities and organizations of water professionals.	SH expect outcomes that surpass results of scientific project; may lead to disappointment if expectations are not satisfied. As example, SWIP will not produce easy-to-use decision or planning tool as part of NRP-61 project; any such results will have to be pushed by project leaders at Eawag after termination of PhD-projects.	Ask SH at early stage about expectations. To avoid disappointment, clearly communicate type of results and which expectations can or cannot be satisfied (and why). We produced information material specifically for communities and as preparation for interviews or workshops (see below).
1.2.b Expectations concerning Eawag?						
	To clarify question 1.2.a, we then asked specifically for expectations, fears or hopes w.r.t. our project and Eawag. We categorized answers and state how often comments belonging to each category were made (in parentheses).	Face-to-face interviews with 27 SH.	Eawag should generalize results, produce information material, guidelines, rationale to motivate communities to carry out strategic planning (9x); analysis of current situation (5x), basis for discussion in communities (4x); estimates about future of infrastructures (3x), networking (3x); decision tool (4x); analysis of non-conventional alternatives (1x); effects of micropollutants (1x); discuss results with authorities and national politicians (1x).	As above: ask about expectations of SH; e.g. with follow-up question to 1.2.a, as 1.2.b here.	As above: risk of disappointing SH.	As above: ask questions, ideally in different ways (1.2.a and 1.2.b); try to avoid disappointment and exaggerated expectations by clearly communicating expected results.
1.2.c General feedback first interview: positive aspects						
	Last question of first interview series: general feedback, separately for positive/ negative aspects/ recommendations. We categorized answers and state how often comments belonging to each category were made (in parentheses). Here: positive aspects	Face-to-face interviews with 27 SH.	Interview very agreeable/ good (13x); interview clear, well structured, well conducted, good questions (9x); no pos. feedback (8x); interesting/ important topic (5x); interview stimulated holistic thinking (4x); my view well acknowledged (2x); good science	Clearly structure interview, carry it out in agreeable and respectful way.	Possible disadvantage of strongly structured interview is restriction to specific questions, but this was not the case here since it was not criticized (see 1.2.d below) and interview even stimulated holistic thinking.	Well prepare interview with clearly structured guideline, but leave room for creativity. Treat respondents with respect, acknowledge their input, expertise and time (this should go without saying).

Step	Description of process	SH involvement	SH feedback	Advantages	Disadvantages	Recommendations
			(1x); project carried out well (1x).			
	1.2.d General feedback first interview: negative aspects					
	As above: general feedback, negative aspects	Face-to-face interviews with 27 SH.	No neg. comment (12x); not right expert (4x); interview cognitively very demanding (4x); too long (3x); focus not clear/ too local (3x); topic too abstract (climate change/ popul. growth not relevant) (2x); questions not understandable for practitioners (complicated/ technical or scientific terms) (2x); discussion "ridiculous" (1x); fear of criticism of cantonal authorities (1x).	Give room for negative feedback to better understand answers, improve further interactions and detect sensitive areas. Problem about long and cognitively demanding interview can only be changed by reducing number and type of questions; must be decided within respective project.	Negative feedback may "hurt". Too late to change length of interview or type of questions to reduce cognitive effort at end of interviews.	Give room for negative feedback. Think strongly about language/ specific formulations to make questions understandable, avoid technical or scientific terms. Consider trade-off between length of interview and required input. Suggestion: general questions to all respondents; tailor sub-set to specific respondent to reduce time demand and cognitive effort.
1.2.e	**General feedback first interview: recommendations**					
	As above: general feedback, recommendations	Face-to-face interviews with 27 SH.	No recommendations (9x); interview other SH (5x); interest in results (7x); reduce time: strict guidance/ reduce questions (2x); reduce cognitive effort: simpler formulation/ reduce technical or scientific terms (2x). Mentioned 1x: send questions before; make questions more concrete; be respectful; keep survey anonymous; consider as many aspects as possible; analyze data neutrally; "just go and ask".	Recommendations are already reflected in positive and negative feedback above. Answers from SH show that they come to similar conclusions as those drawn by ourselves, based on their feedback.	See above	See above
2	**Define objectives and attributes**					
2.1	**Determine and discuss objective one-on-one with SH**					
	Preliminary objectives hierarchy set up by project team, based on engineering requirements for WS and WW system; additionally including "intergenerational equity", "high social acceptance" and "low costs". As first interviews (see above), SH freely stated which objectives they need to compare alternatives. We then showed and discussed our objectives. Interviewee classified objectives into essential/ important/ nice to have. We asked for attributes (details see Methods, Lienert et al. 2014).	Face-to-face interviews with 27 SH.	Very detailed feedback concerning objectives, not presented here for reasons of space. No feedback concerning method.	Asking each SH alone and as first open question about objectives avoids priming effect and allows collecting their ideas, not ours. By presenting and discussing our proposal: consolidation possible if they agreed that their objectives were covered in our hierarchy. Further reduction by classification in "essential" objectives (I really need these).	Face-to-face interviews is very lengthy procedure (for many SH). Risk of long list of objectives, important to only one or few SH. Problem of how to reduce list if goal is concise objectives hierarchy that covers only most fundamental aspects. SH are not aware of methodological requirements of objectives hierarchies.	Trade-offs: avoid priming/ include many perspectives/ create short list of objectives. Alternatively: create objectives in SH workshop (chance of "group opinion"; see below). To reduce objectives, directly present hierarchy; collect feedback w. closed questions (e.g: "do you agree"?). Process objectives thereafter to generate hierarchy applicable for all SH that meets method requirements (e.g. no redundancy).

Step	Description of process	SH involvement	SH feedback	Advantages	Disadvantages	Recommendations
2.2	**Discuss objectives hierarchy in second SH workshop**					
	In second SH workshop, we presented large objectives hierarchy with all "essential" objectives from interviews (see 2.1) and requirements for good objectives. Participants systematically worked through hierarchy with neighbor; discussion which objectives are really needed or missing. We collected notes and discussed objectives in plenum. Each participant designated with points three least relevant objectives. Presentation of our project, ourselves and especially MCDA approach (see 3.1 below).	Workshop with 20 SH (identified with SH analysis, see 1.2 above).	Feedback concerning objectives see Section 2.3 "Discussion of objectives in workshop" above. Feedback concerning workshop see 3.1 below.	Ideally, workshop allows creating concise hierarchy that reflects all opinions. Group process should allow better understanding of other SH (see e.g. Gregory et al. 2012a). It should also be possible to agree on small number of really fundamental objectives that cover all important aspects.	No deletion of objectives: no shared opinion w.r.t. superfluous objectives. "High social acceptance" and "intergenerational equity" most strongly questioned, but no clear justification for exclusion (plenary discussion/ points; see Section 2.3 above); they are also fundamental for sustainability. Project team further processed hierarchy until it was complete, but as concise as possible (see Lienert et al. 2014). Risk of missing fundamental objectives (early consensus).	Face-to-face discussion with neighbor gives voice to shy participants in workshop/ increases understanding. Plenary discussions show breadth of opinions; ideally followed by process of focusing on fundamental objectives. If not, consensus can be "forced" with moderation methods, e.g. assigning points. But excluding objectives can be problematic; as in our case. Workshop bears risk of losing control: good preparation/ moderation/ "emergency plans". Risk of missing out fundamental objectives ("groupthink" heuristic).
2.3	**Feedback to objectives and attributes during second interview series (preference elicitation)**					
	We carried out face-to-face interviews with selected SH in 2013 (see 1.2 above) to elicit their preferences for MCDA. Elicitation of: scaling constants (weights), single-attribute value functions, aggregation scheme, risk attitude. These interviews are not part of work presented here; but we give short overview of feedback concerning objectives and attributes, alternatives and MCDA procedure (for alternatives, see 3.2 below).	Three sets of face-to-face interviews (including reading information material and filling out online questionnaire before interview) with ten SH in each set. SH identified with SH analysis (see 1.2 above).	Understandability Difficulty to understand: some objectives (e.g. "good chemico-physical quality" of DW)/ highly uncertain attributes (e.g. "few gastrointestinal infections")/ attributes w. complex models (e.g. "good chemical state of watercourse": 1. classify pollutants, 2. mathematically aggregate each reference point in catchment, 3. spatially aggregate). Missing or irrelevant objectives e.g. "technology readiness"; "high redundancy of WS"; replace "good chemical state" & "low neg. hydraulic impacts" w. "good eco-morphological state". Attribute ranges (see Table 4) Some doubts; e.g. 100% co-determination of end-users (is not desirable); worst cases for Switzerland of "high reliability of drainage	Understandability Wherever possible, we used attributes common in the field (e.g. chemical state of water). Hence, they are backed by natural-scientific evidence/ we can rely on real numbers (expert estimates or models). Missing or irrelevant objectives Irrelevant objectives can easily be dealt with by giving zero weight. Ranges Where possible, we defined attributes/ ranges to be applicable to other case studies/ to "Boom" or "Doom" scenario. Preferential independence If this requirement holds, the simple linear additive model can be used. Minimum criteria	Understandability Relatively technical or natural-scientific attributes are not necessarily easy to understand for non-experts. Missing or irrelevant objectives Missing objectives cannot be added at later stage of MCDA (respective SH has to accept this). Follow-up option: evaluate sensitivity of best-performing alternatives of MCDA w.r.t. missing objective. Ranges Attribute levels of broad ranges might seem unrealistic. Can make preference elicitation more difficult and affects weights if ranges are not adequately considered. Preferential independence If this requirement does not hold,	Understandability Elicit single-attribute value functions for technical/ natural-scientific attributes from experts (e.g. "good chemical state"). Use expert value functions for other SH/ elicit only scaling constants (weights). Missing or irrelevant objectives Create objectives hierarchy carefully/ with intensive SH interaction (as our example). If SH doubts result because of missing objective, carry out rough estimate of sensitivity of best-performing alternatives to this objective. Exclude irrelevant objectives with zero weight. Ranges Define attributes to be generalizable, allowing for up- or down-scaling in other cases; e.g. use relative, not absolute numbers ("number of pipe failures/ yr/ 1,000 inhabitants" instead

Step	Description of process	SH involvement	SH feedback	Advantages	Disadvantages	Recommendations
			system"; "good chemical state of watercourse" (unrealistic); worst case of 60 CSOs ("few gastro-intestinal infections"; too optimistic). Preferential independence Some objectives not preferentially independent for all SH, e.g. "low future rehabilitation burden" & "exfiltration from sewers"/ "intergenerational equity" & "low costs"/ "high reliability of WS" & "good quality of DW". Minimum criteria In seven of ten WS interviews: alternatives not fulfilling minimal water quality standards are not acceptable. e.g. "microbial and hygienic quality" of DW. For WW, few SH regard current laws as minimal standards/ or as optimal level.	Minimal requirements can easily be implemented in MCDA, i.e. with MAVT/ MAUT by aggregating values from lower to higher levels of objectives hierarchy such that higher-level value is never better than worst value achieved for lower-level objective. Or exclude all alternatives that do not fulfill minimum requirement	more complex aggregation models (e.g. multiplicative) are needed (elicit additional scaling constant!). Minimum criteria Disadvantage of minimal requirements: all alternatives that do not fulfill requirements are excluded or receive equal overall values/ utilities (but alternative that performs better regarding other objectives should probably receive higher values).	of "number of pipe failures"). To make relative numbers tangible, present absolute numbers for case study (see "status quo"; Table 4). If SH think ranges are unrealistic, use example of countries w. lower infrastructure standards. During elicitation, point out ranges repeatedly to avoid "range effect" bias. Preferential independence Construct objectives hierarchy to fulfill this, but check validity in interview (e.g. "do preferences about one attribute depend on level of another?"). Minimum criteria Discuss implication of minimal requirements (see disadvantages) with SH.
	Develop future scenarios					
	First SH workshop					
	Scenario planning not included in standard MCDA. Aim: capture future uncertainty w.r.t. socio-economic development with snap-shot images. We invited 22 community members, excluding high-rank officers to create good workshop feeling. 15 SH participated (all four communities, both water sectors, different roles). We first presented ourselves and SWIP. Scenarios set in year 2050, discussed/ adapted to local case in three groups (equal distribution of perspectives). We used four Swiss scenarios from Swiss National Research Programme (NRP 54; www.nfp54.ch) as framework. Specification to local case based on variation of eight factors, relevant for water infrastructures. Scenarios visualized, pre-sented, discussed in plenum (see Lienert et al. 2014 and Section 3 "Future scenarios"	Workshop with 15 local SH (identified with SH analysis, see 1.2 above).	Summary "what would I be happy about": • know other participants, team-building • know region, networks for communities • identification with project • concrete results/ tool for cost-benefit calculations • better understand objectives and output • deal with unpredictable future scenarios • should be exciting Summary of "learning effect": • good discussion, excellent group work • fruitful/ creative method	We used first workshop to introduce SWIP project; good opportunity to get local participants "on board". Positive (less intimidating) to only include local SH. Scenario planning approach was clearly highly stimulating, very creative and lots of fun. It helped to create team-feeling; raise interest in project. Scenario planning invites thinking in broader terms about future in region, than what is usually done.	Thinking in extreme scenarios might create impression that we are not dealing with the real problems of SH. Scenario workshop needs to be very well prepared and moderated: convey that it is real science, despite being fun. Only limited participants in scenario workshop; else discussion is likely less productive.	Use workshops to introduce project and scientists. Construct groups to later profit from "group feeling"; e.g. concerning collaboration across communities. Whom to include or exclude? e.g. invite only local SH (as in our example)? Only limited number of participants in a workshop: how to select most important ones (e.g. SH analysis)? Very careful preparation and moderation, since things easily get out of control when "playing around". Decide about using framework (as we did), or creating scenarios from scratch.

Step	Description of process	SH involvement	SH feedback	Advantages	Disadvantages	Recommendations
	above). Feedback: "what would I be happy about?"/ "what learning effect did I have?"		• good to think about future • surprised about scenarios/ not realistic • necessary to consider extreme scenarios • challenge to deal with results in real world • good exchange/ collaboration with communities • lots of fun/ creative, now back to reality			
3	**Identify and create decision alternatives**					
3.1	**Second SH workshop to identify decision alternatives with help of a strategy generation table and the future scenarios**					
	First, we introduced project and MCDA approach, and discussed objectives (see 2.2 above). Creation of alternatives in second SH workshop. To stimulate creativity, we used 4 socio-economic scenarios as background (see above). We prepared "strategy generation table" (Howard 1988; Gregory et al. 2012b): 17 basic factors (organizational structure, geographic extent, financial strategy, construction & operation of infrastructure, WW and DW system technology). Each factor has a number of specifications; a decision alternative consists of plausible combinations, which were created in workshop. Twenty workshop participants split into four mixed groups, each assigned to a scenario. Each group created at least two strategic alternatives by choosing plausible specification for each factor (Table 7). Project team later processed and detailed the ten strategic decision alternatives from workshop.	Workshop with twenty SH (identified with SH analysis, see 1.2 above).	No systematic collection of written feed-back to this workshop; following is based on our own impression. We did ask SH to indicate on a poster-sized x-y-grid "how pleased are you with workshop?" (x-axis) and "how confident are you about SWIP project?" (y-axis; scale "very low" to "very high"). Ten of twenty participants gave feedback. High satisfaction with workshop (all above medium), but fairly low confidence in project: three points below medium and three exactly on medium line (others above).	Due to participation, SH understands methods; alternatives are relevant to SH; increases later acceptance of results; avoids overlooking issues obvious to local practitioners. Combining "strategy generation table" with scenarios is highly effective to avoid anchoring on status quo alternatives (Nutt 2004). e.g. generation of conventional central WS & WW treatment alternatives under "status quo"; "Boom" scenario triggered high-tech on-site solutions; "Doom" scenario cheap/ simple alternatives (see Section 4.2 "Results strategic decision alternatives" above). Characteristics of good alternatives: complete, comparable, value-focused (addressing what matters), fully specified, intern-ally coherent, distinct (e.g. Gregory et al. 2012a; Keeney and Raiffa 1976). This is well addressed by strategy generation table: SH are forced to rigorously	Clear disadvantage of strategy generation table: not very creative; not much fun; choosing specification for each factor is tedious work. We later had to commit considerable work to further specify alternatives and include new factors missing in first version of strategy generation table, but important to distinguish alternatives. Strategy generation table is rather time consuming. Duration of workshop was about six hours (three hrs. for objectives (see 2.2 above); three hrs. creating alternatives). SH were tired at end of day and strategy generation was done under time pressure. We think that negative feedback concerning "confidence about project" might have been caused by this fatigue, possibly combined with some doubts about MCDA approach, which seems somewhat difficult to understand.	To reduce feeling of boring work, we recommend creating storylines about strategic decision alternatives with SH in workshop. Carry out factor specifications later by project team w. strategy generation table. Combination ensures that SH are involved, i.e. that alternatives are adapted to local needs, make use of their knowledge and are later better accepted, but that they do not lose interest. Apart from "not much fun" aspect, we find strategy generation table a highly useful and systematic approach that ensures coverage of different aspects/ internal consistency. We recommend combining a rigorous approach (e.g. strategy generation table) with very creative approach (e.g. scenarios as background) to avoid anchoring effects and focus on status quo. Make sure to assign ample time. Because MCDA approach seems difficult to under-stand (general feedback that we receive again and again), we recommend to use every opportunity to present method; e.g. as introduction

Step	Description of process	SH involvement	SH feedback	Advantages	Disadvantages	Recommendations
				cover important elements; increases internal consistency (Tables 7, 8).		to workshop.
3.2	**Feedback to alternatives during second interview series (preference elicitation)**					
	We carried out face-to-face interviews with selected SH in 2013 (see 1.2 above) to elicit their preferences for MCDA. Elicitation of: scaling constants (weights), single-attribute value functions, aggregation scheme, risk attitude. These interviews are not part of work presented here; but we give short overview of feedback concerning the alternatives (for the objectives, attributes and general feedback, see 2.3 above).	Three sets of face-to-face interviews (including reading information material and filling out online questionnaire before interview) with ten SH in each set. SH identified with SH analysis (see 1.2 above).	Understandability of hypothetical alternatives One SH had difficulty to evaluate hypothetical alternatives that are very different today (feedback w.r.t. separate supply of DW/ water for household/ for firefighting). Some hypothetical alternatives are unrealistic, e.g. one SH found it impossible to imagine a system which realizes all rehabilitation demand but has very low reliability. Comparability of hypothetical alternatives Two SH found costs of WS (5% of average annual income) as totally unrealistic for Switzerland ("American circumstances"!), thus difficulty to answer trade-off questions for hypothetical alternatives using this attribute level. Trade-off questions difficult if they invoke moral conflicts, e.g. trade-offs between "few gastrointestinal infections through contact with WW" and "good chemical state of watercourse". Some trade-off questions ask respondents to choose between two unsatisfactory alternatives, which gives uncomfortable feeling. (Methodical issues, e.g. concerning elicitation with trade-off will be addressed in more detail in later papers).	Understandability of hypothetical alternatives To broaden range of decision alternatives also unconventional (but existing) solutions should be considered. In current Switzerland, decentralized, on-site solutions and solutions (e.g. addressing water scarcity) are rarely discussed, but may become more viable in the future (climate change) and are certainly under discussion in more arid regions (e.g. Australia).	Understandability of hypothetical alternatives We included uncommon, somewhat visionary decision alternatives, which seem difficult to assess for some SH. A remaining methodological problem is the construction of hypothetical alternatives that result in unrealistic combinations. Comparability of hypothetical alternatives It is problematic that we had to set the ranges so broadly (see 2.3 above), which results in having to compare hypothetical and extreme alternatives. Generally, trade-off questions seem difficult to answer, especially if they invoke moral conflicts and/ or leave the respondent feeling uneasy about his or her choice.	Understandability of hypothetical alternatives SH should be included in generating decision alternatives (see 3.1 above), to make more exotic decision alternatives better tangible. Comparability of hypothetical alternatives Reasons for working with extreme or unconventional alternatives and broad ranges must be explained as well as possible to SH. We wish the MCDA procedure to be well-applicable to other cases, and to hold under different future scenarios. However, problem remains that some methods force respondents to make morally difficult choices. We discuss this in later papers about elicitation methods. Current recommendation: choose elicitation methods that do not require extreme hypothetical alternatives/ not very difficult moral choices.

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