Interest and difficulties of a wastewater reuse strategy in operational situation

Intérêt et difficultés d'une stratégie de réutilisation des eaux usées en situation opérationnelle

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Summary

The constraints involved in supplying water to a military unit deployed in an operational theater take on a particular dimension in today's context of scarcity of natural water resources, and lead to the exploration of new technical solutions. In this field, the reuse of wastewater is experiencing renewed interest. However, wastewater is a resource which use for everyday purposes requires a complex hazard analysis work and the use of sophisticated technological processes. It is therefore important to give priority to those uses of treated wastewater for which the benefit (water savings) / risk ratio is optimal. For an army on operations, systematically replacing potable water with treated wastewater for toilet flushing would seem to be a first step. Other developments are possible, but require experimentation to better understand the risks involved, and the development of appropriate equipment.
Key words: Water, military operations, wastewater, reclaimed water

Résumé

Les contraintes de l'approvisionnement en eau d'un dispositif militaire déployé sur un théâtre opérationnel prennent une dimension particulière dans le contexte actuel de raréfaction des ressources naturelles en eau et conduisent à explorer de nouvelles solutions techniques. Dans ce domaine, la réutilisation des eaux usées connait un regain d'intérêt. Il s'agit cependant d'une ressource dont l'utilisation pour des usages de la vie courante implique une approche d'analyse des dangers complexe et le recours à des procédés technologiques sophistiqués. Il importe donc de privilégier les usages des eaux usées traitées pour lesquels le rapport bénéfice (économies d'eau) / risque est optimal. Pour une armée en opérations, le remplacement systématique des eaux potables par des eaux usées traitées pour l'alimentation des chasses d'eau paraît être une première étape. D'autres développements sont possibles mais requièrent la réalisation d'expérimentations, afin de mieux en appréhender les risques, et le développement de matériels adéquats.
Mots-clés : Eau, Opération militaire, eaux usées, eaux de récupération

Introduction

As part of a sustainable development approach aimed in particular at saving water, wastewater reuse is booming. Many countries, such as Australia, the United States, Israel and Japan, have for many years now turned to this practice, mainly for agricultural irrigation. Industrial and domestic uses are also being encouraged, in response to the seasonal or permanent water shortages experienced in many parts of the world.

For the armed forces, the reuse of wastewater is a subject of great interest, particularly in an operational context where water supply is a permanent challenge, mobilizing significant material and human resources. In some theaters of operation, natural water resources are scarce, and wastewater reuse appears to be an attractive option for limiting water withdrawals from the natural environment.

However, while wastewater reuse may appear to be a relevant approach in terms of water savings, it is important not to consider this issue in a simplistic way, and to become aware of the importance of the technical challenge and the associated risks for personnel, in order to define an appropriate strategy in this field, reconciling the requirements of the operational context and health safety.

1/ The place of wastewater reuse in operational water policy

1.1 General framework for an operational water policy

In an operational context, water supply has a dual objective. In terms of quality, it is essential not to jeopardize the health of consumers; in terms of quantity, it is important to guarantee a sufficient supply of water for drinking, food preparation and individual and collective hygiene. The volumes of water required by a community vary considerably according to the desired level of comfort: while the minimum survival requirement is a few liters of water per man per day for drinking (1), guaranteeing good hygiene within the workforce means, according to European standards, providing around 100 to 150 liters of water per man per day (2). Both objectives - qualitative and quantitative - entail considerable practical

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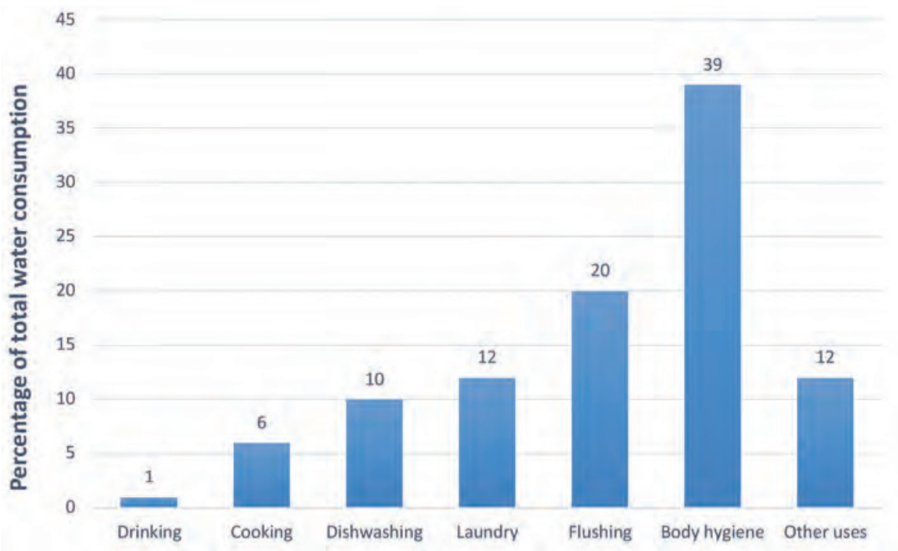

Figure 1: average distribution of water consumption in homes in France (from 3).

constraints in an operational context. To achieve them, improvisation is not the right option and, on the contrary, a genuine water policy needs to be planned for operations. The main thrusts of such a policy are to limit wastage, use this precious commodity sparingly and seek alternatives to traditional resources. Clearly, these various courses of action do not all have the same scope, and their implementation will be largely influenced by the climatic and operational context. However, it is important to have a global vision of all available options in order to be able to make the most of them.

1.2 Main water-saving options

When water is distributed via a pipe network, limiting wastage means acting to reduce water losses in the network, based on careful maintenance. For example, a single leaky toilet flush represents a water consumption of around 200 m^3 per year (3). Another important aspect to consider is the efficiency of treatment systems for water taken from the natural environment. Some water purification processes have rather mediocre production yields (volume of drinking water produced / volume of raw water drawn from the natural environment): for example, around 50 to 60% at best for reverse osmosis. When resources are scarce, treatment processes must be optimized to limit discharges.

Water use must also be rationalized. Non-essential uses should be banned or severely restricted, such as washing vehicles (using around 200 liters of water per wash) or watering vegetation. Unaccustomed to water restrictions, European servicemen and women need to be made particularly aware of water scarcity, and encouraged to change their habits to save water. One frequent observation is the reluctance of military authorities to restrict access to water for personnel. An abundance of water contributes to the comfort and morale of troops, as well as to individual and collective hygiene. While it is justified, and even essential, to guarantee a supply of water enabling everyone to wash themselves, have clean clothes and be able to clean the premises in which they live and work, the volumes of water required can be restricted without really affecting living conditions, in particular by using specific taps or giving preference to water-saving washing machines. Simple habits are also to be encouraged, such as not letting the water run unnecessarily, taking short showers (a three-minute shower consumes around 60 liters of water) or even washing with a glove. For example, leaving the tap running for one minute consumes an average of 10 to 12 liters of water.

The data shown in figure 1, taken from a consumption study in France (3), show that, in a purely quantitative approach to domestic water use, the activities for which the greatest volumes of water are consumed are linked first and foremost to personal hygiene. Toilet flushing uses 20% of water in the home. Laundry represents the third largest consumption item. It might therefore be thought that these three types of use are the ones for which water savings are a priority in order to significantly reduce consumption, but this reasoning needs to be qualified so as not to lose sight of the potential health impact associated with water restrictions in these different areas.

As regards the use of alternative water resources, the options to be explored concern rainwater, a resource which availability is highly uncertain, and atmospheric water vapour. The latter option has been the subject of major technological developments over the last ten years or so, and should be given careful attention (4, 5, 6).

1.3 Reuse of wastewater

In such a global project, the question of wastewater reuse is now at the heart of the debate. The military world must benefit from the experience gained in this field by many civilian operators. The starting point is that when you supply 100 to 150 liters of water per person, you recover around the same volume of wastewater. There is therefore considerable water potential to be exploited.

However, due to a high concentration of various contaminants, this water cannot be used without major risk of contamination for users or the environment. In particular, the direct application of wastewater for crop irrigation is known to be responsible for the transmission of fecal agents through the consumption of plant products grown in this way (7, 8, 9). Even for strictly technical uses in closed circuits, such as supplying cooling systems, the presence of large quantities of organic matter can lead to the deleterious clogging of pipes. The high content of micro-organisms in such water also makes it very difficult to preserve, as fermentation phenomena quickly set in, generating unpleasant odours.

While wastewater clearly represents a potential resource for supplying water to the communities that produce it, the questions that arise concern the treatment methods to be applied to this water with a view to its reuse, and the uses to which it can be safely put once it has been treated. By accepting high treatment costs, it is indeed possible to design a technology that is sufficiently efficient to treat any quality of raw water, and wastewater in particular. However, the aim is to develop strategies for treating wastewater as minimally as possible, in order to reduce treatment costs, with a view to using it wisely, without inducing risks for users. Water treated in this way is often referred to as reclaimed water. This perspective does, however, raise a number of questions and requires a thorough characterization of wastewater.

2/ Wastewater characteristics

The notion of wastewater refers to a wide variety of types of water, both domestic and industrial. The latter will not be discussed here, as most of the wastewater on an operational military site comes from domestic activities, such as washing, toilet flushing, cooking and laundry.

2.1 Wastewater production and disposal

Water from various domestic activities is generally mixed together when it is collected. In an operational context, this may take place in specific containers that are emptied periodically, or via a network of pipes. The wastewater is then sent to a treatment plant before being discharged into the environment. The main aim of wastewater treatment plants is to reduce the organic load of water, particularly in terms of nitrogen and phosphorus, so as not to cause excessive nuisance to the natural receptacle. In fact, excessive inputs of organic compounds into surface waters lead to eutrophication, which considerably disrupts ecosystems. Only water from kitchens generally undergoes specific pre-treatment (decanting) before being sent to the collection system, in order to separately collect the grease it contains in high concentrations.

2.2 Black and gray waters

Toilet water, generated by the evacuation of faeces and urine, is referred to as "black" water. The notion of "gray" water usually refers to water generated by cooking, washing clothes, equipment and premises. It should be noted that some definitions (10, 11) exclude from the outset water from cooking and dishwashing activities, which are considered a separate category due to their very specific characteristics (rich in grease and food debris) or included in the "black" water category.

Black water has very high concentrations of organic matter, particularly rich in nitrogen compounds and phosphorus (11), and of microbial agents of human origin. It is a major source of fecal pathogens. They also contain sometimes significant concentrations of drugs and drug metabolites, due to urinary and/or fecal excretion of these molecules by the body. It should be noted that, although data on this subject are non-existent, drug residues may also be present in gray water as a result, for example, of hand washing after the application of a drug via the cutaneous-mucosal route, or via laundry washing, due to the excretion of certain molecules through sweat.

The characteristics of gray water differ from one site to another, depending on the use from which it is collected (11, 12, 13). Literature data are summarized in table I (11). As a general rule, it has an alkaline pH when used for laundry, and a highly heterogeneous particulate and colloidal load (turbidity, suspended matter). It is rich in biodegradable organic matter (11) and, in the case of laundry water, in phosphates.

Table I: main characteristics of gray water (from 11).

Parameter	Categories of gray water			
	Bathroom	Laundry	Kitchen	Mixed
Turbidity (NTU)	44-375	50-444	298,0	29-375
Total suspended solids (TSS – mg L^{-1})	7 - 505	68 - 465	134 - 1300	25 - 183
Biological oxygen demand (BOD – mgO_2 L^{-1})	50 - 300	48 - 472	536 - 1460	47 - 466
Total nitrogen (mg L^{-1})	3,6 – 19,4	1,1 – 40,3	11,4 - 74	1,7 – 34,3
Total phosphorus (mg L^{-1})	0,11 - >48,8	ND - >171	2,9 - >74	0,11 – 22,8
pH	6,4 – 8,1	7,1 - 10	5,9 – 7,4	6,3 – 8,1

The microbiological quality of gray water is little known and probably highly variable, as it depends on the sanitary state of the population and human behavior (14). Microorganisms may be of human or environmental origin. The few studies available testify to the possible presence of a wide variety of bacterial, viral or parasitic pathogens, and show that concentrations of fecal bacteria in gray water vary over a wide range, between 10^2 and 10^6 CFU/100 mL for *Escherichia coli* (*E. coli*) and intestinal enterococci (15), which is fairly close to the concentrations observed in wastewater in general (between 10^4 and 10^7 CFU/100 mL for *E. coli* and intestinal enterococci). In terms of microbiology, therefore, gray water is not fundamentally of better quality than wastewater in general.

As far as chemical contaminants in gray water are concerned, the available data are scarce and fragmentary; they show a preponderance of personal hygiene and cosmetic products, as well as detergents and biocides (15): phtalates, ultra-violet filters, alkylphenols and alkylphenol ethoxylates, polycyclic aromatic hydrocarbons, parabens, polychlorinated biphenyls, musks, fatty acids, etc. By-products of the initial chemical contaminants are also potentially present, such as trihalomethanes. Laundry water contains large quantities of fibers; the question of microplastics may also be raised, although there is insufficient scientific evidence on this subject. In some cases, unexpected chemicals can be found in gray water, as a result of inappropriate dumping in a sink, particularly solvents, which considerably increases the health risk. As mentioned above, gray water from kitchens is generally particularly loaded with grease and organic debris, unlike other types of gray water, making its treatment with a view to reuse particularly restrictive.

2.3 Overview of available data and consequences

Little specific data is available, but generally speaking, the potential contaminants in wastewater are extremely diverse and largely unpredictable; their presence and concentration also vary widely depending on the sites and activities concerned. There isn't just one type of wastewater, but a wide variety, with varying levels of contaminants. This spatial and temporal diversity makes it particularly difficult to design, *a priori*, a treatment process that eliminates significant hazards so that treated wastewater can be used. Similarly, it is not possible to carry out a robust assessment of the health risks associated with this practice, applicable to all situations. It is therefore important to remember that wastewater reuse requires a case-by-case scientific approach, the difficulty of which should not be underestimated when the nature of the pollutants likely to be present in the water is not under control.

Many countries have widely developed water reuse, mainly for agricultural irrigation, so that feedback exists for this type of use. In most cases, however, the input of chemical pollutants into the soil is not assessed over the long term, making it difficult to establish the environmental balance of such activities. For industrial uses, various approaches have been developed, mainly the use of water in closed circuits or the use of wastewater summarily treated in technical circuits with no risk of human contamination. As far as domestic use is concerned, experience of wastewater reuse is more recent and poorly documented, so the debate is open, but the lack of robust bibliographical data is a major handicap. Hazard analysis in this field is necessary and can lead to solutions that are acceptable from a health point of view, as long as the conditions of use of treated wastewater and the type of treatment applied to it prior to reuse are in line with each other.

3/ Hazard analysis applied to reclaimed water

The reuse of wastewater for domestic purposes can be based on the concept of "direct potable reuse" (16), i.e. the production of drinking water from raw water consisting of wastewater. In principle, this is an entirely realistic option, given that technological solutions exist and have been tried and tested in many countries. As a general rule, the processes implemented for this purpose incorporate a reverse osmosis stage, preceded by filtration pre-treatments to limit membrane clogging, followed by an ultraviolet oxidation stage to degrade any traces of organic contaminants (17, 18, 19) and ensure ultimate disinfection for safety. A carbon filtration stage is also usually included at the end of the process. It goes without saying that the poorer the quality of the raw water, the greater the risk to the consumer in the event of a failure in the treatment process: this risk must motivate great caution in the use of a direct potable reuse approach, with in particular the implementation of attentive and constant monitoring of the water treatment process. For an operational context, a more realistic approach would be to set up less stringent treatment processes, at the risk of producing "low-quality" treated water, and to adapt the authorized uses for this water to its quality. This is a long-standing debate in the military world, but one that is becoming increasingly topical given the current water shortage. Since the production of drinking water is both costly and time-consuming, the question arises as to the usefulness of using drinking water for activities such as showering or, *a fortiori*, toilet flushing. This is the background to the debate on specific military standards for water, with the aim of adapting the expected quality to the uses for which the water is intended.

3.1 Risks associated with the various possible uses of reclaimed water

The risks associated with the use of reclaimed water must be considered in their entirety, depending on the type of use and the context. Users may be exposed to infectious or toxic agents contained in water by direct ingestion (drinking, food), by skin contact, with or without passage through the epidermis, or by inhalation of aerosols, the latter leading to penetration of the agents into the respiratory tract or their swallowing after intervention of the mucociliary escalator. Exposure may be systematic or occasional. These risks apply not only to people using water unfit for human consumption, but also to people in their vicinity, through water splashes or aerosol diffusion.
If we attempt to classify water uses according to the typology of associated risks, we can, in the first instance, and following the advice of recognized health authorities (20), consider as inadmissible an approach consisting in using water of non-potable quality for uses involving ingestion of this water, via drinking or incorporation into foodstuffs. By extension, the use of non-potable water should also be avoided for dishwashing and washing materials and surfaces likely to come into contact with food. Personal hygiene uses are controversial. They expose people to direct skin contact, inhalation of aerosols and ingestion of small quantities of water (e.g. when brushing teeth). The risk of contact is increased if the skin is damaged. The minimum requirement for such uses may seem to be compliance with the microbiological criteria set for drinking water. However, certain chemical agents are known to have effects through contact with the skin, particularly in populations at risk of skin allergy, with skin diseases or atopic skin (this is particularly the case with nickel), or through transcutaneous passage (e.g. trihalomethanes). It is therefore important to avoid oversimplification in such a debate.
When it comes to washing surfaces in technical areas (e.g. workshops) or outdoors, as well as washing vehicles or equipment outdoors, the main concern is for operators, especially when using aerosol-generating equipment (e.g. high-pressure cleaners). Provided that suitable personal protective equipment (masks in particular) is worn to protect operators, and that aerosol formation is limited, the risk associated with this type of activity appears to be very limited at first sight, but needs to be assessed according to the subsequent use made of the surfaces and equipment cleaned in this way.
Toilet flushing is an activity that generates aerosols, which can simply be reduced by closing the toilet lid before flushing. The risk associated with these aerosols is probably more related to the contents of the toilet bowl than to the flushing water. Where water unsuitable for human consumption is used to flush toilets, the main difficulties are linked to the overall microbial and organic load of this water, which must be limited, otherwise storage will be a source of major nuisance (odours linked to fermentation). On the other hand, the chemical risk seems negligible.
Another point of caution is that the coexistence on the same site, or even in the same building, of distribution systems for water of different qualities entails a major risk of water mixing, confusion or misuse, which can lead to contamination of consumers. Accidents of this type have already been described (21), and the increasing use of reclaimed water in buildings should lead to an increase in the number of comparable accidents. The risk of confusion is further increased by the need to provide back-up systems, i.e. a dual water supply. In an operational context, this aspect of the risk associated with reclaimed water is particularly significant. The associated constraints are considerable, particularly when water is transported and distributed in tanks: in such cases, equipment intended for "clean" and "dirty" water must be strictly identified, and well-trained personnel must ensure that the relevant instructions are properly applied.
The main uses of reclaimed water that have seen practical development in the home are for toilet flushing, washing clothes including a final rinse with potable water, and washing floors, both indoors and out. In all cases, it is not a question of using raw wastewater, but of using selected wastewater after appropriate treatment. It is therefore necessary to provide an answer to the question of the quality standards applicable to reclaimed water, and thus to define a suitable treatment approach for each type of water and use.

3.2 Establishing quality standards for reclaimed water

Since wastewater is, by its very nature, too contaminated to be reused without treatment, it is important to devise specific quality standards, which must take into account the intended use of the water. Many countries have established guidelines applicable to treated wastewater intended for reuse,

Table II: guide values for microbiological parameters recommended by the French health agency for wastewater reused in housing (23).

Parameter	Guideline for reclaimed water (domestic use)	Comments
Escherichia coli	ND / 100 mL	NF EN ISO 9308-1 (T90-414) or NF EN ISO 9308-2
Somatic coliphages	≤ 10 PFU /100 mL	NF EN ISO 10705-2

but there are considerable differences in terms of quality standards adopted, reflecting both the complexity of the issue and the differences in experts' risk assessments (11). What's more, most of the standards currently set concern agricultural uses, with or without direct contact with crops, and road maintenance, with strong precautions to avoid contact with people. The quality standards adopted are therefore mainly microbiological, and the long-term risks to the environment are not clearly managed.

Microbiological quality requirements are essential. To limit the risk of accidental human contamination, it seems reasonable to limit the load of fecal agents in reused wastewater: the key parameter is *Escherichia coli*, even if some standards still refer to thermotolerant coliforms. The use of somatic coliphages as a second key indicator of fecal contamination is also advisable, since viruses are usually more resistant than bacteria to conventional disinfection processes. For these two major indicators of water-related biological risk, the limit values set are the subject of controversy. In fact, usage plays a decisive role in this area. Setting stringent requirements for water used to flush toilets may seem excessive, but it helps to limit the risk of spreading fecal pathogens through aerosolization by the flush. What's more, distributing properly disinfected water, albeit unfit for human consumption, is a serious safeguard in the event of accidental water mixing.

Recommended limits for these two parameters in France are given in table II. These values may be considered highly protective, but, as mentioned above, they take into account the risk of accidental mixing of waters. For *Escherichia coli*, some authors suggest a limit value of up to 25 CFU/100 mL for wastewater used to flush toilets (15). It should be noted that parasitic risk parameters are only proposed for water used for agricultural purposes (*Cryptosporidium*, helminth eggs, etc.). In principle, *Legionella* enumeration is reserved for situations likely to result in the formation of aerosols in significant quantities.

Other microbiological parameters could be selected, in particular indicators of the overall microbial load of the water (for example, the enumeration of culturable micro-organisms at 36°C according to NF EN ISO 6222). However, as disinfection of wastewater is generally carried out by chlorination, the parameter "residual concentration of free chlorine" is simpler to use.

As disinfection cannot be carried out without first clarifying the water, other parameters complement the previous ones: they testify to the quality of water clarification. As a general rule, turbidity and total suspended solids are included in this category, providing an estimate of the particulate and colloidal load; their control limits the risk of deposits in installations. It is also necessary to use targeted indicators for the organic component, such as total organic carbon and/or biochemical oxygen demand. These latter parameters are of great importance in the case of wastewater, as they enable us to assess the quantity of substrate available for biofilm development and bacterial fermentation.

Recommended values for these parameters in France are given in table III.

Table III: guide values recommended by the French health agency for wastewater reused in housing, for physico-chemical parameters (23).

Parameter	Guideline for reclaimed water (domestic use)	Comments
Turbidity (NTU)	< 2	NF EN ISO 7027-1
Total suspended solids (TSS – mg L^{-1})	< 10	NF EN 872
Biological oxygen demand (BOD – mgO_2 L^{-1})	< 10	NF EN ISO 5815-1 NF EN 1899-2 ISO 5815-2
Total organic carbon (TOC - mg L^{-1})	< 5	NF EN 1484
Free chlorine (mg L^{-1})	> 0,1 and < 0,5	ISO 7393-2

It is possible to design specific qualities of reclaimed waters according to the different uses for which they are intended. This is what is currently guiding legislators, who distinguish between agricultural "reuse" and industrial or domestic uses of reclaimed waters. However, creating several "sub-qualities" of water increases the technical complexity of water distribution systems and the risk of confusion, and hence of accidents. It therefore seems reasonable to choose as simple an approach as possible, particularly in the context of domestic uses, and not to multiply the number of cases.

4/ Military applications

When it comes to integrating wastewater reuse into the overall water supply strategy of a military force in an operational theater, it is important not to put water savings before the health of personnel, but rather to find an appropriate compromise. Simplistic reasoning, limiting the risk to microbial or even bacterial agents without considering other hazards, should be avoided. The use of reclaimed water should be prioritized for applications where the benefit/risk ratio - between the benefits in terms of water savings and the potential health risks involved - is significant.

Such an approach must always be seen as a major source of accidents, which can be serious in the event of confusion, misuse or negligence. It is therefore essential to have the necessary equipment and competent personnel in place at all times. The production and use of treated wastewater must be constantly monitored to ensure compliance with defined technical requirements. With these general rules clearly in mind, the following recommendations can serve as a starting point for developing a harmonious wastewater reuse policy.

4.1 Selective wastewater collection

Obviously, the ideal is to have as little contaminated wastewater as possible. That is why it is best to focus on wastewater generated by laundry and personal hygiene, i.e. to exclude black water from treatment. The case of water from cooking activities is debatable. The type of contaminants found in this type of water, mainly grease, means that treatment is highly constrained. Conversely, it is easier to characterize the contaminants likely to be present in this type of water, as will be explained in greater detail below.

Whatever choices are made in this area, separate collection of wastewater intended for reuse from that excluded from this approach is necessary. This selective collection implies not only that operational equipment, notably sanitary modules, be designed with this in mind at the level of wastewater discharge pipes, but also that the site's entire wastewater collection system be organized accordingly. As shown in figure 1, this selective approach results in direct discharge of around half the total volume of wastewater, leaving the other half for reuse.

4.2 Control of inputs

The key problem in wastewater hazard analysis is that the nature of the chemical pollutants of raw water destined for recycling is generally unpredictable. This makes it impossible to carry out an exhaustive hazard analysis, to define suitable analytical frameworks and relevant water monitoring parameters. The right approach would be to have a list of the chemical contaminants potentially present in this water, based on an inventory of the "inputs", i.e. the chemicals used by the wastewater-producing site. This is an approach widely used in the agro-industrial sector, which enables us, for example, to envisage the reuse of washing water from processing plants on the basis of a perfect knowledge of all the chemical inputs in the plant concerned. The process must also take into account the metabolites of chemical substances, any impurities, and so on. On this basis, it is possible to carry out a hazard analysis.

We can therefore observe that the greatest difficulty for domestic water is the control of inputs in the case of wastewater from activities linked to personal hygiene. In the case of laundry water, the situation is fairly similar, due to the contaminants brought in by dirty clothes. On the other hand, it seems simpler to control inputs in collective kitchens, so that the wastewater produced by these structures shouldn't be ruled out.

4.3 Untreated gray water storage

The production of wastewater, mainly water used for personal hygiene, is not continuous throughout the day, with a production peak in the morning and another in the evening. As it would be too costly to size the plant to treat this water directly during production peaks, storage prior to treatment is generally necessary, in dedicated containers. The difficulty, however, is that gray water very quickly becomes the site of fermentation, leading to the production of malodorous gases. It is therefore important to design a treatment system that limits raw water storage time. Feedback from experience in this field suggests a maximum duration of 90 minutes (15), which may prove difficult in practical terms.

4.4 Gray water treatment

Gray water is rich in organic matter and various microbial agents. The minimum treatment required for reuse is disinfection, to limit the fermentation phenomena mentioned above. However, it would be illusory to attempt disinfection, either by chemical (chlorination) or physical (ultraviolet lamp) processes, without first eliminating as much suspended matter as possible: in the case of chemical disinfection, the organic compounds present in the water consume active chlorine to form by-products, some of which are known to be toxic (trihalomethanes, haloacetic acids, etc.); in the case of ultraviolet disinfection, the presence of particulate matter interferes with the diffusion of ionizing radiation. Clarification is therefore an essential prerequisite for disinfection. The elimination of particulate and colloidal compounds is also necessary to limit deposits in pipes and tanks and the proliferation of biofilms.

A graywater treatment process is a compromise of sorts, combining processes characteristic of raw water and those more specifically used in drinking water production. Ideally, an aerobic digestion stage should first be implemented to eliminate most of the biodegradable organic matter. Although this type of technique is usually carried out in large-scale concrete tanks, there are also field-adapted equipment already used in mobile wastewater treatment plants. This first stage produces better quality water, with a particle and colloidal load compatible with traditional filtration processes. Correctly dimensioned, a digester can reduce biological oxygen demand to values below 25 $mgO_2\ L^{-1}$. However, it is important to assess the situation carefully before resorting to this approach: in some studies, "bathroom" water was found to be too low in phosphorus for digesters to function properly (22).

Once this has been achieved, it is essential to apply a series of additional treatments to the water, starting with filtration. For economic reasons, this is generally limited to the use of sand filters or ultrafiltration membranes, which are sufficient to achieve the turbidity values set above. Disinfection is essentially carried out by chlorination, in order to maintain an active chlorine residual in the water throughout distribution. The main difficulty lies in the interactions between residual organic matter, mainly nitrogenous, and active chlorine. This is a major argument for excluding black water from recycling, and a general concern in any reuse process. For the non-human contact uses mentioned here, the toxic risk associated with disinfection by-products is negligible; on the other hand, it is important to carefully monitor the performance of the process in terms of disinfection efficiency. This is why it is important to guarantee a minimum concentration of residual free chlorine after treatment.

Clearly, while the treatment processes described here are designed to control microbial pollution, they cannot guarantee the chemical quality of the water produced. This suggests that they can only lead to "sub-quality" water, the use of which must be strictly controlled.

Experience feedback (15) recommends that treated gray water should not be stored for more than 48 hours before use, which implies that production should be organized according to the needs for which it is produced. Similarly, flush tanks should be completely emptied if their use is temporarily suspended due to the absence of users.

4.5 Graywater uses

The complexity of the technological challenge and the associated health risks mean that we should initially give priority to uses for treated wastewater for which the best guarantees of harmlessness are available. In addition, we need to take into account the specific difficulties of the operational context, in particular the capacities available to carry out analytical monitoring of the water produced. For these reasons, toilet flushing would appear to be the preferred use for reclaimed water to limit wasting drinking water. This appears to be the main option to be explored first. On its own, it could save around 20% of potable water compared with current consumption levels. However, this assumes the design of suitable equipment with a separate water supply to the toilet blocks, so that only the flushes are supplied with reclaimed water. In addition, it is essential to provide a back-up for the water supply, because even if the resource is abundant and there is no risk of running out, the possibility of having to shut down the treated wastewater supply system for maintenance or in the event of a breakdown must be taken into account. This possibility of supplementation by potable water must be designed to guarantee against backflow. Generally speaking, buildings are fitted with a total overflow system for the drinking water supply. Less restrictive solutions can be envisaged, such as the use of backflow preventers, but this equipment is costly and requires careful maintenance, which can be incompatible with operational realities.

The search for additional savings may lead to broader reflection, but then a major difficulty arises: the lack of robust bibliographical data on the subject. In France, for example, the use of rainwater for laundry washing has been excluded from the regulatory framework for lack of data, despite a genuine desire on the part of public authorities to encourage this use of reclaimed water. To explore new options, a specific hazard analysis is required. This must be based on a balance sheet of inputs and a risk assessment to determine, for each pollutant identified, the acceptable concentration for the intended use and the type of treatment to be implemented to ensure that this objective is met. As we have already mentioned, this is a complex approach in the case of domestic wastewater, since it is difficult to control inputs, unless we impose the exclusive use of certain hygiene or cleaning products. This approach is in its very first stages in industry, but seems really difficult to transpose to the operational context. However, studies on this subject should be encouraged with a view to developing materials and protocols that can be directly transposed to operational theaters.

Conclusion

Wastewater reuse is now considered a major component of any water supply policy, in response to the increasing scarcity of traditional water resources as a result of climate change. However, it is important to bear in mind the scale of the health risks associated with wastewater and the complexity of the technological challenge involved in treating it. As a receptacle for all forms of human pollution, wastewater cannot be reused without taking infinite precautions in terms of collection, treatment and distribution.

Applied to the context of a military force in operation, the concept of wastewater reuse essentially concerns gray water, the by-product of everyday water use. The quality of this water is highly variable and difficult to control, which complicates the definition of a strategy for its reuse. The most obvious possible developments concern the supply of water to toilet flushing, which would enable water savings of around 20%. For other uses, studies are still needed, particularly in terms of chemical risk management.

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