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GUIDELINES ON PHYSICAL AND CHEMICAL PARAMETERS FOR WATER REUSE IN IRRIGATION

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EXECUTIVE SUMMARY

This report provides vital information relevant to the quality of water and treated wastewater for reuse, primarily for agricultural irrigation (not for drinking purposes). The overall thrust is to develop a direct linkage between human life, soil, water and the environment and quality parameters. The goal is to enhance better water use for agricultural irrigation, groundwater recharge and enrichment of water bodies, such as storage reservoirs, creeks and rivers, to minimize health and environmental risks and to guarantee sustainable production, primarily in agricultural areas.

The report provides both general and more specific guidelines for handling and refers to the chemical and toxic constituents that might be contained in treated wastewater, which are ultimately reused for diverse purposes. The basis for wastewater treatment is the quality of the incoming influent, which commonly requires a sophisticated monitoring and alarm inspection system (If possible on real-time basis). It also provides general directions for monitoring and responsibilities of the organizations that use and dispose of the treated wastewater.

The list of constituents jeopardizing sustainable effluent reuse is relatively long. It includes the salinity parameter as expressed by the electrical conductivity of the effluent. Also to be assessed is the SAR parameter, which is an estimator for hydraulic properties of the soil as given by sodium, calcium and potassium content. Beyond that one has to consider other specific constituents such chlorine, which might be a trigger for hallomethanes generation, boron, manganese, heavy metals and others that frequently emerge. Maximal levels for most constituents are given, some of them based on drinking water quality criteria.

In addition to the information provided, further work is required to produce a report containing case studies and previous, well documented data that will allow experts to utilize the information for implementation of a broad spectrum of cases.

Key words

Wastewater; reuse; toxic and hazardous constituents; risks; sustainable production.

List of Abbreviations

DBP	Disinfection by Products
DOC	Dissolved Organic Matter
ESP	Exchangeable Sodium Percentage
NOM	Natural Organic Matter
ODI	On surface Drip Irrigation
OM	Organic Matter
PE	Processing Element
RO	Reverse Osmosis
RWW	Reclaimed Wastewater
SAR	Sodium Adsorption Ratio
SDI	Subsurface Drip Irrigation
THM	Trihalomethane
TDS	Total Dissolved Solids
TDWW	Treated Domestic WasteWater
UF	Ultra Filtration
UV	UltraViolet

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1. INTRODUCTION

1.1 General

Water shortage in arid and semi-arid regions has stimulated the search for alternative waters. The alternative non-conventional water sources include saline waters, run-off water and treated wastewater (Choi *et al.*, 2003; Liberti *et al.*, 2003; Alcalde *et al.*, 2004; Asano and Cotruvo, 2004). The growing demand for water and increasing environmental awareness has enhanced intensive efforts towards improving the treatment and reuse of saline water, surface waters and domestic wastewater. Reuse of treated wastewater, primarily for agricultural irrigation, solves disposal problems and environmental issues simultaneously. Agriculture in most countries is the largest water consumer. Consequently, extended efforts should be made towards improved utilization of water for irrigation (Table 1). The efforts associated with effluent reuse include studies regarding pathogens viability (bacteria, viruses and parasites) and possibilities of dissolved solids removal. Pathogens content in the disposed or applied effluent has to be considered with regard to their impact on the soil, agricultural raw eaten products and, ultimately, on the human community. Human communities ultimately consume these products. The nutrients content in the effluent (primarily ammonia, phosphate and potassium) and additional constituents might have adverse effects on agricultural productivity, both in the long and short term.

Table 1

Water and consumption for agriculture, industry and domestic utilizations in different countries (Goto, 2002)

Country	Total available Billion m^3	Agriculture % of total	Industry % of total	Domestic % of total
Algeria	4.5	60	15	25
China	2,829	77	18	5
Cyprus	0.2	74	-*	-
Egypt	55.1	86	8	6
Indonesia	2,838	93	1	6
Israel	1.7	64	10	26
Japan	430	64	17	19
Jordan	1.0	75	3	22
Korea	77	73	16	11
Lebanon	1.3	68	4	28
Libya	4.5	87	4	9
Malaysia	580	76	13	11
Morocco	11.1	92	2	5
Philippines	479	88	4	8
Syria	14.4	94	2	4
Thailand	410	91	4	5
Tunisia	2.8	83	3	14
Turkey	36.5	73	11	16

Other constituents that have to be seriously considered include sodium, calcium and manganese, allowing the assessment of the sodium absorption ratio (SAR) of the effluent and related impact on the soil hydraulic properties. Heavy metals (e.g., selenium, vanadium and mercury) that are occasionally contained in the effluent might destroy the soil structure, have adverse toxic effects and ultimately cause a reduction in productivity. The long-term effects are primarily related to the accumulation of the various dissolved solids in the soil, plants and groundwater. In order to minimize health and environmental risks and ultimately to also maintain sustainable production, the applied water quality has to comply with several quality criteria, according to the conditions. Some of the quality criteria are presented and discussed.

Enormous progress has been made during the last decades in reuse of treated domestic wastewater (TDWW) as a combined solution in reducing the quantities of pollutants in municipal and industrial effluent discharged freely, diverted into the sea, used for aquifer recharge and/or reused for other purposes, mainly agricultural irrigation (Campos *et al.*, 2000; Al-Jamal, 2002; Choi *et al.*, 2003). Unfortunately, large quantities of pollutants continue to enter into the main domestic sewerage systems from different sources, due to loosely controlled disposal, and often, ignorance of the potential damage to the environment. The origin of the chemicals contained in raw wastewater and effluent fall into several categories. These categories refer primarily to wastewater; however, they play an important role in the quality of the sludge generated during the treatment stages:

Table 2

Selected classified constituents as can be identifief in treated wastewaters

Type of quality paramete	**Specific quality parameters**	**Systems and factors that are affected**
Physical	TSS, Turbidity.	Irrigation, aquifer recharge, water transportation systems.
Biological	BOD_5, TOC.	Irrigation, water bodies, soils, aquifers, water transportation systems.
Microbial	Faecal coliforms, parasites, total coliforms counts, viruses, nematode eggs, Ascaris.	Human and animal health, water bodies, aquifers.
Chemical: Common	COD, nutrients, alkalinity, sodium, reaction, table salt (EC).	Eutrophication processes, reduced agriculture production.
Heavy metals	Selenium, Boron, Cadmium, Arsenic, Chromium, others.	Plants, human food.
Pesticides	Atrazine, 2,4-D, roundup, others.	Plants, soils, human food and health.
Toxic materials	Bentazon, trifluralin, cyanzine, bromoxynill, others.	Plants, human food and health, aquatic and animal life.
Detergents	Phosphate and free-phosphate.	Plants, human food and health.
Pharmaceuticals	(Per substance, e.g., X-ray contrast media, Carbamazepine, Sulfamethoxazole).	human food and health.

1) chemicals consumed during the treatment of the domestic wastewater processes. Mainly are contained chemical coagulants and flocculants;
2) disinfection by-products that are deliberately added in order to maintain pathogen-clean waters. Common disinfectants include chlorine, ultra violet (UV) radiation, chlorine dioxide, and chloramines; and
3) chemical compounds included in the local industrial regional plants and frequently are not separated and removed prior to merging with the central municipal sewerage system.

Public concerns and perception regarding drinking water and safely treated wastewater reuse are a major challenge for any water organization. Four water quality factors are of particular concern (Table 2): (i) microbiological quality; (ii) total mineral content (e.g., total dissolved solids); (iii) presence of toxicants of the heavy metal type; and (iv) the concentration of stable organic substances. Particularly for the last two categories, recent studies in environmental toxicology and pharmacology have revealed potential long-term health risks associated with chemical compounds such as disinfection by-products (DBPs), pharmaceutically active compounds (PhACs), pesticides, and personal care products (PCPs) at low concentrations (order of magnitudes of ppb and ppt). Those trace organic compounds along with some inorganic compounds such as arsenic and hexavalent chromium found in reclaimed water, are of special concern for human and ecological health risk. In addition, there are growing concerns among the public and the mass media over the trace contaminants in reclaimed water, which were found with the aid of increasingly sensitive detection techniques that enable detection of extremely low contaminant concentrations.

2. EXTRA WATER SOURCES

Water scarcity in arid zones can be alleviated by gradual development of additional local water sources. The development of extra water sources is subject to regional and periodic needs, economic and environmental considerations, and future prospects (Brimberg *et al*., 1995). In order to reduce the dependence of water supply on external sources and alleviate the problems associated with over-pumping of groundwater, it has become necessary to develop the non-conventional and not yet fully exploited water sources existing primarily in the desert regions. These additional water sources have a number of characteristics.

Saline water can be found as tailwater in fields irrigated by open-surface methods and mainly as groundwater in deep fossil aquifers. Commonly, water salinity is expressed by the electrical conductivity (EC) and is in the general EC range of 2 dS/m to 7 dS/m. Saline water contains diverse constituents such as the common table salt, boron, selenium, manganese and others that contribute to the water salinity and ultimately, when applied for irrigation, also to the soils and aquifers. Saline water can be applied for direct agricultural irrigation, for recreation, industry and toilet flushing. Desalination of saline water is more economically attractive than seawater desalination due to the lower dissolved solids content. Application of saline water for irrigation of agricultural crops is associated with improved fruit quality due to higher sugar content, as expressed by the BRIX values in tomatoes, but with reduced yield, however.

Removal of dissolved solids from saline water can primarily be accomplished by implementation of the membrane technology (or supplying low salinity waters). Advanced water treatment allows reduction of the total dissolved solids (TDS) content and to expand saline water utilization for a broad pattern of possibilities. Reverse osmosis (RO) and elctrodialysis (ED) are the leading advanced technologies in water quality improvements. The cost of TDS removal from saline water is commonly in the range of US \$ 0.45/m^3 to US \$ 0.70/m^3 and for conventional seawater is in the range of US \$ 0.75/m^3 to US \$ 1.20/m^3

(Chellan *et al.*, 1998). The actual desalinated water cost depends significantly on the location of the end-user and the solution for brine disposal. Intensive research is in progress in order to reduce the cost of TDS removal.

Runoff water is generated during sparse rainfall events during the wet (winter in many regions in the Mediterranean Basin) season. In areas with low soil surface permeability, floodwater can be diverted to special facilities and stored for future needs, mainly for supplementary summer irrigation. Relatively high capital investments are required for the collection, storage and distribution of water to the end-users. The stochastic nature of runoff water supply raises reliability issues of supply and difficulties in efficiently use of this water. In arid regions, ROW can be used efficiently by implementation, collection and storage of the water in small catchments and water harvesting methods (Boers, 1994). Harvesting methods include collection of the ROW close to the contribution basins and catchments of various sizes (Oron and Enthoven, 1987; Boers, 1994).

One of the directions that require further attention is urban runoff (Duke, 2004). The use of urban runoff should be linked with urban planning. Urban planning should take into account broader design aspects besides the water for the general welfare of the community (Lee and Heaney, 2003; Rapp *et al.*, 2004). Urban ROW can be collected and reused for artificial aquifer recharge due to the intense urbanization processes that limit the free surface areas for natural groundwater recharge.

Substituting conventional waters with treated municipal wastewater can narrow the water gap between supply and demand. Along with improved control of the effluent quality, adequate reuse of even low quality treated domestic wastewater can play a significant role. Reuse of treated wastewater also solves disposal problems, while ameliorating water shortage, primarily during drought conditions (Brenner *et al.*, 1995; Jolis *et al.*, 1995; Oron, 2002). Wastewater reclamation is in the general area of water resource management and reflects societies' increased demand for alternative waters for diverse utilization. They require implementation of advanced technology for water quality control, public acceptance, and improved understanding of the public health risk (Blumenthal *et al.*, 1989; Rose and Gerba, 1991; Bitton and Harvey, 1992; Asano and Levine, 1995). Wastewater is unique in its composition, often associated with environmental and health risks and its acceptability as a substitute for conventional or other non-conventional waters for irrigation or industry, is highly dependent on whether the associated health risks and adverse environmental impacts are within acceptable parameters (Angelakis et al, 1999; Gaspard and Schwartzbrod, 1995). Utilizing advanced application technology, such as conventional on-surface drip irrigation (DI), can largely reduce the risk of environmental pollution and plant contamination during effluent reuse. Even when wastewater is contaminated by viruses, DI and mainly subsurface drip irrigation (SDI) systems are superior to other irrigation methods due to the minimal contact between the wastewater and the above surface exposed plant foliage and fruits (Oron *et al.*, 1995; Oron *et al.*, 1998). The SDI disposal technology may well serve as an answer to the long-term and continuing debate regarding reuse criteria, mainly for regions where it is difficult to control effluent quality (Crook, 1998).

The fate of pathogenic micro-organisms in soils and aquifer porous media is primarily governed by their transport and persistence in the soil medium environment. The survival and transport processes of pathogens in soils and aquifers are controlled by several major factors: (i) climate (temperature, rainfall); (ii) type of soil (texture, pH, water holding capacity, cation exchange capacity, organic matter content, salinity); and, (iii) type of pathogen (Bales et al, 1991; Gannon et al, 1991; Bitton and Harvey, 1992). Treated wastewater, and primarily treated domestic sewage, can be reused for a large pattern of possibilities, primarily for agricultural irrigation (Campos *et al.*, 2000). Reuse of the effluent for industrial purposes, such as cooling of towers, is another option. The major drawbacks of TWW reuse are the high capital investment in the treatment facilities and equipment, the dual piping system required to distribute it separately from potable water, effluent quality control and additional required precaution to minimize health and environmental risks. The treatment level of effluent in relation to the purpose of reuse is of additional concern. The nutrients contained in the TWW reused for agricultural purposes are, however, mostly beneficial (Oron *et al.*, 1998).

Wastewater can be divided into two major categories: (i) domestic wastewater; and (ii) industrial wastewater. Major efforts on treatment are focused on domestic wastewaters due to the relatively large quantities and simplicity of treatment compared to industrial wastewaters. Industrial wastewater commonly needs special and specific treatment due to the uniqueness of the quality generated in each plant. In some places, disposal of industrial wastewater containing a “cocktail of constituents”, some of them toxic, is evident. The toxic constituents frequently destroy the biological processes and cannot be removed by conventional biological treatment methods.

Several advantages can be listed when considering effluent reuse for agricultural production:

a) closing the gap in water availability between supply and demand, primarily in arid regions. That aspect is subject to the prevailing national water situation;
b) using agricultural fields as contributive and productive disposal sites;
c) increased water availability;
d) open-surface storage reservoirs enhance additional pathogens removal (due to direct solar radiation), after the conventional treatment stages;
e) economic benefit of saving the requirements for extra artificial fertilization due to controlled nutrients content; and
f) reduced need for long conveying transportation systems for the disposal of treated wastewater.

3. PUBLIC HEALTH CONCERNS OF UTILIZING THE EXTRA WATERS

3.1 Toxic substances

Municipal low-level treated wastewater can be frequently considered as a pollution source that may affect human health and the environment. The chemical compounds that are used routinely in the manufacturing industry, agricultural production, and in household wastes are the main sources for contamination. One compilation listed almost 8,000 regulated chemicals. A fraction of the potentially toxic chemicals may inadvertently find their way into the municipal wastewater collection systems. There is no effective method to routinely monitor hazardous pollutants present in wastewater (World Health Organization (WHO), 2001). Results from pilot-scale wastewater treatment systems spiked with selected toxic chemicals indicated that up to 90% of the added chemicals might be removed from wastewater. Certain compounds such as di- and tri-chlorobenzenes hexachlorobutadiene, dibutyl phthalate, butyl benzyl phthalate, bis (-ethylhexyl) phthalate, naphthalene, lindane, dieldrin might be found to concentrate in the sludge fractions (WHO, 2001).

Most of the toxic substances contained in treated wastewater end up in the sludge. It is essential, therefore, to deal (even on a limited scale), with the sludge issue. Surveys in the US revealed that both the occurrence and concentrations of toxic pollutants in municipal wastewater and sewage sludge are extremely variable, and the outcome is often influenced by industrial waste pre-treatment requirements. Upon inflow into the wastewater collection system or during the wastewater treatment, trace elements and organic chemical pollutants tend to be absorbed onto particulates and end up in the sludge fraction. However, even effluents processed with the most advanced wastewater treatment technologies contain traces of organic pollutants (WHO, 2001). The US Environmental Protection Agency

(USEPA) conducted a sludge survey from 208 samples in which more than 400 chemical constituents (USEPA, 1990) where identified. Among those analyzed, 254 chemicals were not detected in any of the samples and only 56 chemicals had frequencies of detection of 10% or greater (USEPA, 1990), as is shown in Table 3. The most frequently found (in more than 50% of the samples) hazardous constituents include Ag, Ba, Cd, Cr, Cu, Ni, Pb, Sn, Ti, Zn, 2-propane, toluene, Bis (2 ethylhexyl) phthalate, dioxins. If one were to consider identifying the pollution sources and related hazard processes of the entire world, it is imperative to assume that any potentially toxic chemical would be found in raw wastewater, effluent, and sludge at the end of the treatment stages (WHO, 2001).

Table 3

Frequencies of detection for chemical constituents found in sewage, sludge, according to the USEPA 1986 National Sewage Survey (USEPA, 1990)

Frequency of Detection (%)	**Chemicals**
< 2	Acetophene, Anthracene, Azinphos methyl, Benzyl alcohol, a-BHC, d-BHC, Biphenyl, Chlorobenzene, Chloroform, 2-Chloronaphtalene, DDE, DDT, Di-n-octyl phihlate, Diazinon, Dibensofuran, 1,4-Dichlorobenzene, trans-1,2-Dichloroethane, 1,2,3,4-Diepoxybutane, Dimethoate, Dimethyl phthalate, 1,4-Dioxane, 1-Endosulfan, 2-Methylnaphtalene, N-nitrosodiphthlene, Naled (Dibrom), Naphathalene, 4-methyl-2-Pantanopne, Phenanthrene, Phosphamidon, Tri-o-tolyn, Phosphoric acid, 2-Picoline, Santox (EPN), a-Terpineol, Tetraethylpyrophosphate, Trichloroethene.
3-5	Aldrin, Benz(a) anthraathene, Ben(a) pyrene, Benz(k) fluoranthene, p-Chloroaniline, Chlorpyrifos, Chrysene, Di-n-butyl phthalate, Dieldrin, Ethylbenzene, Heptachlor epoxide, 2-Hexanone, Isobutyl alcohol, Nitrofen (TOK), Pyrene, Styrene, Tetrachloroethene, Tetrachloromethane, Trichlorofluoromethane, Trifluralin (Treflan), m-Xylene, o- and p-Xylene.
6-9	Benz(b) fluranthene acetie acid, ? -BHC, Butyl benzyl phthalate, Chlorobenzilate, Cobalt, 0-Cresol,p-Cymene, n-Docosane, Endrin, Fluoranthene, n-Octadecane.
10-20	2,4-dichlorophenoxy acetie acid, Carbon disulfide, n-Decane, n-Dodecane, n-Eicosane, H-Endosulfanm, n-Hexacosane, n-Octacosane, PCBs, Pentachloronitrobenzene,2,4,5-trichlorophenoxy propionic acid, n-Tetracosane, n-Tetradecane, Thallium, n-Triacontane.
21-50	Antimony, Beryllium, Boron, 2-Butanone, p-Cresol, Cyanides (soluble salts and complexes), Hexanoic acid, Methylene chloride, Phenol, 2,4,5-trichlorophenoxy acetic acid.
51-99	Bis(2-ethylhexyl)phthalate, Fluoride, Nitrate, Nitrite, 2-Propanone, Silver, Tin, Titanium, Toluene, Vanadium, Yttrium.
99 <	Aluminium, Barium, Calcium, Dioxins, Iron, Magnesium, Manganese, Sodium, Cadmium, Copper, Chromium, Nickel, Lead, Zinc.

Toxic substances have to be addressed during effluent application. Reports from China have indicated serious human health problems related to long-term irrigation with wastewater heavily polluted by industrial waste discharge. A report estimated that around 8.4% of the 2.1 x 10^6 hectares of wastewater-irrigated farmlands in China are seriously polluted and almost 50% of the total acreage exhibited pollutant accumulation in soils (WHO, 2001). This also applies to long-term application of sludge from wastewater treatment plants that might contain heavy metals above acceptable standards.

The prevalence of diseases of chemical etiology is only roughly documented. Some diseases may result from exposure to a specific chemical compound. For example, methyl mercury is the cause of the *Minamata* disease. More often, chemical agents act as one of the co-factors in a multi-causal relationship. For example, the Itai-Itai disease is a disorder of complex etiology in which Cd toxicity is only one of the causal factors. Most of them are substances known or suspected to be carcinogenic, mutagenic, or teratogenic, and they are ubiquitous in the environment (WHO, 2001). The latency period between exposures and the expression of the symptoms may be long and the cause-effect relationship may not be exclusive. There may frequently be several chemicals that all cause cancer. Furthermore, the exposure pathways may not be readily identifiable because these chemicals are common in the environment and the long latency period requires tracking of the exposure over possibly a lifetime. As a result, the exposure due to a given pathway cannot always be separated from the background exposure (WHO, 2001).

As the cause-effect relationship becomes ambiguous, epidemiological evidence is difficult, if not impossible, to obtain. Frequently, dose-response relationships must be derived from animal bioassays or other means. Under these circumstances, the acceptable daily intake (ADI) that is used universally as the basis of toxicological assessments may be conservative (WHO, 2001).

Human health and environmental issues involving toxic substances during the land application of wastewater and sewage sludge, always raise safety considerations related to the crop grown. Unambiguous evidence of harm due to treated wastewater reuse has so far not been apparent. It is a challenge to develop criteria that are not overly restrictive to beneficial use of wastewater and sewage sludge and yet protect human health from potential harm that could be caused by the hundreds of toxic chemicals that may be present in municipal wastewater and sewage sludge (WHO, 2001). There are reports indicating that the metal concentrations of soils irrigated with untreated municipal wastewater from Mexico City, increased steadily with the duration of application (Siebe, 1995). Plant uptake of Cd and Pb increased in proportion to the metal concentrations in the soil.

Since the 70s, the fate and food chain transfer of trace elements via land application of municipal sludge have been investigated extensively. As a part of the rule-making effort, a technical review committee of the USEPA compiled a reference that lists more than 2,300 technical articles (US EPA, 1992b).

3.2 The risk associated with the extra waters utilization

Agricultural fields can, according to local needs and conditions, be considered as acceptor sites for extra waters. Several limitations have to be taken into account when reusing extra waters. These can be attributed to a series of risks that can be minimized by additional treatment stages implementing extra control and precaution phases:

a) health risks due to the presence of microbial pathogens (bacteria, viruses, and parasites). These risks are due to direct and indirect contact between the applied effluent;
b) environmental risks associated with migration of chemical, hazardous and toxic substances into the soil, groundwater, occasionally penetrating into crops (fruits) and animals that are later consumed by humans. High content of ammonia (around 40 mg/L) in secondary effluent might be associated in agricultural fields with nitrate accumulation in the groundwater, assuming that the aquifer location is not very deep. Excess of nitrates in the groundwater

consumed by infants might be associated with the infant disease *methemoglobinemia*. Extra dissolved solids accumulation in groundwater might also hinder further use of the water without a primary treatment stage;

c) agricultural risks associated with sustainable production. These are mainly associated with dissolved solids accumulation in the soil, inhabiting long-range production (soils salinization). (This issue refers to accumulation of dissolved solids in the soil, primarily chlorides causing soil salinization);

d) reuse limitations during wet periods when effluent cannot be reused (ultimate solutions are uncontrolled effluent disposal and/or extended storage);

e) extended storage in open surface reservoirs is associated with evaporation water losses (special needs for evaporation suppression is required); and

f) extended storage is associated with increased content of dissolved solids in the open-surface reservoirs due to evaporation.

Risk assessment is a complex and multi-criteria process, undertaken to assess the probability of harm and damage due to environmental contacts and exposure to pollutants (Van Ginneken and Oron 2000). It identifies the emission sources of toxic chemicals and pathways of transport in the environment and quantifies the risks resulting from exposure to such occurrences. Regulatory agencies and international bodies concerned about public health, food safety, and environmental protection are interested in assessing the exposure of the general public, or its subgroups, to hazardous chemicals present in the environment.

The general mathematical quantitative expression for the risk R due to effluent application is assessed by:

$$R = \text{(potential damage)}/\text{(investment in preventive means)} \qquad (1)$$

This expression is further developed to include terms referring to the probability of damage, primarily of diseases breakouts.

Results of risk assessment are often implemented as the basis for adapting regulatory actions or for issuing advisory guidelines that minimize the health risks due to exposure. During land application of reclaimed wastewater and sewage sludge, potentially toxic pollutants may be introduced into the soil, the starting point of the human food chain. Through the food chain transfer, the potentially toxic pollutants may inadvertently affect the health and wellbeing of consumers, as plants absorb the chemicals from the soil. Pollutants accumulated in the soil as the result of land application, may subsequently contaminate surface and groundwater, resulting in additional exposure. The potential health and safety implications of land applications are serious concerns worldwide. To define a safe operating domain, it is imperative that the concepts of risk assessment be employed to establish safe levels of pollutants in applied wastes, receiving soils, or harvested crops. The success of a risk assessment exercise, however, is dependent on the assessment methodology employed and the availability and quality of technical data used and scientific soundness of the analysis (WHO, 2001).

3.3 The risks due to residual disinfection byproducts (DBPs)

In recent years, there has been increased awareness and extended reference to a certain class of pollutants known as disinfection byproducts (DBPs). Disinfection byproducts are formed when organic precursor materials contained in the water react with the disinfectant, such as chlorine or ozone. Disinfection byproduct precursors include aquatic humic substances that are non-biodegradable and originate from peat soils or decaying vegetation. Trihalomethanes (THMs) are one group of DBPs that are formed when water containing organic materials is chlorinated. Two of these compounds, chloroform and bromoform, are probably animal carcinogens and are suspected human carcinogens.

Agricultural pesticides may also contribute to the formation of THMs. Further monitoring is needed before any conclusions can be made and action taken regarding the impact of pesticides.

In addition, there are preliminary indications that seawater intrusion into the land also contributes to THM formation and accumulation, primarily by increasing bromide levels (California Bulletin, 1994). Bromide ions in the water are oxidized to a form that competes with chlorine and reacts more quickly with organic precursor materials to form THMs and other DBPs during disinfection. The elevated bromide levels combined with the chlorination process are mainly important when dealing with drinking waters originated from groundwater. It must be stated that currently, the health effects of THMs are uncertain. Additional sources of THMs are:

1) substances that leach and/or are dissociated from the materials of the distribution systems. These include lead, copper, sometimes zinc and frequently other substances. Polyvinyl Chloride (PVC) plastic pipes include lead and probably other constituents as stabilizers; and
2) industrial wastes, primarily from small facilities releasing wastes with minimal treatment and uncontrolled into the municipal collection system.

Although the difficulties associated with accurate assessment of the quantity of pollutants contributed by each source, the limited information available only permits crude comparisons to be made of the relative impacts of the various sources. Consequently, new diseases, including water-borne diseases, periodically break out either because they are new and hardly recognized (improved detection and monitoring equipment allows better identification), or due to their increased impact. It may also be due to the micro-organisms themselves combined with chemical constituents evolving, and adverse effects on human health or environmental pollution phenomena.

3.4 Risks associated with other chemicals contained in the effluent

The reuse of treated wastewater is associated with a series of health and environmental risks. These can be diminished by adequate treatment along with controlled disposal and reuse. National and international authorities such as WHO, USEPA and other agencies collaborate on risk assessment procedures. These are the forthcoming challenges related to rules for water and wastewater quality. Cooperation between the different agencies provided the initial stages of the state of the art aspects and will lead to acceptable reuse criteria.

3.4.1 Pharmaceutically active chemicals and endocrine disruptors

A large number of drug residues such as the antiphlogistics, lipid regulators, and beta-blockers have been found in treated wastewater effluent (Bruchet *et al.*, 2002). Among the pharmaceutically active ingredients, the residues of antibiotics and hormone-like compounds have attracted the most attention (Quanrud *et al.*, 2003). Although the conventional wastewater treatment is not designed specifically to remove potentially toxic chemicals, the process nevertheless effectively reduces their concentrations in the treated effluent, usually less than 10 mg/L (WHO, 2001).

Endocrine disrupting substances are, mostly, synthetic chemicals that interact with the endocrine systems and result in the disruption of normal biological functions, including growth, development and maturation (Drewes *et al.*, 2003). When interacted with the endocrine system of an organism, these substances may act like a natural hormone and bind to a receptor, may interfere with the normal hormonal responses by binding and, therefore, blocking the receptor, or may interfere with the organism's synthesis and control of the natural hormones (WHO, 2001).

In addition to the natural hormones produced by animals and synthetic steroids found in the contraceptives (17 b-estradiol, estrone, testosterone, and ethynylestradiol), other substances displaying endocrine-disrupting properties include surfactants (alkylphenols and their degradation products nonylphenol and octylphenols), organochlorine pesticides (DDT, dieldrin, lindane, atrazine, trifluralin, and permethrin), plasticizers (dibutyl phthalate, butylbenzylphthalate, diethylhexylphthalate, and polyethylphthalate), dioxins, PCBs, and tributyltin. Under exposure conditions and high concentrations, the adverse effects of selected chemicals on the development and reproduction, cognitive and neuro-behaviour, and immune responses of the exposed organisms have been recognized (WHO, 2001).

The extent of harm caused by the exposure to different levels commonly encountered in the environment is uncertain. It has been hypothesized that endocrine disruptors, acting as weak estrogens, are capable, either alone or in combination, of producing a variety of adverse effects including cancers, reproductive and fertility disorders, learning disability, and immune and thyroid dysfunction (WHO, 2001).

3.5 The impact of pollutants content in effluent

It is important that information related to pollutant concentrations be dealt with and considered in a rational perspective. This can be accomplished by comparing the concentration of a specific pollutant in a sample of water, sediment, or animal tissue and then comparing it with samples taken from the command contaminated sites. This is based on the assumption that the reference data has probably no link to the polluted site, which allows a relatively reliable assessment. Data and information from reference sites have been used in some studies on impure sites around the world.

Another alternative approach is to compare the pollution level with established standards. These standards are commonly established after serious discussions and considerable work by groups of experts. The standards subsequently issued by the local and national authorities (environment; health; water consumers; legislative authorities) become the key levels to be met during the treatment and disposal of the wastes.

4. THE POLLUTANTS LOAD

The load estimates (and related risks) of some pollutants that infiltrate into the soil, groundwater, are in contact with the humans, animals and plants and/or other mediums, depend on the contamination sources, treatment level and site sensitivity. The pollution load also depends on the dosage of the harmful substance and the related exposure duration of the target entity. The complementary aspects refer to the sensitivity of the entity that is offended. Other considerations refer to the seasonal and ambient conditions and related precautions taken at the specific target site. Assessing the pollution load in municipal and industrial effluent is commonly based on repeated monitoring and estimates of other sources or predictive models. It refers to the various types of pollutants, including organic pesticides and non-organic pollutants that are frequently applied in enormous quantities in agricultural areas.

Quantifying the pollutant loads of the various sources is only the first step towards understanding the effects of pollutants on the environment. Many factors other than mass loading, such as environmental conditions and physical characteristics of pollutants, must be considered. For example, the chemical form in which a particular pollutant enters the disposal and/or specific site may influence its effect on organisms. These include, for example, additional constituents contained naturally in the area, potential of oxidation and reduction reactions and reaction as given by the pH. Trace elements in urban and non-urban runoff waters are primarily in particle-associated forms, while those in municipal and industrial effluent are likely to be in dissolved forms; consequently, a different impact can be expected. Timing (e.g., before or after a hydrological event of precipitation), location and distribution of pollutant inputs differ considerably among the various sources and might influence their final degradation or remaining in their original form. All of these factors should be considered when assessing their relative impact.

When analyzing the chemical pollution risk, a clear distinction should be made between the waste emerging from the industry and the portion originating from human and animal activities. This will be the first stage in adequate treatment and prevention of any future damage.

5. TOXICITY FACTORS OF THE VARIOUS WATER SOURCES

5.1 Toxicity hazard of the domestic wastewater

Commonly, the toxicity of treated domestic wastewater (TDWW) imposes negligible chemical health and environmental risks to the community. Treated wastewater can be toxic due to uncontrolled deposal of industrial wastes. Under these circumstances, the added chemicals might jeopardize the entire biotical treatment phases, and mainly constitute a risk to the public and the environment.

5.2 Toxicity of surface urban runoff waters

Water districts and national water authorities have begun programmes aimed at reducing non-point pollutant loads to large water bodies such as oceans, lakes and reservoirs. The first step of the programme involves determination of the toxicity of waters entering the water body. For adequate control, water samples have to be taken from streams, the reservoir release sites, and industrial/commercial plants, agricultural areas, residential, and open space areas. Bioassays of water samples have to be conducted using water parasites, biological indicators, aquatic plants and animals, and freshwater algae. The bioassays must comply with seasonal streams (dry and wet) and related toxicity. However, water samples have to be taken regularly in order to detect changes and to prevent any damage. Validated toxicity level refers to about 80 percent of the toxicity tests.

5.3 Toxicity of open surface areas runoff waters

Agricultural runoff is one of the main contributors of non-urban runoff to the surrounding pollution. Extensively developed agricultural lands contribute particularly large quantities of organic compounds and trace elements to the rivers and other open areas.

Similar studies carried out on the San Joaquin River and its tributary drains during 1988-1990, showed extraordinarily high levels of several agricultural pesticides. On several occasions, levels of some pesticides in parts of the river exceeded the EPA recommended criteria by as much as 30 times (Bennet *et al.*, 2001). In many of the bioassays of water sampled from the river and its tributaries, all of the test organisms died. At times, normal agricultural practises rendered as many as 50 miles of the river toxic.

5.4 Toxicity hazard of industrial wastewater

In most cases, the main causes of water pollution are due to low treatment and uncontrolled disposal of industrial wastewater. There are also cases in which industrial wastewater is disposed of into the urban domestic treatment systems. Although the amounts are small, the content of toxic elements in industrial wastes might hinder adequate treatment of domestic organic wastes. Separate disposal and treatment systems are required for domestic and different other wastes. Generally, uncontrolled disposal of industrial wastewaters imposes the greatest risks on the community and nature, including diverse water sources.

6. MAIN POLLUTING CONSTITUENTS

6.1 Inorganic compounds

The most common contaminating elements are listed in Table 4. Part of these constituents is contained in wastes and is potentially emerging in soils, plants and some animals. Many of them are biologically beneficial in small quantities but will become harmful at high levels of exposure. For some, no toxicological threshold has been established (i.e., Co and Cu) or the thresholds are rather high (i.e., B, F, and Zn). Co, Cu, and Zn can be excluded since the plants are not absorbing them in quantities that might be a risk to human consumption.

Table 4

Inorganic elements included in selected standards and guidelines
(WHO, 2001)

Element	RTI 1998^1	Illinois 1998^2	US EPA 2000^3	US EPA 1993^3	European countries^5	China 1996^6	WHO 2000^7
As	X	X	X	X	X	X	X
B						X	X
Ba	X	X	X				X
Be	X	X	X				
Cd	X	X	X	X	X	X	X
Cr	X	X	X	X		X	X
Co					X		
Cu				X	X	X	X
F	X		X		X		X
Pb	X		X	X	X	X	X
Mo			X	X	X		X
Hg	X		X	X	X	X	X
Ni	X	X		X	X	X	X
Se	X	X	X	X	X		X
Ag	X	X					
Tl			X	X			
Sb		X					X
V	X		X	X			
Zn				X	X	X	
U							X

1) Centre for Environmental Analysis, Research Triangle Institute, 1998; 2) Illinois EPA, 1998; 3) USEPA, 2000; 4) USEPA, 1993; 5) Smith, 1996; 6) Xia, 1996; 7) WHO, 1998.

Chromium is mainly obtained from the galvanization industry. Commonly, it is contained in low concentrations in waste and, therefore, it is relatively difficult to remove. Chromium exists in water systems in two principle oxidation states: Cr^{3+} and Cr^{6+}. The common form is Cr^{3+} where the most toxic one is Cr^{6+}. Cr^{6+} is highly toxic for aquatic life, to zooplankton at less than 0.5 µg/L. It is, therefore, necessary to remove the Chromium prior to reaching conventional wastewater treatment plants.

The main properties of chromium include the following:

a) Cr^{3+}: (i) present under reducing - anoxic (Oxygen Free) conditions; (ii) high tendency for sorption, precipitation and complexation with organic matter, tends to accumulate in bedded sediments under low flow conditions; and
b) Cr^{6+}: (i) highly soluble - limited tendency for sorption, precipitation and complexation; (ii) photochemistry - reduction by light generated free radicals.

Current regulatory approach allows Cr^{3+} to be discharged to transient streams with limited dilution at 50 µg/L, and up to 10 µg/L in drinking waters (Table 5). Further work and regulatory activities are needed to enforce maximal concentrations in water bodies.

Table 5

USEPA fresh water quality criterion (µg/L). (Not to be exceeded more than once in three years. Cr^{6+} toxic to zooplankton at 0.5 µg/L)

Oxidation State	1 Hour Average	4 Day Average
Cr^{3+}	1,700	210 (100 mg/L $CaCO_3$)
Cr^{6+}	15	10 (dissolved)

The inclusion of Mo, and especially B, in this list may be controversial since boric acid is a commonly used household chemical and is not regularly associated with any excessive toxicity. There is limited human toxicological reference to these two elements. The oral reference doses established were derived from limited animal bioassay data that exhibited toxicological effects in the form of cellular necrosis. Boron Mo, and F form anions in soils and, under appropriate circumstances, may be readily absorbed by plants and thus enter into the human food chain (WHO, 2001).

6.2 Organic compounds

Actual and potential chemical pollutants can be classified into several sub-groups. This classification stems mainly from the structure and origin of the substances. The set of compounds in Tables 4 and 6 (around 20 inorganic elements and 28 organic compounds, respectively) will be evaluated for possible inclusion in WHO global guidelines for land application of wastes (WHO, 2001). The toxic chemicals outlined in Tables 4 and 6 represent potential chemical regulations subject to diverse utilization purposes, such as drinking water, industrial or agricultural reuse and hazardous waste management.

Table 6

Organic compounds listed in selected standards and guidelines
(WHO, 2001)

Compound	RTI 1998[1]	European 1996[5]	US EPA 2000[3]	Illinois 1998[2]	China 1996[6]	WHO 1998[7]
Aldrin	X			X		
Benzene	X	X	X		X	X
Benzo(a) pyrene	X	X	X	X	X	X
Chlorodane	X		X	X		
Chlorobenzene	X	X	X			X
Chloroform	X		X	X		
Dichlorobenzene	X	X	X			X
2,4-D	X	X	X			
DDT	X					
Dieldrin	X			X		
Heptachlor	X		X	X		
Hexachlorobenzene	X		X	X		
Pyrene	X	X				
Lindane	X		X			
Methoxychlor	X		X			
Pentachlorophenol	X	X	X	X		
PSBs	X	X	X	X		
Tetrachloroethane	X			X		
Tetrachloroethylene	X		X	X	X	X
Toluene	X			X		X
Toxaphene	X		X	X		
2,4,5-T	X		X			
2,3,7,8-TCDD	X	X	X			
Trichloroethene					X	X
LAS		X			X	
Phthalete (PAE)		X	X			
Alkyl phenols		X				
Aromatic/alkyl amines		X	X			

1) Center for Environmental Analysis, Research Triangle Institute, 1998; 2) Illinois EPA, 1998; 3) U.S. Environmental Protection Agency, 2000; 4) U.S. Environmental Protection Agency 1993; 5) Smith, 1996; 6) Xia, 1996; 7) WHO, 1998.

6.3 Pesticides

Pesticides are used to get rid of insects (insecticides) and plant diseases (herbicides). Pesticides consist of different chemical constituents with some protein elements. According to the conditions and the target body, their application is associated with lethal or temporary elimination of the potential damaging factor. The risk associated with the application of pesticides is due to the following: (i) the residual pesticides remaining in and on the soil are flashed during irrigation or runoff to end-water collecting bodies which serve as water sources for diverse purposes; (ii) residual pesticides remaining in the soil and migrating to the groundwater or are linked with all cultivation activities on the soil surface; and (iii) residual pesticides that also penetrate the plants. The residual content of herbicides in the water and soil vary greatly according to their solubility and adsorptivity in the soil colloidal particles.

Commonly, there are three main processes by which pesticides harm human beings and other living beings: (i) orally, through the mouth and the digestive system; (ii) dermally, namely through the skin (the severity of toxicity depends on dosage, contact time, sensitivity and immune level of the individual, and the part of the body); and (iii) via inhalation processes (the nose and the respiratory system). According to the above, toxicity is usually expressed as the acute oral 50% lethal dosage (LD_{50}) which states that 50% of the harmed community under investigation is killed (Table 7): (i) "acute oral" (relative short time effect) that refers to a single dose taken by mouth or ingested; (ii) "acute dermal" (relative short time effect) that refers to a single dose applied directly to the skin (skin absorption); and (iii) "inhalation" that refers to exposure through breathing or inhaling.

Table 7

Hazard indicators categories (Clemson University, 2004)

Most toxic/hazardous< **>Least toxic/hazardous**

I	II	III	IV
Oral $\mathbf{LD_{50}}^{a}$= 0-50 mg/kg$^{b.}$ **Inhalation** $\mathbf{LC_{50}}^{c}$= 0-0.2 mg/kg.	50-500 mg/kg 0.2-2 mg/L	500-5,000 mg/kg 2-20 mg/L	5,000 mg/kg < 20 mg/kg <
Dermal (skin) $\mathbf{LD_{50}}^{1}$**=** 0-200 mg/kg.	200-2,000 mg/kg	2,000-20,000 mg/kg	20,000 mg/kg <
Eye effects: Corrosive: Corneal opacity not reversible within 7 days.	Corneal opacity reversible within 7 days. Irritation.	No corneal opacity reversible within 7 days.	No Irritation.
Skin effects: Corrosive.	Severe irritation at 72 hours.	Moderate irritation at 72 hours.	Mild or slight irritation at 72 hours.
Signal words: DANGER/POISON: in large boldface letters on the label and usually accompanied by the skull and crossbones symbol.	**WARNING:** in large boldface letters.	**CAUTION:** in large boldface letters.	**CAUTION:** in large boldface letters.
Acute (single) oral dosage lethal to human adults: Few drops to 1 teaspoon.	1 teaspoon to 2 tablespoons.	28 cm^3 to 470 cm^3 [1 ounce to 1 pint].	470 cm^3 < [1 Pint <].

Recently, the Environmental Protection Agency established four toxicity categories based on the LD50 and eye and skin effects of the various pesticides. For safety reasons and as a warning, these toxicity categories are described by the signal words present on the front panel of the pesticides label (Table 7).

Chronic toxicity refers to the long-term harmful effects due to exposure to pesticides (commonly low level). The chronic outcome intensifies with the combination of human immunity, pesticides characteristics and time factor. Standard measurements for assessing toxic levels such as LD_{50} are still required. Toxicity levels of some pesticides are listed in Table 8.

Table 8

Toxicity thresholds of some used pesticides (Iowa State University, 2001)

Trademark	**Common Name**	**Water solubility (ppm at 20-27ºC)**[a]	**Toxicity (acute oral LD$_{50}$) mg/kg**[b]	**Soil Persistence at Common Use Rates (months)**
Accent	nicosulfuron	360	5,000+	1-9
Atrazine	atrazine	33	3,080	2-8
Authority	sulfentrazone	780	2,416	3-7
Banvel/Clarity	dicamba	4,500	1,140	1-1.5
Basagran	bentazon	500	1,100	0.5
Beacon	primisulfuron	70	5,000+	2-9
Bladex	cyanazine	171	835	2-3
Blazer/Ultra Blazer	acifluorfen	Soluble	1,300	1
Buctril	bromoxynil	130	779	1[c]
Classic	chlorimuron	1,200	5,000+	1-9
Command	clomazone	1,100	2,340	3-6
Dual II MAGNUM	metolachlor	530	2,780	2.0-2.5
Eradicane	eptc	370	1,370	1.5-2
Evik	ametryne	185	10,002	1-3
Fusilade	fluazifop-p-butyl	2	4,830	0.25
Gramoxone Extra/max	paraquat	Soluble	120	1[c]
Harness	acetochlor	223	2,150	1.5-2
Lasso	alachlor	242	1,200	1.5-2
Libery	glufosinate	>1millon	2,030	1
Lorox	linuron	75	1,254	2-4
Pinnacle	thifensulfuron	2,400	5,000+	0.25
Poast Plus	sethoxydim	48	2,676	0.25
Princep	simazine	5	5,000	2-8
Prowl	pendimethalin	1	3,380	3-6
Ramrod	propachlor	700	710	1-1.5
Pursuit	imazethapyr	1,400	5,000+	3-11
Reflex	fomesafen	Soluble	5,000+	6-12
Roundup	glyphosate	Soluble		1[c]
Scepter	imazaquin	60-120	>5,000+	3-11
Sencor	metribuzin	1,200	2,890	2-4
Sonalan	ethalfluralin	1	10,000	3-5
Surflan	oryzalin	1	10,000	3-7
Surpass	acetohlor	223	2,150	2-3
Sutan+	butylate	45	3,880	1-1.5
2,4-D	2,4-d	600	300-1,000	0.25
Treflan	trifluralin	1	3,700	3.6

(a) Higher number indicates higher water solubility.
(b) Higher number indicates lower toxicity.
(c) No herbicidal activity in soil, although residues can be detected.

7. REMOVAL OF POLLUTANTS FROM WASTEWATER

7.1 General

Substantial progress has been made over the last decades in controlling pollution. However, there are limits to the amount of environmental protection that can be achieved by current regulatory programmes that emphasize management after pollutants have been generated. Most programmes focus on treatment, control, and disposal, and can sometimes result in the transfer of pollutants from one environmental medium to another, from one site to another, posing an environmental hazard. Only adequate treatment and removal of toxic substances will minimize pollution, along with reduced pollutant environmental loads.

Most treatment methods focus on source reduction or recycling measures that reduce the volume and/or toxicity and health hazard of generated wastes. Most treatment processes are associated with pollution prevention. Several measures can be considered for minimizing pollution hazards:

1) flexible adaptation to environmental constraints;
2) waste minimization along with real reduction in content of toxic substances;
3) adaptation of treatment methods DOORZLQJ recycling part of the VXEVWDQFHV (e.g., Alum that is used in coagulation-flocculation processes can be H[WUDFWHG for another use cycle);
4) implementing advanced treatment technology, primarily membrane processes; and
5) implementation of advancedG management policies for improved operation and maintenance of water facilities. It includes combining wastewater treatment facilities with target sites for effluent reuse, deeper insight into systems combining water supply and quality at the production sites taking into account the characteristics of water requirements (quality and quantity) at the command sites. It also includes combining waters obtained from different sources, such as collecting runoff waters form wadies (seasonal dry bed rivers) and combined storage with treated domestic wastewater.

7.2 Biological treatment processes

Biological processes are more commonly used to treat domestic or combined domestic and industrial wastewater (after primer treatment in the plant yard, also containing a high portion of organic matter) from a municipality. The biological processes simulate natural phenomena in the receiving waters but are improved by implementing better control conditions (e.g., oxygen content, higher exposure to solar radiation). The reactions are completed before the obtained effluent is delivered to environmental sites.

7.3 Physical and chemical treatment processes

Combinations of physical and chemical processes are more often used to treat industrial wastewaters directly because they often contain pollutants that cannot be removed efficiently by biological processes. Industries that deal with biodegradable materials, such as food processing, breweries, dairies, and even paper, plastics and petrochemicals can be combined with biological stages. The emerging membrane technology provides another efficient tool for industrial wastewater treatment.

The purpose of the physical process is usually to treat the suspended matter by separation, rather than the dissolved pollutants. The dissolved solids can be removed mainly by membrane phases. Suspended pollutants are commonly removed by settling or naturally float to the top of the separation facility, depending on whether they are more or less dense than water. The separation processes can be enhanced by mechanical stages and adding chemical flocculants, such as by gentle stirring causing more small particles to collide and stick together, forming larger particles which will settle or rise faster. Chemical flocculants may also be added to produce larger particles. Dissolved air under pressure may be added to cause the formation of tiny bubbles that will attach to particles and enhance flotation processes.

Filtration through a porous media, such as sand (granular filtration), anthracite coal, garnet and others, as a final treatment stage can result in very clear water. The advanced membrane technology probably promises better results; at higher costs, however. ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) are membrane processes which force water through membranes and can remove colloidal material (very fine, electrically charged particles, which commonly will not settle). Absorption on activated charcoal (activated carbon) is another physical process that can remove dissolved chemicals, mainly odours and episode constituents. Air or steam stripping can be used to remove pollutants that are gases or low-boiling liquids from water. The vapours that are removed by air or steam stripping are frequently transferred through beds of activated carbon to prevent air pollution.

Alkaline materials, like sodium or calcium hydroxide, are examples of chemical constituents used in chemical reaction to enhance solids settling. Dissolved iron or aluminium salts or other organic coagulant aids, such as polyelectrolytes, can be added to augment flocculation and settle (or float) the precipitated metal. The coagulant dosage and selection has to be adjusted to the medium separated, mainly according to the main ions content. Chlorine can be used to oxidize toxic cyanide compounds into harmless nitrogen and carbon dioxide components

Degrading organic chemicals by oxidation, using ozone or hydrogen peroxide, alone or in combination with catalysts (chemicals which speed up reactions) and/or ultraviolet light is an additional option, primarily for industrial non-organic wastes. The use of oxidants has to be adjusted to the medium treated along with characterizing all chemical potential reactions.

In municipal treatment plants, chemical treatment in the form of aluminium or iron salts is often used for removal of phosphorus by precipitation. Chlorine or ozone (or ultraviolet light) may be used for disinfection. Sulfur dioxide or sulfite solutions can be used to neutralize (reduce) excess chlorine, which is toxic to aquatic life. Chemical coagulants are also used extensively in sludge treatment to thicken the solids and promote the removal of water.

Boron is one of the toxic constituents hindering high agricultural production in some areas (Table 9). Removal of boron from the applied effluent can improve agricultural productivity. Most of the boron is obtained from treatment plants since it originates from desalinated seawater or water originally obtained, non-officially, from surfactant industry.

Table 9

Boron sensitivity of selected Colorado plants
(B concentration, mg/L) (Mass, 1987)

Sensitive		**Moderately Sensitive**	**Moderately Tolerant**	**Tolerant**
0.5-0.75	0.76-1.0	1.1-2.0	2.1-4.0	4.1-6.0
Peach Onion	Wheat Barley	Carrot Potato	Lettuce Cabbage	Alfalfa Sugar beet
	Sunflower	Cucumber	Corn	Tomato
	Dry Bean		Oats	

*Maximum concentrations tolerated in soil water or saturation extract without yield or vegetative growth reductions. Maximum concentrations in irrigation water are approximately equal to these values.

Removing boron from water is a complicated process and can be prohibitively expensive and impractical. In addition, the concept of mixing two water resources, one raw and the other purified, can reduce the overall quantity of water to be treated, thereby diminishing the economic burden of purification.

Boron reduction of permeates in seawater desalination consist of permeate flow separation. The process is characterized by the collection of permeate from both ends of the membrane vessels. The concentration of boron at the feed end is lower and this stream is used for blending. Permeate flow from the rear end has a high content of boron and has to be treated. The comparative cost of boron reduction by the various alternative methods is very complex, and is highly dependent on various site-specific operational and economic parameters.

Treatment relating to boron removal processes includes several categories. The first are in the precipitate processes group (including coagulation, enhanced coagulation, lime softening and enhanced lime softening). The next two categories are absorption processes by activated alumina and Ion exchange (IX). The last category includes the membrane processes (reverse osmosis (RO) and electro-dialysis-reversal (EDR)).

A preliminary review of these treatment processes indicates that three processes can be best suited for post treatment of seawater permeate: IX, RO and EDR (Kabay *et al.*, 2004) (and a brief discussion of these methods to reduce or remove boron from permeate is given).

8. REUSE CRITERIA FOR LOW QUALITY WATER APPLICATION

8.1 General

Reuse criteria for effluent application for irrigation often includes limits linked with the suspended solids, Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD) and organic chemicals (oil and grease, trichloroacetylaldehyde, petroleum hydrocarbon, and detergent residues). Numerical limits for these chemicals were included, probably because of their potential effects on operation and maintenance (BOD_5, suspended solids, and oil and grease), groundwater pollution, (petroleum hydrocarbon and benzene), or plant growth (petroleum hydrocarbon, detergent residues, etc.). The inclusion of these constituents in the criteria is undoubtedly an indication that these pollutants are prevalent in wastewater streams bound for crop irrigation, at least in some countries (WHO, 2001). Under ordinary circumstances, besides toxic chemicals municipal wastewater also contains other constituents, commonly in low concentrations (Table 10).

Table 10

Typical concentrations of selected elements in untreated wastewater (WHO, 2001)

Element	Concentration (mg/L)
Aluminium	0.3-3
Arsenic	0-0.2
Barium	0-0.2
Boron	0.5-3
Cadmium	0.01-0.2
Chromium	0.1-0.3
Cobalt	-
Copper	0.01-0.5
Iron	0.5-6.5
Lead	0-1
Manganese	0.05-0.15
Mercury	0.0002-0.003
Nickel	0.05-0.5
Zinc	0.01-2.1

Conventional wastewater treatment employing the primary and secondary treatment stages are effective in removing the organic matter (BOD_5) and suspended and colloidal solids from the wastewater. Alternatively, organic matter removal can be expressed by the content of total organic carbon (TOC). When the processes are not designed specifically for their removal, significant quantities of the toxic chemicals in municipal wastewater are removed as colloidal and suspended solids at the end of the treatment process, and are finally accumulated in the sludge fraction as shown in the Table 11. The removal of toxic elements in conventional treatment plants is not consistent and special attention has to be given to the residual content in the effluent. Consequently, the concentrations of toxic chemicals in treated effluent can vary in a relatively broad range. As sludge accounts for a very small fraction of the total mass in wastewater, the concentrations of toxic chemicals tend to become elevated through the subsequent stabilization and volume reduction processes employed in sewage sludge handling (WHO, 2001).

Table 11

Assessed pollutant removal efficiencies of conventional waste water treatment processes (WHO, 2001; Neufeld and Herman, 1975)

Constituent	Influent (mg/L)	Primary Treatment (mg/L)	Secondary Treatment (mg/L)	Overall Removal (%)
Cu	0.39	0.25	0.08	79
Zn	0.66	0.42	0.23	65
Ni	0.30	0.24	0.15	50
Pb	0.03	0.07	0.08	Not Consistent
As	0.015	0.017	0.013	Not Consistent
Cd	0.01	0.02	0.013	Not Consistent
Cr	0.55	0.37	0.013	76

In urban areas, wastewater from industries and commercial establishments is frequently collected and treated at the same facilities that handle the domestic sewerage. Communities that adopted industrial wastes pre-treatment to eliminate toxic pollutant discharges from industries and businesses, often experience dramatic reductions in toxic pollutant concentrations in both treated wastewater and in sewage sludge. When properly treated, wastewater effluent from communities that practise industrial wastewater pre-treatment used for crop irrigation, the toxic chemicals do not constitute a serious issue in terms of public health or the contamination of irrigated fields (WHO, 2001).

Low quality waters contain several constituents that hinder their direct utilization for diverse purposes. Consequently, at least partial treatment is required prior to reuse. Low quality waters might contain pathogen micro-organisms (bacteria, protozoa, helminths, viruses and intestinal parasites) that are the principal infectious agents that can be detected in raw and treated municipal wastewater. The major risk associated with the presence of pathogens is infection due to direct contact. Additional risks are associated with soil contamination and potential migration of the different micro-organisms into the groundwater, which is the primary water source for human consumption.

Effluent also contains various groups of hazardous chemical compounds that might jeopardize public health and contaminate and deteriorate the environment. It includes cationic, anionic and non-ionic surfactants, atmospheric surfactants, solvents, and miscellaneous compounds. The contaminants include around 400 compounds and indicate the environmental hazards associated with non-controlled recharge into the aquifer. Contamination is mainly due to accumulation of the pollutants in the soil and the groundwater.

8.2 The effluent salinity and sodicity

The health and environmental authorities in many countries enforce guidelines for reuse and disposal. These criteria are imposed in order to guarantee safe reuse (primarily for irrigation, aquifer recharge and enrichment of water recreation sites). These reuse criteria frequently raise scientific merits and practical disputes due to the level of treatment, the responsibility of the related authorities and the national factors that will pay for the treatment.

Since the main reuse options are agricultural and ornamental irrigation, the salinity level of the applied effluent is often of first priority (Mass and Hoffman, 1977; Hoffman *et al.*, 1986). An increase in effluent salinity can generally be expected due to household activities (subject to various standards of living). The contribution of household salinity is in a broad range, is estimated from 100 mg/L to 500 mg/L TDS (Siegrist *et al.*, 1976). Consequently, applying treated wastewater refers to application of saline water. Therefore, it is reasonable to take into account, during effluent application, plant tolerance and soil contamination in view of sustainable agricultural production (Tables 12 and 13). The electrical conductivity (EC) is a general measure referring to total dissolved solids (TDS) content, assuming that chlorides are approximately half the total dissolved solids content (Tables 14 and 15). While considering water quality, one must also to take into account the sodium content in reference to calcium and magnesium, as given by the SAR parameter (Table 16; Ayers, 1977). The hazard of sodium content is also strongly related to the soil properties. Elevated concentration sodium (as also compared with calcium and magnesium) in the water and the related soil properties might affect the hydraulic properties of the soils and the water flow pattern (Table 14). Table 17 summarizes some relationships among the various water and soil properties parameters.

Table 12

Proposed limits for irrigation water use based on the electrical conductivity

Classes of water	Electrical Conductivity (dS/m)*
Class 1, Excellent	= 0.25
Class 2, Good	0.25 - 0.75
Class 3, Permissible[1]	0.76 - 2.00
Class 4, Doubtful[2]	2.01 – 3.00
Class 5, Unsuitable[2]	3.00 =

*dS/m at 25° C = mmhos/cm; [1]Lecahing is needed.
[2]A good drainage system is required for sensitive plants.

Table 13

Chloride classification of irrigation water (Mass, 1990)

Chloride (ppm)	Effect on Crops
Below 70	Generally safe for all plants
70-140	Sensitive plants show injury
141-350	Moderately tolerant plants show injury
Above 350	Can cause severe problems

Chloride tolerance of selected crops. Listing in order of increasing tolerance:
(low tolerance) dry bean, onion, carrot, lettuce, pepper, corn, potato, alfalfa.

Table 14

Susceptibility ranges for selected crops to foliar injury from saline sprinkler irrigation (Mass, 1990)

	Na or Cl concentration (mg/L) causing foliage injury			
Na Concentration	**<46**	**46-230**	**231-460**	**460<**
Cl Concentration	**<175**	**175-350**	**351-700**	**700<**
	Apricot	Pepper	Alfalfa	Sugar beet
	Plum	Potato	Barley	Sunflower
	Tomato	Corn	Sorghum	

Foliar injury is influenced by cultural and environmental conditions. These data are presented only as general guidelines for daytime irrigation.

Table 15

Potential yield reduction due to saline water application for selected irrigated crops (Ayers, 1977)

Assessed percentage in yield reduction				
Crop	**0**	**10**	**25**	**50**
	EC[2]			
Barley	5.3	6.7	8.7	12
Wheat	4.0	4.9	6.4	8.7
Sugar beet	4.7	5.8	7.5	10
Alfalfa	1.3	2.2	3.6	5.9
Potato	1.1	1.7	2.5	3.9
Corn (grain)	1.1	1.7	2.5	3.9
Corn (silage)	1.2	2.1	3.5	5.7
Onion	0.8	1.2	1.8	2.9
Beans	0.7	1.0	1.5	2.4

[3] Sensitive during germination. EC should not exceed 3 dS/m for garden beets and sugar beets.

Table 16

The sodium hazard of water based on SAR values

SAR	**Sodium hazard of water**	**Comments**
<5	No hazard	
6-9	Low hazard	Use on sodium sensitive crops must be cautioned
10-17	Medium	Amendments (such as gypsum) and leaching needed
18-25	High	Generally unsuitable for continuous use
26 =	Very high	Generally unsuitable for use

Table 17

Guidelines for interpretations of water quality for irrigation
(Metcalf & Eddy, 1991)

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity (affects crop water availability)				
EC	**dS/m**	**< 0.7**	**0.7-3.0**	**3.0 <**
TDS	**mg/l**	**< 450**	**450-2000**	**2000 <**
Permeability (affects infiltration rate of water into the soil. Evaluate using EC and SAR or adj R_{Na} together)				
SAR = 0-3		**and EC ^{3} 0.7**	**0.7-0.2**	**0.2 <**
3-6		**^{3} 1.2**	**1.2-0.3**	**0.3 <**
6-12		**^{3} 1.9**	**1.9-0.5**	**0.5 <**
12-20		**^{3} 2.9**	**2.9-1.3**	**1.3 <**
20-40		**^{3} 5.0**	**5.0-2.9**	**2.9 <**
Specific ion toxicity (affects sensitive crops)				
Sodium (Na)				
Surface irrigation	**SAR**	**< 3**	**3-9**	**9 <**
Sprinkler irrigation	**mg/l**	**< 70**	**70 <**	
Chloride (Cl)				
Surface irrigation	**mg/l**	**< 140**	**140-350**	**350 <**
Sprinkler irrigation	**mg/l**	**< 100**	**100 <**	
Boron (B)	**mg/l**	**< 0.7**	**0.7-3.0**	**3.0 <**
Miscellaneous effects (affects susceptible crops)				
Nitrogen (Total N)	**mg/l**	**< 5**	**5-30**	**30 <**
Bicarbonate (HCO_3) (overhead sprinkling only)	**mg/l**	**< 90**	**90-500**	**500 <**
Residual chlorine (overhead sprinkling only)	**mg/l**	**< 1.0**	**1.0-5.0**	**5.0 <**
TSS (clogging potential of irrigation system)*	**mg/l**	**< 50**	**50-100**	**100 <**

8.3 Trace elements

Trace elements in reclaimed water normally occur in concentrations less than a few mg/L, with usual concentrations less than 100 µg/L. Some are essential for plants and animals but all can became toxic at elevated concentrations or doses. The elements of greatest concern at elevated levels are: cadmium, copper, molybdenum, nickel and zinc. Nickel and zinc are of a lesser concern than cadmium, copper and molybdenum because they have visible adverse effects in plants at lower concentrations than the levels harmful to animals and humans. Zinc and nickel toxicity reduces as pH increases. Cadmium, copper, and molybdenum, however, can be harmful to animals at concentrations too low to affects plants. Cadmium is of particular concern as it can accumulate in the food chain. In addition, it was found that the input of heavy metals from commercial chemical fertilizer impurities were far greater than that contributed by the reclaimed water as is shown in Table 19. Maximum recommended heavy metals concentrations for agricultural irrigation in the topsoil concentrations of heavy metals and trace elements are given in Tables 18 and 19. Table 20 proposes allowable heavy metal content in water for different national and international authorities.

Table 18

Maximum allowed concentration of metals in irrigation waters (Truong and Claridge, 1992)

Element	Total Concentration (mg/L)
Aluminium	5.00
Beryllium	0.10
Chromium	0.10
Copper	0.20
Lead	0.20
Manganese	0.20
Molybdenum	0.01
Selenium	0.02
Arsenic	0.10
Cadmium	0.01
Cobalt	0.05
Iron	1.00
Lithium	2.50
Mercury	-
Nickel	0.20
Zinc	2.00

The recommended maximum concentrations for “long-term continuous application on all soils” are set conservatively to include sandy soils that have low capacity to leach (and so to sequester or remove) the element in question. These maximal values are below the concentrations that produce toxicity when the most sensitive plants are grown in nutrient solutions or sand cultures to which the pollutant has been added. This does not mean that if the suggested limit is exceeded phytotoxicity will occur. Most of the elements are readily fixed or tied up in soil and accumulate with time. Repeated applications in excess of suggested levels might induce phytotoxicity. The criteria for short-term use (up to 20 years) are recommended for fine-textured neutral and alkaline soils with high capacities to remove the different pollutant elements (EPA, 2004).

Table 19

Recommended limits for constituents in reclaimed effluent for irrigation (EPA, 2004)

Constituent	Long-Term Use (mg/L)	Short-Term Use (mg/L)	*Remarks*
Aluminium Al	5.0	20	Can cause non-productiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion eliminate toxicity.
Arsenic As	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan Grass to less than 0.05 mg/L for rice.
Beryllium Be	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L to kale to 0.5 mg/L for bush beans.
Boron B	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a *few tenths* mg/L in nutrient solutions Toxic to many *sensitive* plants (e.g., citrus) at 1 mg/L. Usually sufficient quantities in reclaimed water to correct soil deficiencies. Most grasses are relatively tolerant at 2.0 to 10 mg/L.
Cadmium Cd	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.
Chromium Cr	0.1	1.0	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt Co	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper, Cu	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride, F	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron Fe	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead, Pb	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium Li	2.5	2.5	Tolerated by moat crops at concentrations up to 5.0 mg/L in soil. Toxic to citrus at low doses - recommended limit is 0.075 mg/L.
Manganese, Mn	0.2	10.0	Toxic to a number of crops from a few-tenths to a few mg/L in acidic soils.
Molybdenum Mo			Non-toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel Ni	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium Se	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels at selenium.
Titanium, Ti Tungsten, W	B	B	Effectively excluded by plants; specific tolerance levels unknown.
Zinc Zn	2.0	10.0	Toxic to many plants in widely varying concentrations; reduced toxicity at increased pH (6 or above) and in line-textured or organic soils.
Constituent	**Recommended Limit**		**Remarks**
pH			Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals toxicity desorbed above).
TDS	500-2,000 mg/L		Below 500 mg/L, no detrimental effects are usually noticed. Between 500 and 1,000 mg/L, TDS in irrigation water can affect sensitive plants. At 1,000 to 2,000 mg/L, TDS levels can affect many crops and careful management practises should be followed. Above 2,000 mg/L, water can be used regularly only for tolerant plants on permeable soils.
Free Chlorine Residual	<1 mg/L		Concentrations greater than 5 mg/L cause severe damage to most plants. Some sensitive plants may be damaged at levels as low as 0.05 mg/L.

Table 20

Recommended maximum concentrations of trace elements in irrigation waters In different countries

Element		Maximum Concentration mg/L			
Code	**Name**	**USA**[1]	**SA**[2]	**FAO**[3]	**COL**[4]
Al	Aluminium	5.0	5.0	5.0	5.0
As	Arsenic				
Be	Beryllium	0.10	0.10	0.10	0.10
Cd	Cadmium	0.01	0.01	0.01	0.01
Co	Cobalt	0.05	0.05	0.05	0.05
Cr	Chromium	0.10	0.10	0.10	0.10
Cu	Copper	0.02	0.04	0.02	0.02
F	Fluoride	1.0	2.0	1.0	1.0
Fe	Iron	5.0	5.0	5.0	5.0
Li	Lithium	2.5			
Mn	Manganese	0.20	0.02	0.20	0.20
Mo	Molybdenum	0.01	0.01	0.01	0.01
Ni	Nickel	0.20	0.02	0.20	0.20
Pb	Lead	5.0	0.10		
Se	Selenium	0.02	0.02	0.02	0.02
Sn	Tin	-	-	-	-
Ti	Titanium	-	-	-	-
W	Tungsten	-	-	-	-
V	Vanadium	0.10	-	0.10	0.10
Zn	Zinc	2.0	4.0	2.0	2.0

1) Pescod and Alka (1988).
2) Pescod and Alka (1988).
3) Food and Agricultural Organization of the United Nations, Ayers (1977).
4) Republica de Colombia, Ministerio de Salud 1984, Article 40 Agricultural use.

8.4 Soaps and detergents

General

Removing diseases factors, germs and other contaminants that are in contact with humans, plays an important role in maintaining high-level health standards of daily life. It can be achieved mainly by using soaps (made of materials formed by nature) and detergents (synthetic ingredients) that are ultimately disposed of into the sewage systems. Commonly, water is mixed with soaps and detergents. The water surface tension causes water to bead up on surfaces (glass, fabric), which slows wetting of the surface and inhibits the cleaning process. According to their characteristics, the water drops will hold their shape and will not spread, hence less efficient in “the cleaning process". The surface tension of the drops can be reduced and spread by using chemical surfactants surface-active agents. Surfactants have ionic properties and perform other important functions in cleaning, such as loosening, emulsifying (dispersing in water) and holding particles (mainly of soils) in suspension until they can be rinsed away. Surfactants can also provide alkalinity, which is useful in removing acidic soils. Commonly, surfactants are classified by their ionic (electrical charge) properties in water:

- anionic (negative charge are) used in laundry and hand dishwashing detergents, household cleaners, and personal cleansing products. They ionize (are converted to electrically charged particles) in solution, carry a negative charge and have excellent cleaning properties);
- non-ionic (no charge) are typically used in laundry and automatic dishwasher detergents and rinsing aids. Because they do not ionize in solution and thus have no electrical charge, they are resistant to water hardness and clean well on most soils. The most widely used are alcohol ethoxylates); and
- cationic (positive charge) and amphoteric (variable, either positive or negative charge) are used in personal cleansing and household cleaning products for their mildness, sudsing and stability. They have the ability to be anionic (negatively charged), cationic (positively charged) or non-ionic (no charge) in solution, depending on the pH (acidity or alkalinity) of the water. Imidazolines and betaines are the major amphoterics).

Soap is an anionic surfactant. Other anionic as well as non-ionic surfactants are the main ingredients in today's detergents. All of them reach the wastewater treatment systems and ultimately the treated effluent that will be reused for diverse purposes.

Soaps consist of water-soluble sodium or potassium salts of fatty acids. They are made from fats and oils, and can be mainly treated by strong alkali. Alkalis are used to make detergent surfactants. Sodium and potassium hydroxide are the most common alkalis. Common detergents contain one or more surfactants. Subject to their chemical structure, the surfactants used in detergents can be engineered to perform well under a variety of conditions.

Regulations

Regulations issued in most countries refer primarily to precautionary statements. Measures to be enforced in relation to human safety are implemented on household cleaning product labels. Specific criteria for concentration levels can be hardly found (Adelaide legislation, 2004). The regulations stipulate that clear statements follow a standard format. Safety measures include: an evaluation process and cautionary labelling; a consumer education programme on the proper use, storage and disposal of cleaning products; and supports the efforts of the soap and detergent industry towards human safety. In addition, the industry works closely with poison control centres to assure that, in the event of accidental exposure, treatment information is available to healthcare providers.

The related environmental risk assessment associated with detergents uses considers the exposure level and effects of individual ingredients: (i) enabling industry scientists to predict the concentration of the ingredient from all sources, including cleaning products, at various locations in the environment; and (ii) finding and recommending maximal concentrations of the ingredients at which no harm will be caused to animals, plants or micro-organisms living in the environment (the no-effect concentration). The general approach, which in most cases depends on local combinations of conditions, is based on the mixed impact of the potential toxicity and the “end body” (Figure 1). Consequently, it is rather difficult to specify unique conditions of hazard, health and environmental risks.

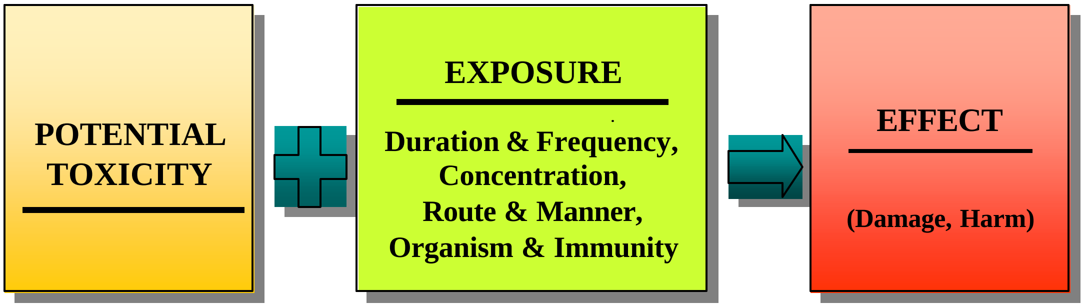

Figure 1. Assessing the damage due to exposure to potential toxic material and detergents

Table 21

Measures to be undertaken to guarantee minimal adverse impact during detergents use

CAUTION or WARNING (Mild hazard)	• A warning label is usually placed on the container of the cleaning products. • Cleaning products not likely to cause permanent damage as a result of unintentional exposure if adequate first aid is provided. • Most washing machines, laundry and dishwasher detergents, disinfectants and all-purpose cleaners are included this category
DANGER (Greater precaution should be taken)	• A warning label is frequently published on special purpose products used for irregular work, such as toilet cleaning, oven cleaning or opening of drain systems. • Unintentional exposure of the eyes or sensitive skin and various organisms to the concentrated products is risky and could cause long-term damage. • Could be found in products which are associated with flames and breakout of fire.

9. MONITORING AND RESPONSIBILITIES

9.1 General

Responsibilities for the treatment and monitoring of influent and effluent quality frequently become major issues. The general recommended approach is that the organization (actually a type of end-user) that accepts clean and high quality water is also responsible for its treatment. Water is a national commodity and is commonly supplied by a national authority. Consequently, the organization that is using the water has to return it to the national authority in a quality similar to that when it was obtained. This approach also stands when another consumer is using the treated wastewater prior to its final disposal. The major outcome is that the end-user, prior to finally discarding it, is responsible for the treatment, monitoring and reporting to the relative national control authorities.

9.2 Monitoring

The ultimate goal of monitoring is to have a reliable system allowing the identification of water quality in a real time. This holds for most water quality indicators. It will allow systems to be set off under uncertain conditions, or alternatively, to initiate an emergency programme and minimize hazardous situations.

The availability of using online and real-time quality indications is limited. Sensors for oxygen and electrical conductivity are available. Although there are expensive sensors for nitrogen, phosphate and potassium, they can be used for almost continuous monitoring. On-line monitoring of most heavy metals and hazardous constituents is limited. Frequently, bioassays monitoring systems are used that include, for example, fishes or other living organisms that react immediately to toxic water. The bioassay methods are commonly limited to specific ions. Further research has to be undertaken in order to improve online water quality monitoring. One promising direction is to implement geographic information systems (GIS) methods to monitor water quality in open surface water bodies (Stark *et al.*, 1996). The GIS method is based on using sensitive detectors enabling differentiation between various wavelengths returned from water bodies. The different wavelengths can be interpreted into diverse contamination levels. Besides the simplicity of operating such permanently installed systems, it allows the availability of online real-time data for immediate reaction under emergency conditions.

A related issue is the location of monitoring points. Obviously, monitoring points have to be installed in the wastewater collection systems at some representative points. Similarly, effluent quality has to be monitored at some end-user and disposal points. Monitoring can be maintained at different levels of screening in order to minimize expenses at a high level of reliability and provide possibilities for quick response.

Currently, online monitoring of oxygen, electrical conductivity, turbidity, temperature, and possibly also, sensors for nitrogen and others, is recommended. If real-time methods are not available, sampling for pathogens and organic matter at least once every two months should be maintained.

The presence of toxic and hazardous constituents should be based on at least one sampling every six months. Under specific suspicious conditions, the frequency of monitoring should be increased.

9.3 Responsibilities

The organization considered to be the end-user will be responsible for water/effluent quality and its monitoring. It will be the obligation of the end-user organization to report to the national control authorities and public, all information on both the amounts of wastes treated and disposed of and the relative qualities. Arrangements between end-users in the train of treatment and reuse of are always welcome subject, however, to regulations and instructions.

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