DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

REUSE ALTERNATIVES FOR MEAT PROCESSING INDUSTRY WASTEWATER

by
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October, 2007
İZMİR

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A Thesis Submitted to the
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ABSTACT

Continuous population growth, global warming, and rapidly industrialization cause to the water shortage. Nowadays, water shortage is a very significant problem. Depending on this problem, the present water sources get limited. And these limited water sources must be protected. Therefore, some precautions must be taken such as water reclamation and reuse. In this thesis, instead of discharging the treated wastewater, water reclamation and reuse alternatives have been researched. Thus, the effluent values that taken from the wastewater treatment plant which built in TAN-ET meat industry plant were investigated. In the first chapters, the knowledges were given about water shortage problem, wastewater reuse in industry, agricultural applications of reclaimed water, groundwater recharge with reclaimed water, wastewater reuse for the other applications, wastewater reuse experience around the world, the cost of wastewater reclamation and reuse and health assessment of wastewater reuse. In the next chapter, the general knowledge were given about the meat processing industries and their treatment plants. In the last chapters, knowledge about treatment plant of MIGROS TURK T. A.S. TAN-ET Meat Processing Industry were given; and; its effluent values were investigated to reuse alternatives.

Keywords : wastewater, reuse, water reclamation, meat processing.

ET İŞLEME TESİSİ ATIKSULARININ YENİDEN KULLANIM ALTERNATİFLERİ

ÖZ

Sürekli nüfus artışı, küresel ısınma, ve hızla büyüyen endüstrileşme su sıkıntısına sebep olmaktadır. Günümüzde su sıkıntısı çok önemli bir problemdir. Bu probleme bağlı olarak, mevcut su kaynakları sınırlı hale gelmektedir. Ve bu sınırlı su kaynakları korunmalıdır. Bu yüzden, atık suyun geri kazanımı ve geri kullanımı gibi bazı önlemler alınmalıdır. Bu tezde, arıtılmış atık suyun deşarjı yerine, suyu geri kazanma ve yeniden kullanım alternatifleri araştırılmıştır. Bunun için, MIGROS TURK T. A.S. TAN-ET Et İşleme Tesisinde bulunan atık su arıtma tesisinden alınan çıkış suyu değerleri incelendi. İlk bölümlerde, su sıkıntısı, atık suyun endüstriyel amaçlı kullanımı, tarımsal amaçlı kullanımı, yer altı suyu geri beslemesi ve kentsel amaçlı kullanımları gibi diğer uygulamaları, dünyadaki atık suyun yeniden kullanım örnekleri, geri kazanım ve yeniden kullanımın maliyeti ve sağlık açısından etkiler hakkında bilgiler verildi. Sonraki bölümde, et işleme endüstrileri ve onların arıtma tesisleri hakkında genel bilgiler verildi. Son bölümde, MİGROS TÜRK T. A.Ş. TAN-ET Et İşleme Endüstri Tesisi ve arıtma tesisi hakkında bilgi verildi; ve çıkış suyu değerleri yeniden kullanım alternatiflerine göre incelendi.

Anahtar kelimeler: atık su, yeniden kullanım, geri kazanım, et işleme.

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Water is very valuable natural source for life. “Plants, wildlife, and fish depend on sufficient water flows to their habitats to live and reproduce. The lack of adequate flow, as a result of diversion for agricultural, urban, and industrial purposes, can cause deterioration of water quality and ecosystem health” (Water Recycling and Reuse: The Environmental Benefits). However, water shortage is very popular problem all over the world nowadays. Water shortages, particularly during periods of drought, have necessitated stricter control measures on rates of water consumption and development of alternative water sources. Water reclamation and reuse has become an attractive alternative for the supplementation of water throughout the world.

> The concept of deriving beneficial uses from treated municipal and industrial wastewater coupled with increasing pressures on water resources has prompted the emergence of wastewater reclamation, recycling, and reuse as integral components of water resource management. The inherent benefits associated with reclaiming treated wastewater for supplemental applications prior to discharge or disposal include preservation of higher quality water resources, environmental protection, and economic advantages. A major catalyst for the evolution of wastewater reclamation, recycling, and reuse has been the need to provide alternative water sources to satisfy water requirements for irrigation, industry, urban non-potable and potable water applications due to unprecedented growth and development in many regions of the world (Asano, 2001).

> Water recycling has proven to be effective and successful in creating a new and reliable water supply, while not compromising public health. Non potable

> many parts of the United States, the uses of recycled water are expanding in order to accommodate the needs of the environment and growing water supply demands. Advances in wastewater treatment technology and health studies of indirect potable reuse have led many to predict that planned indirect potable reuse will soon become more common (Water Recycling and Reuse: The Environmental Benefits).

Meat processing industry is one of the important industry types of Turkey. Wastewater produced from this industry, which has a COD/BOD ratio of about 1.75, has very similar characteristics with domestic wastewater and it does not contain some constituents such as heavy metals, which can cause some problems for reuse application. Therefore, reuse alternatives of meat processing wastewater should be taken into consideration. The quality of reclaimed water depends on the units used in the treatment plants.

In this thesis, general information about meat processing industry and wastewater reuse alternatives are given in general. Then, reuse alternatives of treated meat processing industry wastewater are discussed in detail. The reclaimed water can be used in any places where the water is needed. So, reuse options of treated meat processing wastewater were evaluated for all possible necessities, such as agricultural reuse, industrial reuse, groundwater recharge, etc. Wastewater reuse application depends on many different factors such as legislative and political issues, technical, economical, environmental and social issues. For this reason, all reuse application alternatives were evaluated according to our regulations and EPA criteria.

This study was funded by The Research Foundation of Dokuz Eylül University (Project No: 2005.KB.FEN.057).

1.2 Scope and Aims of the Thesis

The scope of the thesis was to evaluate the reuse alternatives of the meat processing industry. The aims of the thesis are as follows:

- To characterize the meat processing industry wastewater,
- To investigate the reusability of treated meat processing wastewater for beneficial uses, such as agricultural irrigation, process water usage, ground water recharge, etc.,
- To determine the additional treatment units for the examined meat processing plant.

CHAPTER TWO
AN OVERVIEW OF WATER REUSE

2.1 Water Shortage

> The world is running out of water. Humans are polluting, depleting, and diverting its finite freshwater supplies so quickly, we are creating massive new deserts and generating global warming from below. In many parts of the world, surface waters are too polluted for human use. Ninety per cent of wastewater in the Third World is discharged untreated. Eighty per cent of China's and 75 per cent of India's surface waters are too polluted for drinking, fishing, or even bathing. The story is the same in most of Africa and Latin America. Humans, using powerful new technology, are mining groundwater sources far faster than they can be replaced, creating drought in once-fertile areas. When water is taken from an aquifer to grow crops in the desert, another desert is created (Water depletion the next looring crisis).

“Turkey is situated in a semi-arid region, and has only about one fifth of the water available per capita in water rich regions such as North America and Western Europe. Water rich countries are ones which have 10.000 cubic meters of water per capita yearly” (The global water shortage and Turkey’s water management retrieved).

“In arid and semi arid regions where precipitation is generally limited to 4 or 5 months a year, water resources development projects, especially storage systems and irrigation networks, are indispensible for sustainable socioeconomic development. A case in point is the Middle East” (The global water shortage and Turkey’s water management retrieved).

Turkey already faced with the danger of drought as a consequence of global warming. Figure 2.1 shows the withdrawal to availability water ratio of the world.

with respect to total renewable resources. It is a criticality ratio, which implies that water stress depends on the variability of resources. Water stress causes deterioration of fresh water resources in terms of quantity (aquifer over-exploitation, dry rivers, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc.) (Water crisis retrieved). Turkey must take urgent action deal with the water shortage problem if it is to avoid the routine importation of basic agricultural goods -- including wheat, cotton and other crops -- in coming years. A recent report by the Turkish Union of Agricultural Chambers (TZOB) stresses that based on compilations from 720 local agricultural chambers in Turkey, the cost of the drought reached 5 billion YTL last year alone.

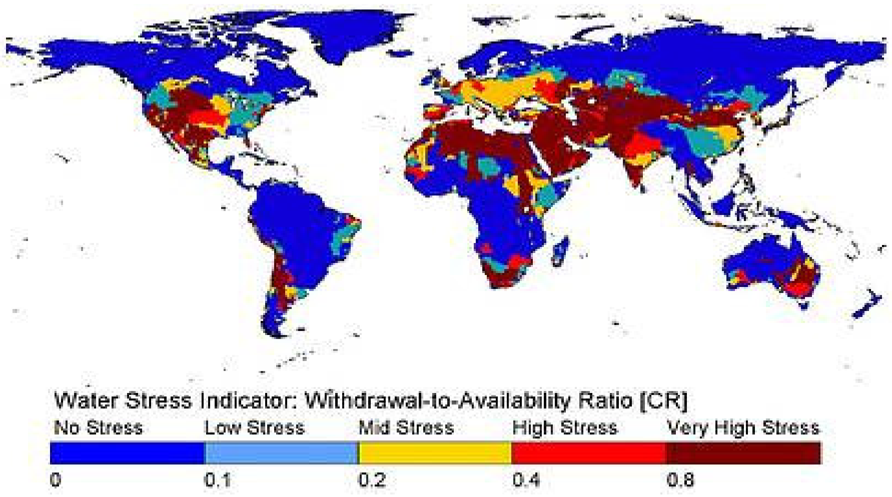

Figure 2.1 Water stress circumstances of the world (Water Crisis Retrieved)

Turkey has the fastest some rivers of the world. But, Turkey is located in lower rows in terms of the water reserves. The threats concerning future have reached to serious dimensions for that sources management in Turkey have not adopted good and sustainable management policy in the international standards (Water or …).

Water quantity must be minimum between 8.000 and 10.000 m^3 per capita yearly for that a country can been water rich. In Turkey, this quantity is 1430 m^3 per capita yearly. And, Turkey is not water rich country (Table 2.1; Figure 2.2). General

Directorate of State Hydraulic Works (DSI) general management's data Project that our water sources will use with 100 percent in 2030. It is estimated that population of Turkey will be 80 millions and usable water quantity will be 1100 m^3 per capita yearly in 2030. And Turkey will be a country water stress borne (Water sources of Turkey). According to these data, it is unavoidable that Turkey will contend with very serious water crisis in 2050 or 2100.

Table 2.1 According to countries the yearly usable water quantities per capita

Country – Continent (average)	**Usable Water Quantity (per capita yearly)**
Sudan	1200 m^3
Lebanan	1300 m^3
Turkey	1430 m^3
Iraqi	2020 m^3
Asia	3000 m^3
West Europe	5000 m^3
Africa	7000 m^3
South America	23000 m^3
World	7600 m^3

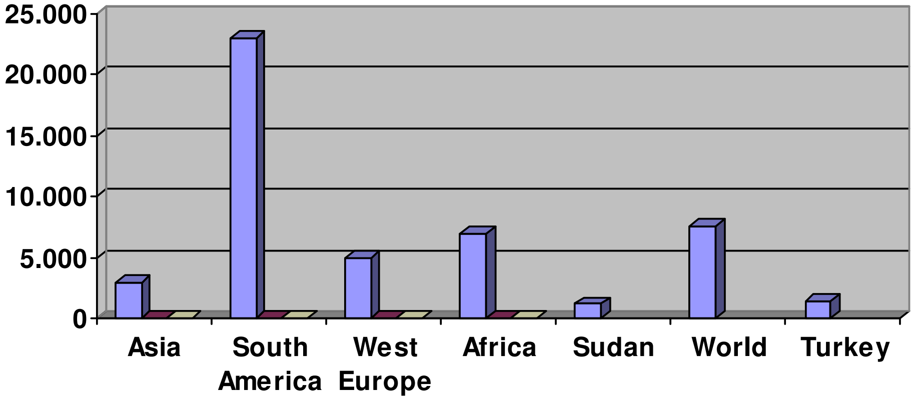

Fıgure 2.2 According to countries the yearly usable water quantities per capita

Annual usable water quantity is 112 billions m^3 in Turkey. It is used as 70 percent in agricultural applications, 20 percent in industrial applications, and 10 percent in potable – usage water of total water. In next years, it is estimated that the agriculture fields will increase 75 percent and domestic water usage will 260 percent in country. It is a true that total watery fields in Turkey have disappeared more than 50 percent in result of inefficient management and usage of water sources in last 40 years. With cause of the wrong policy and applications, the situation of our streams, groundwaters, and lakes deteriorate. In last 15 years, our groundwaters have decreased 18-20 meters with cause of extreme usage in Middle Anatolia. It is clear and certain of that the existed water sources are used inadvertently that it will cause to serious results. It is necessary to develop the water management policy and to implement this application country wide (Water sources of Turkey).

The aim of an efficient water management policy can be summarized as following.

- To fertilize the water usage
- To protect the water sources and to develop precautions
- To decrease total demand.

It is estimated that the expected World Water Forum that is eventuates in Turkey in 2009 will redound great deal to Turkey in this direction.

2.2 Wastewater Reuse in Industry

About 25 % of worldwide water demand is related to industrial applications (Metcalf & Eddy, 2003). The cost-effectiveness of using reclaimed water for industrial purposes depends on the distance the water must be transported between the reclamation facility and the point of use. In addition, the availability and cost of alternative water sources influences the degree to which reclaimed water is used.

Water recycling has been implemented successfully in several industries, and in other cases, reclaimed municipal wastewater has been used as an external water source for industrial applications. Alternative approaches for industrial recyling and reuse include reuse of municipal wastewater for an industrial process, cascading use of industrial process water between sucessive processes within an industy, and agricultural reuse of industrial water use are of particular interest because they are high volume uses with excellent prospects for using reclaimed municipal wastewater:

- recirculating cooling tower make-up,
- once-through cooling,
- process water.

Asano (1998) explain that the other industrial recycling applications are such as commercial laundries that can recover heat, detergent and water; car and truck washing establishments; pulp and paper industries; steel production; textiles; electroplating and semiconductor industries; boiler-feed water; and water for stack gas scrubbing.

2.2.1 Cooling Make-up Water

In several industrial water reuse applications, cooling tower make-up water represents a significant water use for many industries and is currently the predominant industrial water reuse application. For industries such as electric power generation stations, oil refining, and many other types of manufacturing plants, one-half of a facility's water use may be cooling tower make-up water. A cooling tower normally operates as a closed-loop system, it can be viewed as a separate water system with its own specific set of water quality requirements, largely independent of the particular industry involved (Metcalf & Eddy, 2003). Thus, using reclaimed water for cooling tower make-up water is relatively easy and is practiced in many states of the world.

There are significant variations among large industrial cooling systems. Once-through-non contact cooling is often used at large power facilities or refineries near the ocean. Direct contact cooling is used when inert material being processed. Non-contact recirculating cooling is used at large inland industries with limited water sources.

Industrial cooling tower operations face four water quality problems:

1) scaling
2) metallic corrosion
3) biological growth
4) fouling

2.2.1.1 Scaling

Calcium scales such as calcium carbonate, calcium sulfate, and calcium phosphate are the most significant cause of cooling tower scaling problems. Magnesium scales such as magnesium carbonate and phosphate can be a problem. Silica deposits are particularly difficult to remove from the heat exchanger surfaces; however, most waters contain relatively small quantities of silica.

Reducing the potential for scaling in wastewater is achieved by controlling the formation of calcium phosphate, which is the first calcium salt to precipitate if phosphate is present. Treatment is usually accomplished by removing phosphates by precipitation. Other treatment methods, such as ion exchange, reduce scale formation by the removal of calcium and magnesium; however, these tehniques are comparatively expensive and their use is limited (Asano, 1998).

2.2.1.2 Metallic Corrosion

In cooling systems, corrosion can occur when an electrical potential between dissimilar metal surfaces is created. Cathode that is noble (rare) metals and anode that is active metals influence each other; and the corrosion occurs. Water quality greatly affects metallic corrosion. Contaminants such as total dissolved solids (TDS) increase the electrical condutivity of the solution and accelerate the corrosion reaction. Dissolved oxygen and certain metals such as manganese, iron, and aluminum promote corrosion because of their high oxidation potential. The corrosion potential of cooling water can be controlled by the addition of chemical corrosion inhibitors. The chemical requirements to control corrosion in reclaimed water are usually much higher than for freshwater.

2.2.1.3 Biological Growth

The warm, moist environment inside the cooling tower makes an ideal environment for promoting biological growth. Nutrients, particularly N and P, and available organics further cause the growth of microorganisms. Biological growths may also settle and bind other debris present in the cooling water, which may further inhibit effective heat transfer. Certain microorganisms also create corrosive byproducts during their growth. According to Asano (1998), biological growths can be usually controlled by the addition of the biocides as part of the internal chemical treatment process that may inlude the addition of acid for pH control, the use of bioides, and scale and biofoul inhibitors. Because reclaimed water contains a greater concentration of organic matter, it may require larger dosages of biocides. It is possible, however, that most of the nutrients and available organic matter are removed from the reclaimed water during biological and chemical treatment.

When reclaimed water is used for cooling, the assurance of adequate disinfection is a primary concern to protect the health of workers. The disinfection requirements for reclaimed water usage in industrial processes are made on case-by-case basis. The most stringent requirement, similar to unrestricted reclaimed water use in food grop irrigation, would be appropriate if exposure to spray were possible.

2.2.1.4 Fouling

Fouling refers to the process of attachment and growth of deposits of various kinds in cooling tower recirculation systems. The deposits consist of biological growths, suspended solids, silt, corrosion products, and inorganic scales (Asano,1998). Inhibition of heat transfer in the heat exchangers an result. Control of fouling is achieved by the addition of chemical dispersant. Dispersants are also added at the point of use, is the usual case for freshwater cooling systems. Also, the chemical coagulation and filtration processes required for phosphorus removal are effective in reducing the concentration of contaminants that contribute to fouling.

In most cases, disinfected secondary effluent is supplied for noncritical, once-through cooling. For recirculating cooling tower operation, most wastewaters contain constituents which, if not removed, would limit industries to very low cycles of concentration in their cooling towers. Additional treatment includes lime clarification, alum precipitation, or ion exchange. Treatment processes used for both external and internal treatment of cooling or boiler make-up water are summarized in Table 2.2 (Asano, 1998).

Table 2.2 Processes used in treating water for cooling or boiler makeup

	Cooling		
Processes	**Once-through**	**Recirculated**	**Boiler make-up**
Suspended solids and colloid removal:			
Straining	x	x	x
Sedimentation	x	x	x
Coagulation		x	x
Filtration		x	x
Aeration		x	x
Microfiltration		x	x
Dissolved-solids modifiation softening:			
Cold lime		x	x
Hot lime soda			x
Hot lime zeolite			x
Cation-exchange sodium		x	x
Nanofiltration			x

Table 2.2 (continued)

	Cooling		
Processes	**Once-through**	**Recirculated**	**Boiler make-up**
Alkalinity reduction cation exhange:			
Hydrogen		x	x
Cation-exchange hydrogen and sodium		x	x
Anion exhange			x
Dissolved-solids removal:			
Evaporation			x
Demineralization		x	x
Reverse osmosis/nanofiltration		x	x
Ion exchange		x	x
Dissolved-gas removal:			
Degasification			
Mechanical		x	x
Vacuum	x		x
Heat			x
Internal conditioning:			
pH adjustment	x	x	x
Hardness sequestering	x	x	x
Corrosion inhibition general		x	x
Embrittlement			x
Oxygen reduction			x
Sludge dispersal	x	x	
Biological control			
Chemicals	x	x	
Ozone		x	
Ultraviolet light		x	

2.2.2 Boiler – Feed Water

The use of reclaimed water differs little from the use of conventional public supplies for boiler-feed water; both usually require extensive additional treatment. Quality requirements for boiler-feed make-up water are also dependent on the pressure at which boilers are operated, as shown in Table 2.3 (Guidelines for water reuse). Generally, the higher the pressure, the higher quality of water required. Very high pressure boilers require make-up water of distilled quality. High alkalinity may contribute to foaming, resulting in deposits in superheaters, reheaters, and turbines. Bicarbonate alkalinity, under the influence of boiler heat, may lead to the release of carbon dioxide, which is a source of corrosion in steam-using equipment.

Table 2.3 Recommended industrial boiler-feed water quality criteria (Guidelines for water reuse)

Parameter	**Low Pressure (<150 psig) (<7182 Pa)**	**Intermediate Pressure (150-700 psig) (7182-33516 Pa)**	**High Pressure (>700 psig) (>33516 Pa)**
Silica, mg/L	30	10	0.7
Aluminum, mg/L	5	0.1	0.01
Iron, mg/L	1	0.3	0.05
Magnesium, mg/L	0.3	0.1	0.01
Calcium, mg/L	--	0.4	0.01
Magnezyum, mg/L	--	0.25	0.01
Ammonia, mg/L	0.1	0.1	0.1
Bicarbonate, mg/L	170	120	48
Sulfate, mg/L	--	--	--
Chloride, mg/L	--	--	--
Dissolved solids, mg/L	700	500	200
Copper, mg/L	0.5	0.05	0.05
Zinc, mg/L	--	0.01	0.01
Alkalinity, mg/L	350	100	40
pH	7-10	8.2-10	8.2-9
Suspended solids, mg/L	10	5	0.5
COD, mg/L	5	5	1

In general, both potable water must be treated to reduce hardness to nearly zero. According to Mays (1996), removal or control of insoluble salts of calcium and magnesium and control silica and aluminum are required, since these are the principal causes of scale build-up in boilers. Depending on the characteristics of the reclaimed water, lime treatment (including flocculation, sedimentation, and recarbonation) may be required, possibly followed by multimedia filtration, carbon adsorption, and nitrogen removal. High purity boiler-feed water for high pressure boilers also may require treatment by reverse osmosis or ion exchange.

2.2.3 Industrial Process Water

The suitability of reclaimed water for use in industrial processes depends on the particular use. For example, the electronics industry requires water of almost distilled quality for washing circuit boards and other electronic components (Guidelines for water reuse). On the other hand, the tanning industry can use relatively low-quality water. Requirements for textiles, pulp and paper and metal fabricating are intermediate. Thus, in investigating the feasibility of industrial reuse with reclaimed water, the potential users must be contacted to determine specific requirements for process water. Industrial water reuse quality concerns and potential treatment processes are given in Table 2.4.

2.2.3.1 Pulp and Paper

Reuse of reclaimed water in the paper and pulp industries a function of the cost and grade of paper. Impurities found in water, particularly certain metal ions and color bodies, can cause paper to change color with age. Biological growth can cause clogging of equipment and odors and can affect the texture and uniformity of the paper. Corrosion and scaling of equipment may result from the presence of silica, aluminum, and hardness. Discoloration of paper may occur due to iron, manganese, or microorganisms. Suspended solids may decrease the brightness of the paper.

Table 2.4 Summary of water quality issues of importance for industrial water reuse

Parameter	Potential Problem	Advanced Treatment Process
Residual organics	Bacterial growth, slime/scale formation, foaming in boilers	Nitrification, carbon adsorption, ion exchange
Ammonia	Interferes with formation of free chlorine residual, causes stress corrosion in copper-based alloys, stimulates microbial growth	Nitrification, ion exchange, air stripping
Phosporus	Scale formation, stimulates microbial growth	Chemical precipitation, ion exchange, biological phosporus removal
Suspended Solids	Deposition, "seed" for microbial growth	Filtration
Calcium, magnesium, iron, and silica	Scale formation	Chemical softening, precipitation, ion exchange

2.2.3.2 Chemical Industry

The water quality requirements for the chemical industry vary greatly according to production requirements (Guidelines for water reuse). Generally, waters in the neutral pH range (6.2 to 8.3), moderately soft, with low turbidity, SS, and silica are required; dissolved solids and chloride content are not critical.

2.2.3.3 Textile Industry

Water used in textile manufacturing must be nonstainig; hence, they must be low in turbidity, color, iron, and manganese. Hardness may cause curds to deposit on the textiles and may cause problems in some of the processes that use soap. Nitrates and nitrites may cause problems in dyeing.

2.3 Agricultural Application of Reclaimed Water

Although irrigation has been practiced throughout the world for several millennia, it is only in the last century that the importance of the quality of the irrigation water has been recognized. Almost 60 percent of all the world’s fresh water withdrawals go towards irrigation uses. Large-scale farming could not provide food for the world’s large populations without the irrigation of crop fields by water gotten from rivers, lakes, reservoirs, and wells. When water is used as potable and industrial requirements, about 90 percent of the water used is eventually returned to the environment where it replenishes water sources (water goes back into a stream or down into the ground) and can be used for other purposes. But of the water used for irrigation, only about one-half is reusable. The rest is lost by evaporation into the air, transpiration from plants, or is lost in transit, by a leaking pipe, for example.

The feasibility of using reclaimed water for irrigation is evaluated based on several factors including; salinity, trace elements, and water infiltration rates, and other water quality criteria. Salinity can influence the soil osmotic potential, specific ion toxicity, and result in degradation of soil physical conditions (Asano, 1998). Excess salinity results in salt accumulation in the crop root zone that leads to a loss in yield. Plant damage can result from excess salinity. The best way to avoid salinity problems is to ensure a net downward flux of water and salt through the root zone. Under such conditions, adequate drainage is needed to allow water and salt to migrate below the root zone. Long-term use of reclaimed water for irrigation is not generally possible without adequate drainage (Asano, 1998). Long-term soil exposure to reclaimed water results in higher levels of nitrogen and phosphorus, while potassium, calcium, magnesium, and sodium tend to be more variable. The guidelines for interpretation of water quality for irrigation is given in Table 2.5 (Rowe, 1995).

Table 2.5 Guidelines for interpretation of water quality for irrigation

		Degree of Restriction of use		
Parameter	Units	Slight to None	Moderate	Severe
Salinity, ECw	dS/m, mmhos/cm	<0.7dS/m	0.7-3.0 mmhos/cm	>3.0 mmhos/cm
Total dissolved solids, TDS	mg/l	<450	450-2000	>2000
Total suspended solids, TSS	mg/l	<50	50-100	>100
Bicarbonate, (HCO^{3-})	mg/l	<90	90-500	>500
Boron (B)	mg/l	<0.7	0.7-3.0	>3.0
Chloride (Cl^-), sensitive crops	mg/l	<140	140-350	>350
Chloride (Cl^-), sprinklers	mg/l	<100	>100	>100
Chloride (Cl^2), total residual	mg/l	<1.0	1.0-5.0	>5.0
Hydrogen sulfide (H_2S)	mg/l	<0.5	0.5-2.0	>2.0
Iron (Fe), drip irrigation	mg/l	<0.1	0.1-1.5	>1.5
Manganese(Mn), drip irrigation	mg/l	<0.1	0.1-1.5	>1.5
Nitrogen (N), total	mg/l	<5	5-30	>30
Sodium (Na^+), sensitive crops	mg/l	<100	>100	>100
Sodium (Na^+), sprinklers	mg/l	<70	>70	>70
SAR	mg/l	<3	3-9	>9

2.3.1 Salinity and SAR

Irrigation water that percolates through and below the root zone transports a portion of the accumulated salts from the upper root zone. Salts leached from the upper root zone accumulate to some extent in the lower part but evntually are moved below the root zon by sufficient leaching. Consequently, salinity tends to increase with depth resulting in the threefold higher average soil salinity of the applied water. Crops respond to average salinity of the root zone. The fraction of applied water that passes through the entire rooting depth and percolates below is called the *leaching fraction* (LF).

$$LF = \frac{\text{Depth of water leached below the root zone}}{\text{Depth of water applied at the surface}} \qquad (1)$$

The amount of salt that accumulates in the root zone is inversely proportional to the LF. For reclaimed water irrigation, it is desirable to achieve an LF above 0.5. If the salinity of irrigation water (EC_w) and the leaching fraction are known, that salinity of the drainage water that percolates below the root zone can be estimated by using Equation 1-2.

$$EC_{dw} = \frac{EC_w}{LF} \qquad (2)$$

where EC_{dw} is the electrical conductivity of the drainage water percolating below the root zone which is equal to salinity of soil-water, EC_{sw}.

Water infiltration problems tend to occur in about the top four inches (10 cm) of the soil and are related to the structural stability of the surface soil. Depending on the relative pH and mineral composition of the soil and the applied water, minerals may precipitate in the soil from the applied water, be leached from soils by applied water, or minimal interaction will result. Changes in soil permeability that result from applied water influence the effective infiltration rate. An important parameter used to evaluate soil/water interactions is the *sodium adsorption ratio* (SAR):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{3}$$

where the concentrations of sodium and calcium are expressed in milliequivalents per liter (meq/L).

The calcium levels in reclaimed wastewater are high enough that leaching of calcium from the surface soil does not occur to any significant extent. However, high sodium levels can be a major concern in planning irrigation projects with reclaimed water.

At a given sodium adsorption ratio, the infiltration rate is proportional to salinity. Adverse effects of excess sodium include impaired soil permeability. Asano (1998) defines SAR from the figure in this way: ‘‘The SAR can be used in conjunction with the salinity (electrical conductivity (EC_w)) of the applied irrigation water to assess potential permability problems as shown in Figure 2.3. For SAR levels below about 5, and ECw levels above about 1, minimal effect on soil permeability will result for application of reclaimd wastewater. However, for SAR levels above 20 and ECw levels below 3, severe effects on soil permeability are likely unless additional precautions are taken’’. General guidelines for salinity in agricultural irrigation water are given in Table 2.6 (Rowe, 1995).

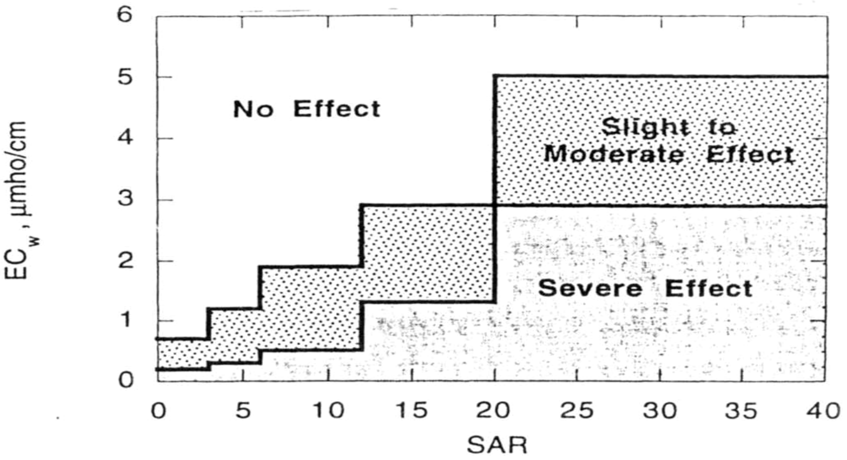

Figure 2.3 Influence of irrigation water ECw and SAR levels on soil permeability

Table 2.6 General guidelines for salinity in agricultural irrigation water (Rowe, 1995, p. 25)

Classification	**TDS (mg/L)**	**EC (mmhos/cm)**
Wafer for which no detrimental effects are usually noticed	500	0.75
Water that can have detrimental effects on sensitive crops	500-1,000	0.75-1.50
Water that can have adverse effects on many crops, requiring careful management practices	1,000-2,000	1.50 -3.00
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000-5,000	3.00-7.50

2.3.2 Total Dissolved Solids

Total dissolved solids (TDS) is an expression for the combined content of all organic and inorganic substances contained in a liquid which are present in a molecular, ionized or micro-granular suspended form. Generally the operational definition is that the solids must be small enough to survive filtration through a sieve size of two micrometers. Total dissolved solids are normally only discussed for freshwater systems, since salinity comprises some of the ions constituting the definition of TDS (Water and total dissolved solids). The principal application of TDS is in the study of water quality for streams, rivers, and lakes, although TDS is generally considered not as a primary pollutant (e.g. it is not deemed to be associated with health effects), but it is rather used as an aggregate indicator of presence of a broad array of chemical contaminants.

Primary sources for TDS in receiving waters are agricultural runoff, leaching of soil contamination and point source water pollution discharge from industrial or sewage treatment plants (Water and total dissolved solids). The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium, and chloride, which are found in nutrient runoff, general stormwater runoff and runoff from snowy climates where road de-icing salts are applied. The chemicals may be cations, anions, molecules or agglomerations on the order of 1000 or fewer molecules, so long as a soluble micro-granule is formed. More exotic and harmful elements of TDS are pesticides arising from surface runoff. Certain naturally occuring total dissolved solids arise from the weathering and dissolution of rocks and soils.

Total dissolved solids are differentiated from total suspended solids (TSS), in that the latter can not pass through a sieve of two micrometers and yet are indefinitely suspended in solution.

The two principal methods of measuring total dissolved solids are gravimetry and electrical conductivity. Gravimetric methods are the most accurate and involve evaporating the liquid solvent to leave a residue which can subsequently be weighed with a precision analytical balance. This method is generally the best, although it is time consuming and leads to inaccuracies if a high proportion of the TDS consists of low boiling point organic chemicals, which will evaporate along with the water. ın the most common circumstances inorganic salts comprise the great majority of TDS,and gravimetric methods are appropriate.

Electrical conductivity of water is directly related to the concentration of dissolved ionized solids in the water. Ions from the dissolved solids in water create the ability for that water to conduct an electrical current, which can be measured using a conventional conductivity meter. When correlated with laboratory TDS measurements, electrical conductivity provides an approximate value for the TDS concentration, usually within ten percent accuracy.

2.3.3 Sodium, Chloride, Boron

Sodium, chloride, and boron are soluble constituents in reclaimed wastewater that can interfere with plant growth. Sodium in irrigation water can affect soil stucture as well as reduce soil aeration.

The most current toxicity problem for crops irrigated with reclaimed wastewater is from boron. The source of boron in reclaimed wastewater is household detergents or discharges from industrial plants. Other sources can be industrial plants or runoff entering the sewage system where boron fertilizers are used. The average boron concentration in the earth's crust is 10mg/kg with an average concentration in the ocean of 5 mg/l. Boron concentrations in freshwater rarely go above 1 mg/l anda re generally less than 0.1 mg/l. The amount of boron available to plants in soil is pH dependent. Maximum boron adsorption by soil has been found to be at pH 9. Limits of boron in irrigation systems are given in Table 2.7 (Rowe, 1995).

Chloride and sodium also increase during domestic water usage, especially where water softeners are used. When excessive residual chlorine (above 5 mg/l) is present in reclaimed wastewater due to chlorine disinfection, severe plant damage can occur if reclaimed water is sprayed directly on foliage (Asano, 1998). For sensitive crops, specific ion toxicity is difficult to correct without changing the crop or the water supply.

Table 2.6 Limits of boron in irrigation water (Boron in milligrams per liter or parts per million)

	Crops Group		
Class of water	Sensitive	Semitolerant	Tolerant
Excellent	<0.33	<0.67	
Good	0.33-0.67	0.67-1.33	1.0-2.0
Permissible	0.67-1.0	1.33-2.0	2.0-3.0
Doubtful	1.0-1.25	2.0-2.5	3.0-3.75
Unsuitable	>1.25	>2.5	>3.75

2.3.4 Trace Elements

Trace elements in reclaimed water normally occur in concentrations of less than a few mg/L, with usual concentrations less than 100 microgram/L. Some are essential for plants and animals, but many can become toxic at elevated concentrations or doses. The mechanisms of potential food contamination from irrigation with reclaimed water include: physical contamination, where evaporation and repeated spplication may result in a build-up of contaminants on crops; uptake through the roots from the applied water or the soil; and foliar intake (Mays, 1996). Some chemical constituents are known to accumulate in particular crops, thus presenting potential health hazards to both grazing animal and humans. The concentrations of heavy metals and other trace elements in reclaimed water generally are much less than those in biosolids from wastewater treatment plants, which also may be applied to agricultural land.

The most important trace elements in wastewater include cadmium, chromium, copper, molybdenum, nickel, zinc, lead, and mercury. Cadmium, copper, and molybdenum can be harmful to animals at concentrations too low to affect plants. Cadmium is of particular concern because it can accumulate in the food chain. It does not adversely affect ruminants in the small amounts they ingest. Most milk and beef products are unaffected by livestock ingestion of cadmium because it is stored in the liver and kidneys of the animal rather than the fa tor muscle tissues (Mays, 1996). Copper is not toxic to monogastric animals, but may be toxic to ruminants; however, their tolerance to copper increases as available molybdenum increases. Molybdenum can also be toxic when available in the absence of copper. Nickel and zinc are 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 (Mays, 1996, p. 21.11). Zinc and nickel toxicity decrease as pH increases.

2.3.5 Nutrients

The nutrients most important to a crop's needs are nitrogen, phosphorus, potassium, zinc, boron, and sulfur. Reclaimed water usually contains enough of these nutrients to supply a large portion of a crop's needs.

The most benefical nutrient is nitrogen. Both the concentration and form of nitrogen need to be considered in irrigation water. While excessive amounts of nitrogen stimulate vegetative growth in most crops, they may also delay maturity and reduce crop quality and quantity (Guidelines for water reuse). Excessive nitrate in forages can cause an imbalance of nitrogen, potassium, and magnesium in the grazing animals and is a concern if forage is used as a primary feed source for livestock.

The nitrogen in reclaimed water may not be present in concentrations great enough to produce satisfactory crop yields, and some supplemental fertilizer may be necessary. Even though the irrigation rate exceeds the crops' consumptive needs, the dilute nature of the nitrogen (approximately 18mg/l) requires supplemental fertilizers at certain times of the year (Guidelines for water reuse).

Phosphorus contained in reclaimed water is usually too low to meet a crop's needs; yet over time it can build up in the soil and reduce the need for phosphorus supplementation. Excessive phosphorus does not appear to pose any problem to crops, but can be a problem in runoff to surface water.

2.3.6 Irrigation Systems

Most systems use a system of underground pipes, sprinklers, and emitters to water specific areas of a garden or turf, and divide the propertiy into specific areas so that plants with similar root depths and watering needs can be watered by the same irrigation valve and cycle (Guidelines for water reuse). An irrigation controller includes a timer that activates the valves for each watering zone.

Distribution systems may be classified into three broad categories:

1) surface systems
2) sprinkler systems
3) drip irrigation systems

2.3.6.1 Surface Systems

Surface irrigation systems (ridge and flood, graded borders) normally result in the discharge of a portion of the irrigation water from the site. These systems rely on surface grade and channels to help distribute the wastewater. Gated pipes discharge the wastewater at one end of a field and gently sloping furrows carry the wastewater throughout the field. Row crops and plant nurseries on level terrain are well suited for surface irrigation. Surface irrigation systems require less equipment than sprinkler systems anda re not subject to spray drift problems. However, surface irrigation systems do not uniformly disribute the wastewater; the heaviest applications occur near the discharge points.

2.3.6.2 Sprinkler Systems

These systems are overhead systems, which use sprinkler heads to spray water over an area, and this system is the most common. They work on slopes with up to 30 percent grade and are not limited by wastewater quality. All types of crops can be irrigated using sprinkler systems. Solid set sprinkler systems are most often used in wastewater reuse systems; center pivot, traveling gun, and traveling lateral systems also have applications.

Some limitations to the use of sprinkler systems are the purchase, placement costs, and field space for the equipment. Uncultivated tracks must be maintained for traveling systems. Field operations must maneuver around solid set systems. Another limitation of sprinkler systems is spray drift. Setbacks must be included in the field layout to minimize spray drift onto roads and dwellings.

2.3.6.3 Drip Irrigation Systems

Drip irrigation systems use low-rate emitters to deliver wastewater slowly to the plant. Wastewater must be very low in solids, and disinfection may be required to reduce biofilms that can clog emitters. Drip systems can be used on any slope and are well suited to permanent planting, such as landscaping. The equipment and installation costs for drip systems may be high, but they do not create spray drift problems and, if buried, do not interfere with agricultural operations.

Drip irrigation emits a slow and steady application of water at the roots of plants and shrubs, directly where it is needed rather than through the air where it evaporates. The rate of flow is determined by the size of the aperture of the emitter and by the number of emitters programmed on a single valve or cycle. Care should be taken to not overload the system and exceed the household’s water pressure capacity. It is generally preferable to program several areas with separate watering cycles than try to water a large area on a single cycle.

For irrigating fruits and vegetables drip irrigation method is much more efficient than flood irrigation. Water is sent through plastic pipes that are either laid along the rows of crops or even buried along their rootlines. Evaporation is cut way down, and up to one-fourth of the water used is saved, as compared to flood irrigation.

2.4 Groundwater Recharge with Reclaimed Water

The use of groundwater recharge as a water reuse application can satisfy multiple objectives. Groundwater recharge with reclaimed wastewater is an approach to wastewater reuse that results in the planned augmentation of groundwater resources (Asano, 1998). The purposes of artificial recharge of groundwater include:

1) arresting the decline of groundwater levels due to excessive groundwater withdrawals
2) protection of coastal aquifers against saltwater intrusion from the ocean
3) to store surface water, including flood or other surplus water, and reclaimed wastewater for future use.

Pumping of grundwater aquifers in coastal areas may result in seawater intrusion into the aquifers, making them unsuitable as sources of potable supply or for other uses where high salt levels are intolerable (Guidelines for water reuse). A battery of injection wells and extraction wells can be used to create a hydraulic barrier to maintain intrusion control. Reclaimed water can be injected directly into a confined aquifer and subsequently extracted, if necessary, to maintain a seaward gradient and thus prevent inland subsurface seawater intrusion.

Infiltration and percolatin of reclaimed water takes advantage of the subsoils' natural ability for biodegradation and filtration, thus providing additional in situtreatment of the wastewater and additional treatment reliability to the overall wastewater management system. The treatment achieved in the subsurface environment may eliminate the need for costly advanced wastewater treatment processes, depending on the method of recharge, hydrogeolgical conditions, requirements of the downstream users, and the other factors. In some cases, the reclaimed water and groundwater blend and become indistinguishable (Guidelines for water reuse).

Groundwater recharge helps provide a loss of identity between reclaimed water and groundwater. This loss of identity has a positive psychological impact where reuse is contemplated and is an important factor in making reclaimed water acceptable for a wide variety of uses including potable water supply augmentation.

Groundwater aquifers provide a natural mechanism for storage and subsurface transmission of reclaimed water. Irrigation demands for reclaimed water are often seasonal, requiring either large storage facilities or alternative means of disposal when demands are low. In addition, suitable sites for surface storage facilities may not be available, economically feasible, or environmentally acceptable. ‘‘Groundwater recharge eliminates the need for surface storage facilities and the attendant problems associated with uncovered surface reservoirs, such as evaporation losses, algae blooms resulting in deterioration of water quality, and creation of odors’’ (Guidelines for water reuse). Also, groundwater quifers serve as a natural distibution system and may reduce the need for surface transmission facilities.

Metcalf & Eddy (2003) summarize advantages of storing water to the underground.

1) the cost of artificial recharge may be less than the cost of equivalent surface reservoirs.

2) the aquifer serves as an eventual distribution system and may eliminate the need for surface pipelines or canals.

3) water stored in surface reservoirs is subject to evaporation, potential taste and odor problems due to algae and other aquatic productivity, and pollution; these may be avoided by underground storage.

4) suitable sites for surface reservoirs may not be available or environmentally acceptable.

5) the inclusion of groundwater recharge in a water reuse project may also provide psychological and aesthetic secondary benefits as a result of the transition between reclaimed water and groundwater.

While there are obvious advantages associated with groundwater recharge, there are possible disadvantages to consider:

1) Extensive land areas may be needed for spreading basins.

2) Energy and injection wells for recharge may be prohibitively costly.

3) Recharge may increase the danger of aquifer contamination. Aquifer remediation is difficult, expensive, and may take years to accomplish.

4) Not all added water may be recoverable.

5) The area required for peration and maintenance of a groundwater supply system (including the groundwater reservoir itself) is generally larger than that required for a surface water supply system.

6) Sudden increases in water supply demand may not be met due to the slow movement of groundwater.

7) Inadequate institutional arrangements or groundwater laws may not protect water rights and may present liability and other legal problems.

2.4.1 Groundwater Recharge Methods

There are two options by which groundwater can be recharged with reclaimed wastewater:

1) surface spreading or percolatin
2) direct injection

2.4.1.1 Surface Spreading

In most cases wastewater receives at least secondary treatment and disinfection, and often tertiary treatment, prior to surface spreading, although primary effluent has been successfully used in soil-aquifer treatment systems at some spreading sites where the extracted water is to be used for nonpotable purposes (Mays, 1996, p. 21.19). A disadvantage of using primary effluent is that infiltration-basin hydraulic-loading rates may be lower.

Algae can clog the soil surface of spreading basins and reduce infiltration rates. Algae further aggravate soil clogging by removing carbon dioxide, which raises the pH causing precipitation of calcium carbonate (Mays, 1996, p.21.19). Reducing the detention time of standing water within the basins minimizes algal growth. Infiltration basins should be shallow enough to avoid compaction of the clogging layer. Scarifying, rottilling, or discing the soil following the drying cycle can help alleviate clogging potential, although scraping the bottom to remove the clogging layer is more effective.

Contaminants in the subsurface environment are subject to biodegradation by microorganisms, adsorption, filtration, ion exchange, volatilization, dilution, chemical oxidation and reduction, and chemical prepication and complex formation. ‘‘For surface spreading operatins, most of the removals of both chemical and microbiolgical constituents occur in the top 6 ft (2 m) of the vadose zone at the spreading site’’ (Asano, 1998).

Particles larger than the soil pores are strained off at the soil-water interface. Particulate matter, including some bacteria, is removed by sedimentation in the pore spaces of the media during filtration. Viruses are removed mainly by adsorption. The accumulated particles gradually from a layer restricting further infiltration. Suspended solids that are not retained at the soil-water interface may be effectively removed by infiltration and adsorption in the soil profile. As water flows through passages formed by the soil particles, suspended and colloidal solids too small to be retained by straining are intercepted and adsorbed onto the surface of the stationary soil matrix through hydrodynamic actions, diffusion, impingement, and sedimentation.

Some inorganic constituents such as chloride, sodium, and sulfate are unaffected by ground passage, but there can be substantial removal of ther inorganic constituents. Iron and phosphorus removalsin excess of 90 percent have been achieved by precipitation and adsorption in the underground, although the ability of the soil to remove these and other constituents may decrease over time. ‘‘Heavy metal removal varies widely for the different elements, ranging from 0 to more than 90 percent, depending on speciation of the influent metals’’ (Mays, 1996).

Some trace elements, e.g., silver, chromium, fluoride, molybdenum, and selenium are strongly retained by soil. There are indications that once metals are adsorbed, they are not readily desorbed. Boron, which is mainly in the form of undissociated boric acid in soil solutions, is rather weakly adsorbed and, given sufficient amounts of leaching water, most f the adsorbed boron is desorbed.

For surface spreading operations where an aerobic zone is maintained, ammonia is effectively converted to nitrates, but subsequent denitrification is dependent, in part, on anaerobic conditions during the flooding cycle and is often partial and fluctuating unless the system is carefully managed (Mays, 1996). Adsorption of organic constituents retards their movement and attenuates concentration fluctuations. The degree of attenuation increases with increasing adsorption strength, increasing distance from the recharge point, and increasing frequency of input fluctuation. Some chemical constituents can desorb and move chromatographically in the underground.

2.4.1.2 Direct Injection

Direct injection involves pumping reclaimed water directly into the groundwater zone, which is usually a confined aquifer. Injection requires water of higher quality than surface spreading to prevent clogging because of the absence of sil-matrix treatment afforded by surface spreading, and the potential requirement to have the injection water meet drinking water standards or match or exceed the quality of the groundwater supply. Treatment processes beyond secondary treatment that may be used prior to injection include disinfection, filtration, air stripping, ion exchange, granular activated carbon, and reverse osmosis or other membrane-seperation processes. With various subsets of these processes in appropriate combinations, it is possible to satisfy the full range of water quality requirements for injections.

‘‘Clogging of injection wells can be caused by accumulation of organic and inorganic solids, biolgical and chemical contaminants, and dissolved air and gases from turbulence. Concentrations of suspended solids of 1 mg/L or greater can clog an injection well’’ (Mays, 1996). Low concentrations of organic contaminants can cause clogging due to bacteriolgical growth near the point of injection.

2.4.2 Proposed Groundwater Recharge Regulations

The use of reclaimed wastewater for groundwater recharge, particularly in groundwater basins that serve as sources of domestic water supply is associated with a broad spectrum of health concerns. Water extracted from a groundwater basin for domestic use must be of acceptable physical, chemical, microbiolgical, and radiological quality. The major concerns governing the acceptability of groundwater recharge projects are that adverse health effects could result from the introduction of pathogens or trace amounts of toxic chemicals into groundwater that is eventually consumed by the public. ‘‘In light of uncertainties over potential long-term health effects from exposure to trace levels of organic and inorganic contaminants, it is important to ensure the absence of toxic compounds in recharged groundwater’’ (Guidelines for water reuse). A source control program to limit discharges of harmful constituents to the sewer system must be an integral part of any recharge project. Extreme caution is warranted because of the difficulty in restoring a groundwater basin once it is contaminated. Additional cost would be incurred if groundwater quality changes resulting from recharge necessitated the treatment of extracted groundwater and the development of additional water sources.

The level of municipal wastewater treatment necessary to produce reclaimed water suitable for groundwater recharge depends upon the groundwater quality objectives, hydrogeological characteristics of the groundwater basin, and the amount of reclaimed water and percentage of reclaimed water applied. The major considerations are:

1) the total quantity and type of water available for recharge on an annual basis,

2) the size of the groundwater basin and probability of dilution with natural groundwaters,

3) soil types,

4) depth to groundwater,

5) method of recharge,

6) the length of time the reclaimed water is retained in the basin prior t withdrawal for domestic use.

These factors must be evaluated in establishing criteria for groundwater recharge with reclaimed wastewater (Asano, 1998).

In the United States, federal requirements for groundwater recharge in the context of wastewater reuse have not been established to date (Guidelines for water reuse). In general, wastewater reuse requirements for grundwater recharge are regulated by individual state agencies on a case-by-case determination. In the 1990s, wastewater reuse regulations were proposed in California targeted at groundwater recharge applications (Guidelines for water reuse). The proposed regulations reflect a cautious attitude toward short-term and long-term health concern. It is necessary in order to rely on the combinations of the controls intended in the groundwater recharge operation for these regulations. No single method of control is universally effective for control of the transmission and transport of contaminants of concern into and through the environment. In other words, a combination of source control, wastewater treatment processes, treatment standards, recharge methods, recharge area, and monitoring wells are specified. And, all controls are thought as a complete regulations.

The method by which reclaimed wastewater is applied for groundwater recharge and the ‘project category’ identify a set of conditions that constitute an acceptable project. An equivalent level of perceived risk is inherent in each project category when all conditions are met and enforced. Groundwater recharge projets with reclaimed municipal wastewater must be controlled by the main concerns. Because, adverse health effects with introduction of pathogens or trace amounts of toxic chemicals into groundwater that is consumed by the public.

2.5 Other Applications

2.5.1 Water Reuse For Urban Application

Another application for reuse of reclaimed wastewater is to satisfy secondary water requirements in urban areas. The development of dual distribution systems is a growing practice worldwide, particularly in areas with high rates of urban water usage (Asano, 1998, p.37). Other urban water reclamation options include subpotable uses, such as for recreational lakes, parks, and playgrounds, and toilet flushing. Examples of sub-potable applications include: water hazards on golf courses; ponds and lakes for swimming; fishing and boating; and creation of wetlands as wildlife habitats.

Urban water reuse systems are derived from secondary treatment processes supplemented with sand filtration and high-dose chlorination. Chemical coagulation, filtration, and ozonation are effective for stream restoration and flow augmentation. With these processes, they are prevented that waterborne insects hatches and that the foam consists. In this way, acceptable aesthetic water quality consists. The reclaimed water quality must be appropriate for support of indigenous flora and fauna. Increased nutrient levels in the reclaimed wastewater may give rise to algal blooms that can cause eutrophic conditions and non-aesthetic conditions in ponds and lakes. Ponds used for fishing must be examined for constituents that can bioaccumulate in fish and biomagnify in the food chain. Wetlands provide water quality enhancement by natural assimilation processes as long as the quality of the applied reclaimed wastewater is suitable for plant growth. As with landscape irrigation, the salinity of the water is an important consideration.

2.5.2 Snow Generation

Reclaimed water can be used to make artificial snow making and the water quality for this purpose must be the highest due to possible human contact. ‘‘Reclaimed water is transported by 9 mile long pipeline and stored in the reservoir where an aerator is installed and supplies air to reclaimed water’’(Mays, 1996). The water from this reservoir is used for snow making on resort’s ski slopes in winter and for irrigation to maintain a grass cover on the ski slopes and prevent erosion in summer. Snow generation using reclaimed water could increase natural stream when snow melts.

2.5.3 Aquacultural Reuse

Fish and aquatic vegetables grow well in treated wastewater. WHO recommends that the treated wastewater used for aquaculture should not contain any viable human trematode eggs, and the fish or aquatic vegetable pond should not contain more than 1000 fecal coliforms per 100 ml.

2.5.4 Golf Courses Irrigation

The number of applications of reclaimed wastewater for irrigation of golf courses is growing in the United States. In Florida, 419 golf courses were reported to use 110 mgd of reclaimed water for irrigation, accounting for 19 percent of reclaimed water used for irrigation in Florida in 2001. Reuse systems featuring golf courses irrigation represented about 43 percent of all reuse systems in Florida (Guidelines for water reuse).

2.5.5 Sport Fields Irrigation

Reclaimed wastewater is being used to irrigate sport fields at community centers and schools where there is not enough fresh water for this purpose. Because of the possibility of human contact, reclaimed water for this purpose must be of the highest quality.

2.6 Wastewater Reuse Experience Around the World

2.6.1 Wastewater Reuse for Agriculture in Israel

Wastewater reuse is more agricultural purposeful in Israel. The hypothesis that drip irrigation, and mainly, subsurface systems can be implemented for secondary wastewater disposal even for processing agricultural products and vegetables eaten raw has been examined recently in a series of field studies in Israel (Asano, 1998). Many commercial fields in Israel are currently irrigated with domestic effluent. Experiments with field crops were conducted at the commercial site of the Revivim and Mashabay-Sade Farm (RMF), located near the City of Beer-Sheva. In continued experiments, the effluents in two different fields of Israel have been used. Secondary effluent from the Greater Dan Region treatment facility adjacent to the City of Tel-Aviv (around 130 * 10^6 m^3 per year) is transported via a branched pipe system for reuse in the southern Negev Desert (approximately 100 km long) after a Soil Aquifer Treatment (SAT) stage.

The crops on the RMF include corn, wheat, alfalfa, cotton, ryegrass, and in the Arad Heights vineyard, almond trees, sunflowers, wheat, and various field crops for seed production. A similar crop pattern is parcticed in the fields of Kibbutz Chafets-Chaim. At all three sites, the domestic wastewater is treated in a stabilization pond system. In these sites, the most used effluent application methods are sprinkler irrigation and drip irrigation systems. Secondary treated domestic wastewater and tap water is applied in the various experimental sites for comparison purposes.

2.6.2 Wastewater Reclamation and Reuse in Tunisia

According to Asano (1998), Tunisia will likely suffer from water shortages in the next century. Problems of water scarcity may intensify because of population growth, the rise in living standards, accelerated urbanization, increase in water consumption and, pollution of water resources.

Wastewater reuse has become a necessity and even a priority in the Tunisian national water resources strategy (Asano, 1998). It is an essential component of the policy to integrate all water resources into an effective management plan. Furthermore, Tunisia is among the very few Mediterranean countries which have elaborated and implemented a national wastewater reuse policy for many years.

2.6.3 Water Recycling in Los Angeles County

The Sanitation Districts of Los Angeles County, formed in 1923 by an act of the California State legislature have a long history as pioneers in the field of water recycling, culminating in one of the most advanced and widespread programs for the treatment, distribution and reuse of reclaimed water.

The level of treatment provided by the Districts' water reclamation plants is necessary to comply with effluent requirements for discharge to the local waterways. Full-body contact with the reclaimed water occurs on occasion. Consequently, no additional treatment is required for direct, non-potable reuse. These uses currently include, but are not necessarily limited to, landscape irrigation of all public areas, irrigation of food and fodder crops and pasture, water supply for livestock, non-restricted recreational impoundments, groundwater recharge, injection into oil-bearing zones and industrial processes.

Almost all of these categories of reuse can be found within the Districts' service areas. By the end of 1996, reclaimed water produced by the Districts was supplied directly to 360 sites for landscape irrigation at 90 parks, 85 schools (from day care to universities), 66 roadway greenbelts, 17 golf courses, 19 nurseries, 5 cemeteries, and 55 miscellaneous landscaped areas (churches, hospital, commercial buildings, auto dealerships, landfills, etc.); for agricultural irrigation at 10 sites; and for industrial process water at 12 sites (paper manufactoring, carpet dyeing, concrete mixing, cooling, oil field repressurization and construction applications) (Mays, 1996, p. 22.10).

Revisions to the reuse regulations are expected in the next few years and will formally include additional reuse applications to those already approved: toilet and urinal flushing, cooling towers, fire fighting, commercial laundries, artificial snow making, street cleaning, and various construction uses such as dust control, soil compaction, consolidation of backfill, sewer line flushing and concrete mixing. Many facilities in southern California have already begun to utilize reclaimed water for toilet and urinal flushing, including the Districts' newly constructed administrative office expansion which dual-plumped for this use.

2.6.4 Wastewater Reclamation and Reuse in City of St. Petersburg, Florida

Geographically, the city is located at the tip of the Pinellas County peninsula on Florida's west-central coast (Asano, 1998, p. 1037). St. Petersburg is now Florida's fourth largest city with a resident population of over a quarter of a million together with several thousand extra transient winter visitors escaping the harsh cold of the more northerly regions of the continent. The supply of drinking water for the ever increasing population and the treatment of wastewater have thus played dominant roles in the growth and development of this city over the years from its inception in 1880 up to the present day.

In order to fully understand and appreciate the multiple factors that resulted in St. Petersburg's decision to develop a reclaimed water distribution systems, a review of the historical development of the potable water supply and wastewater disposal systems is essential. Rapidly decreased potable water supplies must be preserved. It must be led to the development of the reclaimed water distribution irrigation systems of nation.

2.7 The Cost of Wastewater Reclamation and Reuse

Water quality requirements for reuse alternatives vary depending on the extent of potential public exposure. Unfortunately, wastewater reclamation cost is not well-documented. The development of a cost estimate includes projections of capital costs, annual operation and maintenance costs and life cycle cost. Total reclamation system life cycle cost is estimated by combining amortized capital cost with annual operation and maintenance costs and converting to €/m^3 (by dividing the estimated life cycle cost, €/yr, by the reclamation facility capacity, m^3/yr). The life cycle analysis is based on a 20-year facility life and return rate of 10%. Wastewater reclamation system costs are presented as a function of facility capacity, end-use option and treatment process configuration.

Costs have been identified by Asano (1998) estimating facility construction costs, equipment purchases and operation and maintenance fees. Initially, reclamation systems are analysed in terms of individual components based on design criteria. Cost data are derived for each element of a reclamation system at various capacity levels and unit sizes. One of the first efforts to develop a rationale basis for projecting reuse costs were technical information published in the report “Wastewater reuse and recycling technology”. Eighteen beneficial reuse options were identified ranging from agricultural irrigation to groundwater recharge. Thirteen levels of wastewater treatment comprising 24 different unit process configurations were developed and analysed subsequently in terms of life cycle costs. Assuming certain water quality requirements for each reuse alternative, specific treatment schemes were then linked with the respective beneficial use. A summary of the costs estimated in the mentioned study is presented in Table 2.8 (Cost of Reuse).

Cost savings, based on the additional water sources, additional water transmissions mains, and additional treatment that would not be required or that would be postponed, would represent benefits and, therefore, decrease the present value of the necessary investments. Further, in developing countries the costs for collection and treatment of wastewater can be construed as benefits in terms of providing sewerage services that would be necessary even in the absence of reclamation and reuse (Guidelines for water reuse).

Table 2.8 Summary of estimated water reclamation treatment process life cycle costs

Reuse alternative	Recommended treatment process	Annual costs (€/m³)[a, b]
Agricultural irrigation	Activated sludge	0.16-0.44
Livestock and wildlife watering	Trickling filter	0.17-0.46
Power plant and industrial cooling	Rotating biological contactors	0.25-0.47
Urban irrigation – landscape	Activated sludge, filtration of secondary effluent	0.19-0.59
Groundwater recharge – spreading basins	Infiltration – percolation	0.07-0.17
Groundwater recharge – injection wells	Activated sludge, filtration of secondary effluent, carbon adsorption, reverse osmosis of advanced wastewater treatment effluent	0.76-2.12

(a): Costs are estimated for facility capacities ranging from 4,000 to 40,000 m^3/d. Lower cost figure within each treatment process category represents cost for a 40,000 m^3/d reclamation plant while the upper cost limit is presented for a 4,000 m^3/d facility, (b): Annual costs include amortized capital costs based on a facility life of 20 years and a return rate of 7 %.

2.8 Health Asssessment of Wastewater Reuse

Toxic chemicals and pathogenic microorganisims are presented in untreated wastewater. And, this is a great problem. Because, chemicals or microbiological constituents in wastewater cause to the health concern. Control measures include elimination or reduction in concentration of these constituents in reclaimed water and, where appropriate, practices to prevent or limit direct or indirect contact with the reclaimed water.

Health significant microorganisms and chemical constituents clearly are present in untreated wastewater and, thus, justifiably present a health concern (Guidelines for water reuse). It is also clear that for most uses of reclaimed water, conventional, widely practiced water and wastewater treatment processes are capable of reducing these hazardous constituents to acceptable levels or virtually eliminating them from the water. For some uses, (e.g., indirect potable reuse), advanced treatment processes may be necessary to accomplish this task.

The use of reclaimed water for agricultural irrigation and various municipal uses may result in human exposure to pathogens or chemicals, creating potential public health problems. Water reclamation and reuse and the disposal of sludge from wastewater treatment may also have adverse effects on environmental quality if not managed properly.

Planning for water reuse projects should include the development and implementation of regulations that will prevent or mitigate public health and environmental problems. Such regulations include:

1) A permit system for authorizing wastewater discharges; technical controls on wastewater treatments;

2) Water quality standards for reclaimed water that are appropriate to various uses;

3) Controls that will reduce human exposure, such as restrictions on the uses of reclaimed water;

4) Controls on Access to the wastewater collection system, and controls to prevent crossconnections between the distribution Networks for drinking water and reclaimed water;

5) Regulations concerning sludge disposal and facility siting; and

6) Mechanisms for enforcing all of the above regulations, including monitoring requirements, authority to conduct inspections, and authority to assess penalties for violations.

Wastewater irrigation poses a number of potential risks to human health via the consumption of or exposure to pathogenic microorganisms, heavy metals, harmful organic chemicals such as endocrine disrupting compounds and pharmaceutically-active compounds. Of these, pathogenic microorganisms are generally considered to pose the greatest threat to human health. A wide variety of pathogenic microorganisms is found in wastewater, including bacteria, viruses, protozoans and parasitic worms. The concentration of pathogens in wastewater is dependent on the source population and the susceptibility to infection varies from one population to another.

CHAPTER THREE
WASTEWATER REUSE REGULATIONS

3.1 EPA Guidelines

The U.S. Environmental Protection Agency, in conjunction with the U.S. Agency for International Development, published Guidelines for Water Reuse in 1992. The primary purpose of the document is to provide guidelines, with supporting information, for utilities and regulatory agencies in the U.S., particularly in states where standards do not exist or are being revised or expanded. EPA has determined that guidelines will encourage reuse in areas where it is not now allowed or practiced and may eliminate some of the inconsistencies that characterize current regulations. It is EPA's view that national water reclamation and reuse standards are not necessary and that comprehensive guidelines, coupled with flexible state regulations, will foster increased consideration and implementation of reuse projects.

The guidelines address all important aspects of water reuse and include recommended treatment processes, reclaimed water quality limits, monitoring frequencies, setback distances, and other controls for various water reuse applications. The guidelines address water reclamation and reuse for non potable applications as well as indirect potable reuse by groundwater recharge and augmentation of surface water sources of supply. The treatment processes and reclaimed water quality limits recommended in the guidelines for various reclaimed water applications are given in Table 3.1 (Guidelines for water reuse).

Both reclaimed water quality limits and wastewater treatment unit processes are recommended for these reasons:

1) Water quality criteria involving surrogate parameters alone do not adequately characterize reclaimed water quality;

3) Expensive, time-consuming, and in some cases, questionable monitoring for pathogenic microorganisms is eliminated without compromising health protection;

4) Treatment reliability is enhanced.

In the U.S., total and faecal coliforms are the most commonly used indicator organisms in reclaimed water. The total coliform analysis includes organisms of both faecal and non faecal origin, while the faecal coliform analysis is specific for coliform organisms of faecal origin. Therefore, faecal coliforms are better indicators of faecal contamination than total coliforms, and the authors of the guidelines, upon the recommendation of noted microbiologists, chose the use faecal coliform as the indicator organism. The guidelines state that either the membrane filter technique or the multiple-tube fermentation technique may be used to quantify the coliform levels in the reclaimed water.

The guidelines suggest that, regardless of the type of reclaimed water use, some level of disinfection should be provided to avoid adverse health consequences from inadvertent contact or accidental or intentional misuse of a water reuse system (Guidelines for water reuse). For non potable uses of reclaimed water, only two different levels of treatment and disinfection are recommended. Reclaimed water used for applications where no direct or indirect public or worker contact with the water is expected should receive at least secondary treatment and be disinfected to achieve a faecal coliform concentration not exceeding 200/100mL for these reasons: most bacterial pathogens will be destroyed or reduced to low or insignificant levels in the water; the concentration of viable viruses and parasites will reduced somewhat; disinfection of secondary effluent to a faecal coliform level of 200/100mL is readily achievable at minimal cost; and significant health-related benefits associated with disinfection to lower, but not pathogen-free, levels are not obvious.

For uses where direct or indirect contact with reclaimed water is likely or expected, and for dual water systems where there is a potential for cross-connections with potable water lines, disinfection to produce reclaimed water having no detectable faecal coliform organisms/100mL is recommended (Guidelines for water reuse). This more restrictive disinfection level is intended to be used in conjunction with tertiary treatment and other water quality limits, such as 2 NTU in the wastewater prior to disinfection. This combination of treatment and water quality has been shown to be capable of producing reclaimed water that is essentially free of measurable levels of pathogens.

The guidelines include limits for faecal coliform organisms but do not include parasite or virus limits. Parasites have not been shown to be a problem at reuse operations in the U.S. at the treatment levels and reclaimed water limits recommended in the guidelines, although there has been considerable interest in recent years regarding the occurrence and significance of *Giardia lamblia* and *Cryptosporidium parvum* in reclaimed water. Where filtration and a high level of disinfection are recommended in Table 3.1 to produce reclaimed water that is essentially pathogen-free, it may be necessary to provide chemical addition prior to filtration to assure complete removal of parasites (Guidelines for water reuse).

While viruses are a concern in reclaimed water, virus limits are not recommended in the guidelines for following reasons:

1) A significant body of information exists indicating that viruses are inactivated or removed to low or immeasurable levels via appropriate wastewater treatment;

2) The type and concentration of viruses in wastewater are difficult to determine accurately because of low virus recovery rates;

3) There are a limited number of facilities having the personnel and equipment necessary to perform the analyses;

4) The laboratory analyses can take as long as 4 weeks to complete;

5) There is no consensus among public health experts regarding the health significance of low levels of viruses in reclaimed water;

6) There have not been any documented cases of viral disease resulting from the reuse of wastewater in the U.S. While recombinant DNA technology provides new tools to rapidly detect viruses in water, e.g., nucleic acid probes and polymerase

chain reaction technology, methods currently in use are not able to quantify viruses or differentiate between infective and non-infective virus particles.

Unplanned or incidental indirect potable reuse occurs in many states in the U.S., while planned or intentional indirect potable reuse via groundwater recharge or augmentation of surface supplies is less widely practiced. Whereas the water quality requirements for non potable water uses are tractable and not likely to change significantly in the future, the number of quality constituents to be monitored in drinking water (and, hence, reclaimed water intended for potable reuse) will increase and quality requirements are likely to become more restrictive. Consequently, it would not be prudent to suggest a complete list of reclaimed water quality limits for all constituents of concern. In addition to some specific wastewater treatment and reclaimed water quality recommendations, the guidelines provide some general recommendations to indicate the extensive treatment and water quality requirements that are likely to be imposed where indirect potable reuse is contemplated. The guidelines do not advocate direct potable reuse and do not include recommendations for such use.

The guidelines published by EPA include recommended water quality limits other than those specified in Table 3.1. The guidelines document includes suggested chemical constituent limits for most of the uses presented in Table 3.1. For example, for urban uses of reclaimed water, the guidelines recommend that the product water be non toxic upon ingestion. This is recommended to protect against inadvertent and infrequent ingestion; it is not meant to imply that wastewater meeting the requirements for urban reuse is acceptable as a source of potable water. Other recommendations addressing urban use of reclaimed water include the following: clear, colorless, and odorless product water; a setback distance of 15 m (50 ft) from irrigated areas to potable water supply wells; maintenance of a chlorine residual of at least 0.5 mg/L in the distribution system; treatment reliability and emergency storage or disposal of inadequately-treated water; and cross-connection control via reduced pressure principle backflow prevention devices on potable water service lines at areas receiving reclaimed water and color-coded or taped reclaimed water lines and appurtenances. Similar design and operational recommendations are included in the guidelines for the other reclaimed water applications presented in Table 3.1.

It is explicitly states in the *Guidelines for Water Reuse* that the recommended treatment unit processes and water quality limits presented in the guidelines ‘‘are not intended to be used as definitive water reclamation and reuse criteria. They are intended to provide reasonable guidance for water reuse opportunities, particularly in states that have not developed their own criteria or guidelines’’.

Table 3.1 EPA Suggested Guidelines for Reuse of Municipal Wastewater [1] (Guidelines for water reuse).

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Urban Reuse All types of landscape irrigation (e.g., golf courses, parks, cemeteries) also vehicle washing, toilet flushing, use in fire protection system and commercial air conditioners, and other uses with similar Access or exposure to the water.	• Secondary[4] • Filtration[5] • Disinfection[6]	• pH = 6-9 • ≤ 10 mg/L BOD[7] • ≤ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] • ≥ 1 mg/L Cl_2 residual[11]	• pH – weekly • BOD – weekly • Turbidity – continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• Consult recommended agricultural (crop) limits for metals • A lower level of treatment, e.g., secondary treatment and disinfection to achieve ≤ 14 fecal coli/100 mL, may be appropriate at controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. • Reclaimed water should be clear, odorless, and contain no substances that are toxic upon ingestion. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • A chlorine residual of 0.5 mg/L or greater in the distribution system is recommended to reduce odors, slime, and bacterial regrowth. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[b]	Comments
Restricted Access Area Irrigation					
Sod farms, silviculture sites, and other areas where public Access is prohibited, restricted, or infrequent.	• Secondary[4] • Disinfection[6]	• pH = 6-9 • ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14] • ≤ 1 mg/L Cl_2 residual [11]	• pH – weekly • BOD – weekly • SS – daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• Consult recommended agricultural (crop) limits for metals • If spray irrigation, SS less than 30 mg/L may be necessary to avoid clogging of sprinkler heads. • Provide treatment reliability.
Agricultural Reuse – Food Crops Not Commercially Processed[15]					
Surface or spray irrigation of any food crop, including crops eaten raw.	• Secondary[4] • Filtration[5] • Disinfection[6]	• pH = 6-9 • ≤ 10 mg/L BOD[7] • ≤ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] • ≥ 1 mg/L Cl_2 residual [11]	• pH – weekly • BOD – weekly • Turbidity – continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• Consult recommended agricultural (crop) limits for metals • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • High nutrient levels may adversely affect some crops during certain growth stages. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Agricultural Reuse – Food Crops Commercially Processed[15] Surface Irrigation of Orchards Vineyards					
	• Secondary[4] • Disinfection[6]	• pH = 6-9 • ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14] • ≥ 1 mg/L Cl_2 residual [11]	• pH – weekly • BOD – weekly • SS – daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public	• Consult recommended agricultural (crop) limits for metals • If spray irrigation, SS less than 30 mg/L may be necessary to avoid clogging of sprinkler heads. • High nutrient levels may adversely affect some crops during certain growth stages. • Provide treatment reliability.
Agricultural Reuse – Non Food Crops					
Pasture for milking animals; fodder, fiber, and seed crops	• Secondary[4] • Disinfection[6]	• pH = 6-9 • ≤ 10 mg/L BOD[7] • ≤ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] • ≥ 1 mg/L Cl_2 residual [11]	• pH – weekly • BOD – weekly • SS – daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public	• Consult recommended agricultural (crop) limits for metals • If spray irrigation, SS less than 30 mg/L may be necessary to avoid clogging of sprinkler heads. • High nutrient levels may adversely affect some crops during certain growth stages. • Milking animals should be prohibited from grazing for 15 days after irrigation ceases. A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 mL, should be provided if this waiting period is not adhered to. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Recreational Impoundments					
Incidental contact (e.g., fishing and boating) and full body contact with reclaimed water allowed.	• Secondary[4] • Filtration[5] • Disinfection[6]	• pH = 6-9 • $\leq$ 10 mg/L BOD[7] • $\leq$ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] • $\geq$ 1 mg/L Cl_2 residual	• pH – weekly • BOD – weekly • Turbidity – continuous • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells if bottom not sealed	• Dechlorination may be necessary to protect aquatic species of flora and fauna. • Reclaimed water should be non-irritating to skin and eyes. • Reclaimed water should be clear, odorless, and contain no substances that are toxic upon ingestion. • Nutrient removal may be necessary to avoid algae growth in impoundments. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • Fish caught in impoundments can be consumed. • Provide treatment reliability.
Landscape Impoundments					
Aesthetic impoundments where public contact with reclaimed water is not allowed.	• Secondary[4] • Disinfection[6]	• $\leq$ 30 mg/L BOD[7] • $\leq$ 30 mg/L SS • $\leq$ 200 fecal coli/100 mL[9,13,14] • $\geq$ 1 mg/L Cl_2 [11]	• pH – weekly • SS – daily • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells if bottom not sealed	• Nutrient removal processes may be necessary to avoid algae growth in impoundments. • Dechlorination may be necessary to protect aquatic species of flora and fauna. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Construction Uses Soil compaction, dust control, washing aggregate, making concrete.	• Secondary[4] • Disinfection[6]	• ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14] • ≥ 1 mg/L Cl_2 residual [11]	• BOD – weekly • SS – daily • Coliform - daily • Cl_2 residual – continuous		• Worker contact with reclaimed water should be minimized. • A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 mL, should be provided where frequent worker contact with reclaimed water is likely. • Provide treatment reliability.
Industrial Reuse Once – through cooling	• Secondary[4]	• pH = 6-9 • ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14] • ≥ 1 mg/L Cl_2 residual [11]	• pH – weekly • BOD – weekly • SS – daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to areas accessible to the public.	• Windblown spray should not reach areas accessible to users or the public.
Recirculating cooling towers	• Secondary[4] • Disinfection[6] (chemical coagulation and filtration[5] may be needed)	• Variable, depends on recirculation ratio.		• 300 ft (90 m) to areas accessible to the public. May be reduced if high level of disinfection is provided.	• Windblown spray should not reach areas accessible to users or the public. • Consult recommended water quality limits for make-up water. • Additional treatment by user is usually provided to prevent scaling, corrosion, biological growths, fouling and foaming. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Environmental Reuse Wetlands, marshes, wildlife habitat, stream augmentation	• Variable • Secondary[4] and disinfection[6] (min.)	Variable, but not to exceed : • ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14]	• BOD – weekly • SS – daily • Coliform - daily • Cl_2 residual – continuous		• Dechlorination may be necessary to protect aquatic species of flora and fauna. • Possible effects on groundwater should be evaluated. • Receiving water quality requirements may necessitate additional treatment. • The temperature of the reclaimed water should not adversely affect ecosystem. • Provide treatment reliability.
Groundwater Recharge By spreading or injection into non potable aquifers	• Site-specific and use dependent • Primary (min) for spreading • Secondary[4] (min.) for injection	• Site-specific and use dependent	• Depends on treatment and use	• Site-specific	• Facility should be designed to ensure that no reclaimed water reaches potable water supply aquifers. • For injection projects, filtration and disinfection may be needed to prevent clogging. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Indirect Potable Reuse Groundwater recharge by spreading into potable aquifers.	• Site-specific • Secondary[4] and disinfection[6] (min.) • May also need filtration[5] and/or advanced wastewater treatment[16]	• Site-specific • Meet drinking water standards after percolation through vadose zone.	Includes, but not limited to, the following: • pH – daily • Coliform - daily • Cl_2 residual – continuous • Drinking water standards – quarterly • Other[p] – depends on constituent	• 2000 ft (600 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	• The depth to groundwater (i.e., thickness of the vadose zone) should be at least 6 feet (2 m) at the maximum groundwater mounding point. • The reclaimed water should be retained underground for at least 1 year prior to withdrawal. • Recommended treatment is site-specific and depends on factors such as type of soil percolation rate, thickness of vadose zone native groundwater quality, and dilution. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • The reclaimed water should not contain measurable levels of pathogens after percolation through the vadose zone. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Indirect Potable Reuse Groundwater recharge by injection into potable aquifers	• Secondary[4] • Filtration[5] • Disinfection[6] • Advanced wastewater treatment[16]	Includes, but not limited to the following: • pH = 6.5 - 8.5 • ≤ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] • ≥ 1 mg/L Cl_2 residual • Meet drinking water standards	Includes, but not limited to the following: • pH – daily • Turbidity – continuous • Coliform - daily • Cl_2 residual – continuous • Drinking water standards – quarter • Other[17] – depends on constituent	• 2000 ft (600 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	• The reclaimed water should be retained underground for at least 1 year prior to withdrawal. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • Recommended quality limits should be met at the point of injection. • The reclaimed water should not contain measurable levels of pathogens at the point of injection[12]. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus inactivation. • Provide treatment reliability.
Augmentation of surface supplies	• Secondary[4] • Filtration[5] • Disinfection[6] • Advanced wastewater treatment[16]	Includes, but not limited to the following: • pH = 6.5 - 8.5 • ≤ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] • ≥ 1 mg/L Cl_2 residual • Meet drinking water standards	Includes, but not limited to the following: • pH – daily • Turbidity – cont. • Coliform - daily • Cl_2 residual – continuous • Drinking water standards – quarterly • Other[17] – depends on constituent	• Site-specific	• Recommended level of treatment is site-specific and depends on factors such as receiving water quality, time and distance to point of withdrawal, dilution and subsequent treatment prior to distribution for potable uses. • The reclaimed water should not contain measurable levels of pathogens[12]. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus inactivation. • Provide treatment reliability.

1 These guidelines are based on water reclamation and reuse practices in the U.S., and they are especially directed at states that have not developed their own regulations or guidelines. While the guidelines should be useful in many areas outside the U.S., local conditions may limit the applicability of the guidelines in some countries.

2 Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility.

3 Setback distances are recommended to protect potable water supply sources from contamination and to protect humans from unreasonable health risks due to exposure to reclaimed water.

4 Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contactors, and many stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and SS do not exceed 30 mg/l.

5 Filtration means the passing of wastewater through natural undisturbed soils or filter media such as sand and/or anthracite.

6 Disinfection means the destruction, inactivation, or removal of pathogenic microorganisms by chemical, physical, or biological means. Disinfection may be accomplished by chlorination, ozonation, other chemical disinfectants, UV radiation, membrane processes, or other processes.

7 As determined from the 5-day BOD test.

8 The recommended turbidity limit should be met prior to disinfection. The average turbidity should be based on a 24-hour time period. The turbidity should not exceed 5 NTU at any time. If SS is used in lieu of turbidity, the average SS should not exceed 5 mg/l.

9 Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. Either the membrane filter or fermentation tube technique may be used.

10 The number of faecal coliform organisms should not exceed 14/100 ml in any sample.

11 Total chlorine residual after a minimum contact time of 30 minutes

12 It is advisable to fully characterize the microbiological quality of the reclaimed water prior to implementation of a reuse program.

13 The number of faecal coliform organisms should not exceed 800/100 ml in any sample.

14 Some stabilization pond systems may be able to meet this coliform limit without disinfection.

15 Commercially processed food crops are those that, prior to sale to the public or others, have undergone chemical or physical processing sufficient to destroy pathogens.

16 Advanced wastewater treatment processes include chemical clarification, carbon adsorption, reverse osmosis and other membrane processes, air stripping, ultrafiltration, and ion exchange.

17 Monitoring should include inorganic and organic compounds, or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutogenic and are not included in the drinking water standards.

3.2 World Health Organization (WHO) Guidelines

Guidance in establishing water reclamation and reuse regulations also is provided by the World Health Organization (WHO). In 1971, WHO sponsored a meeting of experts on water reuse, culminating in a report recommending health criteria and treatment processes for various reclaimed water applications. The applications ranged from irrigation of crops not intended for human consumption, for which the criteria were freedom from gross solids and significant removal of parasite eggs, to indirect potable reuse for which secondary treatment followed by filtration, nitrification, denitrification, chemical clarification, carbon adsorption, ion exchange or membranes, and disinfection were recommended. For non potable urban reuse and contact recreation, secondary treatment followed by sand filtration and disinfection were recommended. However, the health criteria differed in that for the urban reuse only a general requirement for effective bacteria removal and some removal of viruses was specified, while for contact recreation a bacterial standard of not more than 100 coliform/100 ml in 80 percent of samples and the absence of skin-irrigating chemicals were specified.

In 1985, a meeting of scientists and epidemiologists was held in Engelberg, Switzerland, to discuss the health risks associated with the use of wastewater and excreta for agriculture and aquaculture. The meeting did not consider other uses of reclaimed water. The meeting was sponsored by WHO, the World Bank, United Nations Development Programme, and the International Reference Centre for Wastes Disposal. Health-related and other research made available since publication of the 1973 WHO guidelines were reviewed, and a revised approach to the nature of health risks associated with agriculture and aquaculture was developed. A model was developed of the relative health risks from the use of untreated excreta and wastewater in agriculture or aquaculture. The meeting concluded that the health risks resulting from irrigation with well treated wastewater were minimal and that current standards and guidelines are overly conservative and unduly restrict appropriate project development, thereby encouraging unregulated use of wastewater.

The Engelberg Report developed tentative microbial quality guidelines for reclaimed water used for irrigation. It was recommended that the number of intestinal nematods should not exceed a geometric mean of one viable egg/L for all irrigation and that for the irrigation of edible crops, sports fields, and public parks, the number of faecal coliform organisms should not exceed 1.000/100 ml. The participants reasoned that, if those limits are met, other pathogens such as trematode eggs and protozoan cysts also are reduced to undetectable levels. The participants recognized, in addition, that social and behavioural patterns are of fundamental importance in the design and implementation of reuse projects. The meeting recommended that WHO initiate revision of the 1973 guidelines.

A WHO Scientific Group on Health Aspects of the Use of Treated Wastewater for Agriculture and Aquaculture met in Geneva in 1987, and their report has been published by WHO as *Health Guidelines for the Use of Wastewater for Agriculture and Aquaculture*. These WHO guidelines reaffirm the recommendations of the Engelberg Report. The recommended microbiological quality guidelines for irrigation are summarized in Table 3.2. The guidelines are based on the conclusion that the main health risks are associated with helminthic disease and, therefore, a high degree of helminth removal is necessary for the safe use of wastewater in agriculture and aquaculture. The intestinal nematodes covered serve as indicator organisms for all of the large settleable pathogens. The guidelines indicate that other pathogens apparently become non-viable in pound systems with long retention times, implying that all helminth eggs and protozoan cysts will be removed to the same extent. The helminth egg guidelines are intended to provide a design standard, not a standard requiring routine testing of the effluent.

The scientific group concluded that no bacterial guidelines are necessary in cases where the only exposed populations are farm workers, due to a lack of evidence indicating a health risk from bacteria. The recommended bacterial guideline of a geometric mean faecal coliform level of 1.000/100 ml was based on the evaluation of epidemiological studies and was considered by the scientific group to be technically feasible in developing countries. Most of the epidemiological investigations studied the application of untreated or poorly-treated wastewater for irrigation of food crops in developing countries. They mainly focused on disease incidence related to parasites and paid little attention to bacteria and viruses. The scientific group indicated that the potential health risks associated with the use of reclaimed water for lawn and park irrigation may present greater potential health risks than those associated with the irrigation of vegetables to be eaten raw and, hence, recommended a faecal coliform limit of 200/100 mL for such urban irrigation.

The WHO guidelines recognize that there are limited health effects data for reclaimed water used for aquaculture and do not recommend definitive bacteriological quality standards for this use. However, tentative bacterial guidelines in the guidelines recommend a geometric mean of 1.000 faecal coliforms/100 mL, which is intended to insure that invasion of fish muscle, is prevented. The same faecal coliform standard is recommended for pond water in which aquatic vegetables (macrophytes) are grown. Since pathogens may accumulate in the digestive tract and intraperitoneal fluid of fish and pose a risk through cross-contamination of fish flesh or other edible parts-and subsequently to consumers if hygiene standards in fish preparation are inadequate-a recommended public health measure is to ensure maintenance of high standards of hygiene during fish handling and gutting. A total absence of viable trematode eggs, which is achievable by properly-designed and operated stabilization pond systems, is recommended as the appropriate helminth quality guideline for aquaculture use of reclaimed water.

The 1989 WHO guidelines identify waste stabilization ponds as the method of choice in meeting these guidelines in warm climates where land is available at reasonable cost. Based on helminth removal, the guidelines recommend a pond retention time of eight to ten days, with at least twice that time required in warm climates to reduce faecal coliforms to the guideline level of 1.000/100 ml. Experience at some existing full-scale and demonstration stabilization pond systems indicates that the desired reductions of helminths and faecal coliform organisms may be difficult to achieve in practice.

The Scientific Group that developed the WHO guidelines criticized the California *Wastewater Reclamation Criteria* as being too stringent, not based on epidemiological evidence, unattainable, and not appropriate for developing countries. The California standards are intended to ‘‘establish acceptable levels of constituents of reclaimed water and to prescribe means for assurance of reliability in the production of reclaimed water to ensure that the use of reclaimed water does not impose undue risks to health’’. The California criteria are based on the control of all wastewater-associated pathogens of concern in the U.S., including parasites, bacteria, and viruses. They were developed for use in that state, where they have been shown to be readily attainable at more than 250 reclamation facilities. It is not surprising that the California standards and those of other states and industrialized countries are not achievable in developing countries due to economic, technological, and institutional differences between developed and developing countries.

The WHO guidelines are significantly less restrictive than regulations or guidelines of many industrialized countries. The intentions of international organizations such as the World Bank and United Nations Development Programme, who sponsored early work in this area, were to introduce at least some treatment of wastewater prior to crop irrigation, particularly in developing countries. This concept is understandable and commendable, and the WHO guidelines satisfy that intent. The WHO guidelines are appropriate as an interim measure in some countries until there is an ability to produce higher quality reclaimed water. It is unlikely that the WHO guidelines will replace existing criteria in most industrialized countries.

Table 3.2 World health recommended microbiological guidelines for wastewater use in agriculture.[a]

Category	*Reuse Conditions*	*Exposed Group*	*Intestinal nematodes*[b] *(arithmetic mean no. of eggs per liter)* [c]	*Fecal Coliforms (geometric mean no. per 100mL)* [c]	*Wastewater Treatment Expected to Achieve the Required Microbiological Quality*
A	Irrigation or crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	_<1	1.000[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment.
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	_<1	No standards recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and fecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

a In specific cases, local epidemiological, sociocultural, and environmental factors should be taken into account, and the guidelines modified accordingly

b *Ascaris* and *Trichuris* species and hookworms.

c During the irrigation period.

d A more stringent guideline (200fecal coliforms per 100 mL) is appropriate for public lawns, with which the public may come into direct contact.

e In the case of fruit trees, irrigation should cease 2 weeks before fruit should be picked off the ground. Sprinkler irrigation should not be used.

3.3 Reuse Standards in Turkey

Water reuse has been officially legitimized in 1991 through the regulation for irrigational wastewater reuse issued by the Ministry of Environment (Development of tools and guidelines for the promotion of the sustainable urban wastewater treatment and reuse in the agricultural production in the Mediterranean countries). Since then, there have been no changes and revisions of the regulation, however, the applications have not been satisfactorily realized so far.

Table 3.3 Turkish water quality criteria for irrigation, according to classes

Quality Criteria	**Class I (Perfect)**	**Class II (Satisfactory)**	**Class III (Usable)**	**Class IV (Usable with care)**	**Class V (Improper harmful)**
EC_{25} (microhos at 25 ^oC) $\times 10^6$	0-250	250-750	750-2,000	2,000-3,000	>3,000
Sodium (Na, %)	<20	20-40	40-60	60-80	>80
Sodium Adsorption Ratio (SAR)	<10	10-18	18-26	>26	
Residual Sodium Carbonate (RSC) in meq/l or mg/l	>1.25 <66	1.25-2.5 66-133	>2.5 >133		
Chloride (Cl^-) in meq/l or mg/l	0-4 0-142	4-7 142-249	7-12 249-426	12-20 426-710	>20 >710
Sulphate ($SO_4^=$) in meq/l or mg/l	0-4 0-192	4-7 192-336	7-12 336-575	12-20 575-960	>20 >960
Total Salt Concentration (mg/l)	0-175	175-525	525-1,400	1,400-2,100	>2,000
Boron Concentration (mg/l)	0-0.5	0.5-1.12	1.12-2.0	>2.0	-
Class of Irrigation Water *	C_1S_1	C_1S_2, C_2S_2, C_2S_1	C_1S_3, C_2S_3, C_3S_3, C_3S_2 C_3S_1	C_1S_4, C_2S_4, C_3S_4, C_4S_4, C_4S_3, C_4S_2 C_4S_1	-
NO_3^--N or NH_4^+-N (mg/l)	0-5	5-10	10-30	30-50	>50

Faecal Coliform** 1/100 ml (CFU in 100 ml)	0-2	2-20	20-100	100-1,000	>1,000
BOD_5 (mg/l)	0-25	25-50	50-100	100-200	>200
TSS (mg/l)	20	30	45	60	>100
pH	6.5-8-5	6.5-8.5	6.5-8.5	6.5-9	<6 or >9
Temperature (^{o}C)	30	30	35	40	>40

* there exists a diagram that indicates the relationship between SAR and electrical conductivitiy

** varies according to type of plantation

The most important criteria for evaluating the suitability of treated wastewater for irrigation use are: public health aspects, salinity (especially significant in arid regions), heavy metals and harmful organic substances. In addition to standards, regulations can include best practices for wastewater treatment and irrigation techniques as well as regarding crops and areas to be irrigated.

In Turkey, the WHO standards have been adopted except the limits for the intestinal nematodes and the residual chlorine. Concerning the microbiological standards, the Turkish regulation consists of only faecal coliform parameter and, it seems to be insufficient and needs to be revised in terms of health aspects (Table 3.3). Boron concentrations are known to be important for Turkey’s conditions as the country is rich in boron sources. The table stating the boron concentrations in terms of irrigation water is given below in Table 3.4.

Table 3.4 Classification of irrigation water with respect to resistance of plants to boron mineral

Classification of irrigation water	**Boron concentration (mg/l) sensitive plants***	**Boron concentration (mg/l) semi-sensitive plants****	**Boron concentration (mg/l) tolerable plants*****
I	< 0.33	< 0.67	< 1.0
II	0.33-0.67	0.67-1.33	1.00-2.00
III	0.67-1.00	1.33-2.00	2.00-3.00
IV	1.00-1.25	2.00-2.50	3.00-3.75
V	> 1.25	> 2.50	> 3.75

*e.g. walnut, lemon, fig, apple, grape and bean., ** e.g. barley, wheat, maize, oats, olive and cotton. *** e.g. sugar beet, clover, horse bean, onion, lettuce and carrot.

In the same Part, a table exists on maximum allowable concentration of heavy metals and toxic elements in irrigation water. It is given below in Table 3.5 and is adopted from EPA. There are two more Tables on reuse of treated effluent for irrigation purposes. Table 3.6 states the technical limitations and related on reuse of water in irrigation and Table 3.7 indicates the suitability of treated domestic wastewater in irrigation without disinfection.

Table 3.5 Maximum allowable concentration of heavy metals and toxic elements in irrigation water in Turkey

Elements	**Max. total amount to be given to unit area of land (kg/ha)**	**Maximum allowable concentration in every type of soil and under continuous irrigation (mg/l)**	**Maximum allowable concentration in clayey soil (pH: 6.0-8.5) irrigation less than 20 years (mg/l)**
Aluminum	4,600	5.0	20.0
Arsenic	90	0.1	2.0
Beryllium	90	0.1	0.5
Boron	680	specified in Table 9 of the bulletin	2.0
Cadmium	9	0.01	0.05
Chromium	90	0.1	1.0
Cobalt	45	0.05	5.0
Copper	180	0.2	5.0
Fluoride	920	1.0	15.0
Iron	4,600	5.0	20.0
Lead	4,600	5.0	10.0
Lithium *	-	2.5	2.5
Manganese	920	0.2	10.0
Molybdenum	9	0.01	0.05*/**[1]
Nickel	920	0.2	2.0
Selenium	18	0.02	0.02
Vanadium	-	0.1	1.0
Zinc	1,840	2.0	10.0

* 0.075 mg/l is recommended for irrigation of citrus fruits

*/** allowable concentration in only acidic clay soil with high iron content

Table 3.6 The technical limitations and related basis on reuse of water in irrigation

Type of crops	Technical limitations
Orchard and vineyards	-No spray irrigation -Fruits falling on ground cannot be eaten -Faecal coliform <1,000/100 ml
Fibrous and seed crops	-Surface or spray irrigation -Disinfection and biological treatment are required for spray irrigation -Faecal coliform <1000/100 ml
Feed crops, flowers, vegetables which are not eaten raw	-Surface irrigation -Minimum mechanical treatment

Table 3.7 Suitability of treated domestic wastewater in irrigation without disinfection

	Arable land	Meadow and pasture	Vegetables	Feed crop	Fruit production	Forestry & woodland
Effluent of biological treatment plant or pre-treatment effluent (with 2 hours detention time sedimentation tank)	(+) for both NP & P	(+) for both NP & P	(-) for both NP & P	(+) for NP (-) for P	(-) for both NP & P	(+)
Effluent of aerobic stabilization ponds and lagoons	(+) for NP (-) for P	(+) for NP (-) for P	(-) for both NP & P	(+) for NP (-) for P	(-) for both NP & P	(+)

NP= no plantation

P= plantation (with or with out fruits)

3.4 European Union (EU)

Identification of a competent authority or authorities is the responsibility of each individual state in the context of the implementation of the European Water Framework Directive. Each European country has its own water management system consisting of the state water departments and the local authorities. The Ministries of the Environment, Agriculture, and Health are the main state water departments that issue statutes and water policies as well as implement water related legislation. Most of the regulations are under the umbrella of the EU water framework directive (WFD) and represent the major advance in the European policy with the concept of good ecological status and water management at the river basin level (Janosova, Miklankova, Hlavinek, Wintgens; 1982).

It is currently essential to look at the local authorities in European regions, who are mostly responsible for the supervision of collection, treatment and disposal of wastewater. These water authorities on a local scale and the effectiveness of a participatory approach in water planning could help to achieve a “cultural shift” to recognise the potential benefits which water reuse programs can bring (Medaware, 2005).

3.5 Reuse Standards in France

France has been irrigating crops with wastewater for years. Because of a new interest for wastewater reuse, the Health Authorities issued in 1991 the Health guidelines for reuse, after treatment, of wastewater for crop and green spaces irrigation.

In 1991 France enacted a comprehensive national code of practice under the form of recommendations from the Conseil Supérieur díHygiène Publique de France (CSHPF) (Guidelines for water reuse). These recommendations use the WHO guidelines as a basis, but complement them with strict rules of application. In general, the approach is very cautious and the main restrictions given by the CSHPF are:

- The protection of the ground and surface water resources.
- The restriction of uses according to the quality of the treated effluents.
- The piping networks for the treated wastewaters.
- The chemical quality of the treated effluents
- The control of the sanitary rules applicable to wastewater treatment and irrigation facilities
- The training of operators and supervisors.

The CSHPF calls for strict observation of these restrictions to ensure the best possible protection of the public health of the populations concerned. In fact, the authorizations for wastewater reuse are granted on a case by case basis after review of a highly detailed dossier.

3.6 Reuse Standards in Italy

Existing Italian legislation General Technical Standards – G.U. 21.2.77 sets the limits depending on the type of vegetables and grazing crops to 2 and 20 FC/100 cm3, respectively. Moreover, the law prescribes that in the presence of surface aquifers in direct contact with surface waters, adequate preventive measures must be used to avoid any deterioration of their quality. A new law relative to municipal wastewater is being prepared that gives better attention to the management of water resources and in particular to the reuse of treated wastewater. Industry will be encouraged to use treated wastewater. Municipal wastewater treatment companies have already planned to build a separate supply network for wastewater reuse by industries. In the metropolitan area of Turin, for example, the two main companies (Azienda Po Sangone (APS) and CIDIU) have already done so. Finally, a proposal for establishing national regulations on wastewater recycling and reuse has been implemented. Criteria proposed are incorporated in the recent legislation. Comparison of regional guidelines with Italy and WHO standards is given in Table 3.8.

Table 3.8 Microbiological standards for irrigation with municipal wastewater: comparison of regional guidelines with Italy and WHO standards

Organisation or region	**TC (MPN/100 ml) (a)**	**FC (MPN/100 ml)**	**Nematode eggs (no/L)**
WHO	Not set	1,000(b)	1
Italy	2(b) , 20(c)	Not set	Not set

[a] mean value of 7 consecutive sampling days
b unrestricted irrigation
c restricted irrigation

CHAPTER FOUR
MEAT PROCESSING INDUSTRY

4.1 Introduction to Process

The meat processing industry is an industry that handless the slaughtering, processing, and distribution of animals such as cattle, pigs, sheep, and other livestock. The industry is primarily focused on producing meat for human consumption, but it also yields a variety of by-products including hides, feathers, dried blood, and through the process of rendering, oil such as tallow and protein meals such as meat & bone meal.

The subgroups of the meat industry are given in Figure 4.1. The meat industry can be divided into two main groups:

1. Slaughterhouses
2. Integrated facilities

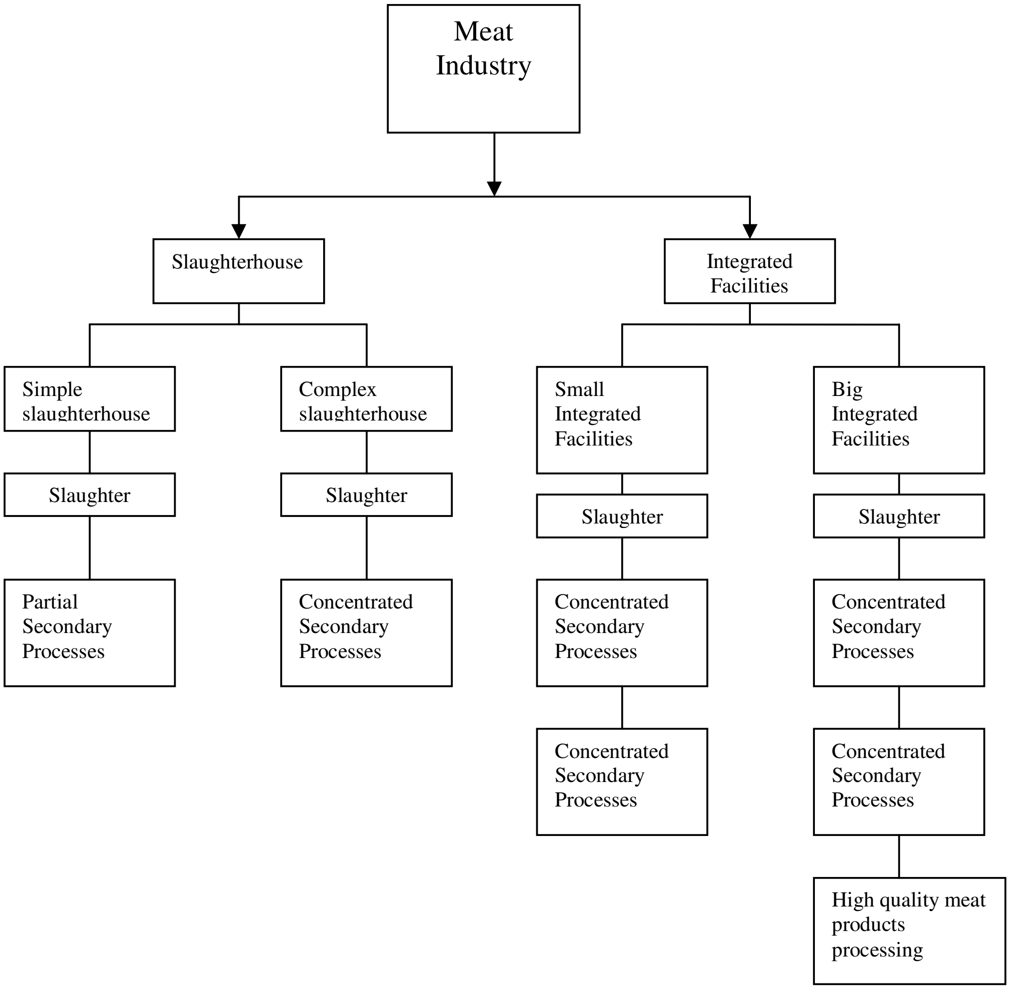

Figure 4.1 The subgroups of the meat industry (Dursun & Özen, 1999)

The meat processing industry can be evaluated in two categories:

1. Red Meat Production
2. Rendering

4.1.1 Red Meat Production

The typical flow scheme of the red meat process is given in Figure 4.2 and some important units are described briefly below:

4.1.1.1 Lairages

Before food animals are slaughtered, they are kept in the waiting lairages. The main pollutants of the lairages are the faeceses of animals, the urea, the food wastes, the sludge that to be constituted and the materials that to be used for cleaning. The materials are collected with a channel. Dry cleaning can be applied for solid matters removal (Sweeten, 1996).

4.1.1.2 Slaughtering

In slaughterhouse, the animals are sheared with mechanical methods and their bloods are collected with the different channel. The wastewater from a slaughterhouse typically contains blood, manure, hair, fat, feathers and bones and may be at high temperatures. Blood itself has a high BOD: 150,000 - 200,000 mg/l, the extreme value being 405,000 mg/L. Cattle contain up to 23 kg blood per animal, and typically 16 kg of blood are recovered in the sticking and bleeding area. The remaining 7 kg are lost, which represents a waste load of 3 kg BOD/tone of slaughtered animal. If blood is not separated, the pollution load will increase till 10 kg BOD/tone (Schraufnagel, 1962).

4.1.1.3 Blood operating

Blood constitutes the highest pollution load in effluent, and the bleeding area of the slaughter floor is the main source of blood contamination. Blood has a very high organic content, and it is also the main contributor to nitrogen loads in effluent. The collected blood is dried, and it is used for making of fodder and fertilizer (Sweeten, 1996).

4.1.1.4 Skinning process

After the slaughtering process; the skin is removed from the head, and the head is removed from the carcase. In the middle and big facilities, the hides are carried out with mechanical methods (Schraufnagel, 1962).

4.1.1.5 Hide process

The hides must be washed and must be salted. The hides must be washed and must be salted. Therefore, salty wastewater is produced from this process (Sweeten, 1996).

4.1.1.6 Bristle removal

In order to remove bristles, heating is applied at the temperature of between 35 and 65°C in a heating tank. The bloods, filths, wastes, and bristles are collected in these tanks. The pollution load is about 0.15 kg BOD/tone in this process. The separated bristles are cleaned with mechanic method. In wastewater produced from bristle removal operation includes bristles, bloods, and filths (Rendering, meat).

4.1.1.7 Separation of offal

After the hide and bristle removal, the carcase is butchered and offal is removed. Offal is the entrails and internal organs of a butchered animal. The word does not refer to particular list of organs, but includes most internal organs other than muscles or bones. Depending on the cultural context, offal may be considered as waste material that is thrown away, or as delicacies that command a high price. Offal not used directly for human or animal food is often processed in a rendering plant, producing material that is used for animal feed, fertilizer or fuel. Blood, tissues, and oil are the main pollutants in wastewater produced from offal separation (Rendering, meat).

4.1.1.8 Intestine operating

The intestines can directly be sent to rendering. Intestines must be mashed and cut, before go to rendering. Also, the intestines can be used for the production of wiener in the integrated facilities. In this operation, oil quantity of wastewaters is high and waste load is about 0.6 kg BOD/tone (Günter, 1959).

4.1.1.9 Washing and cooling

The aim of this stage is the prevention of spoiling of meats. The carcasses are washed and are cooled between 0.5 and 1.5°C. During this process, the water quantity that to be consumed is very high (Industries and recycling businesses).

4.1.1.10 Meats breaking

During this process, meat pieces, blood, and bone are wasted.

4.1.1.11Rendering

Rendering is an industrial process that converts waste animal tissue into stable, value-added materials. Rendering process can be located inside or outside of the facilities (Meat processing).

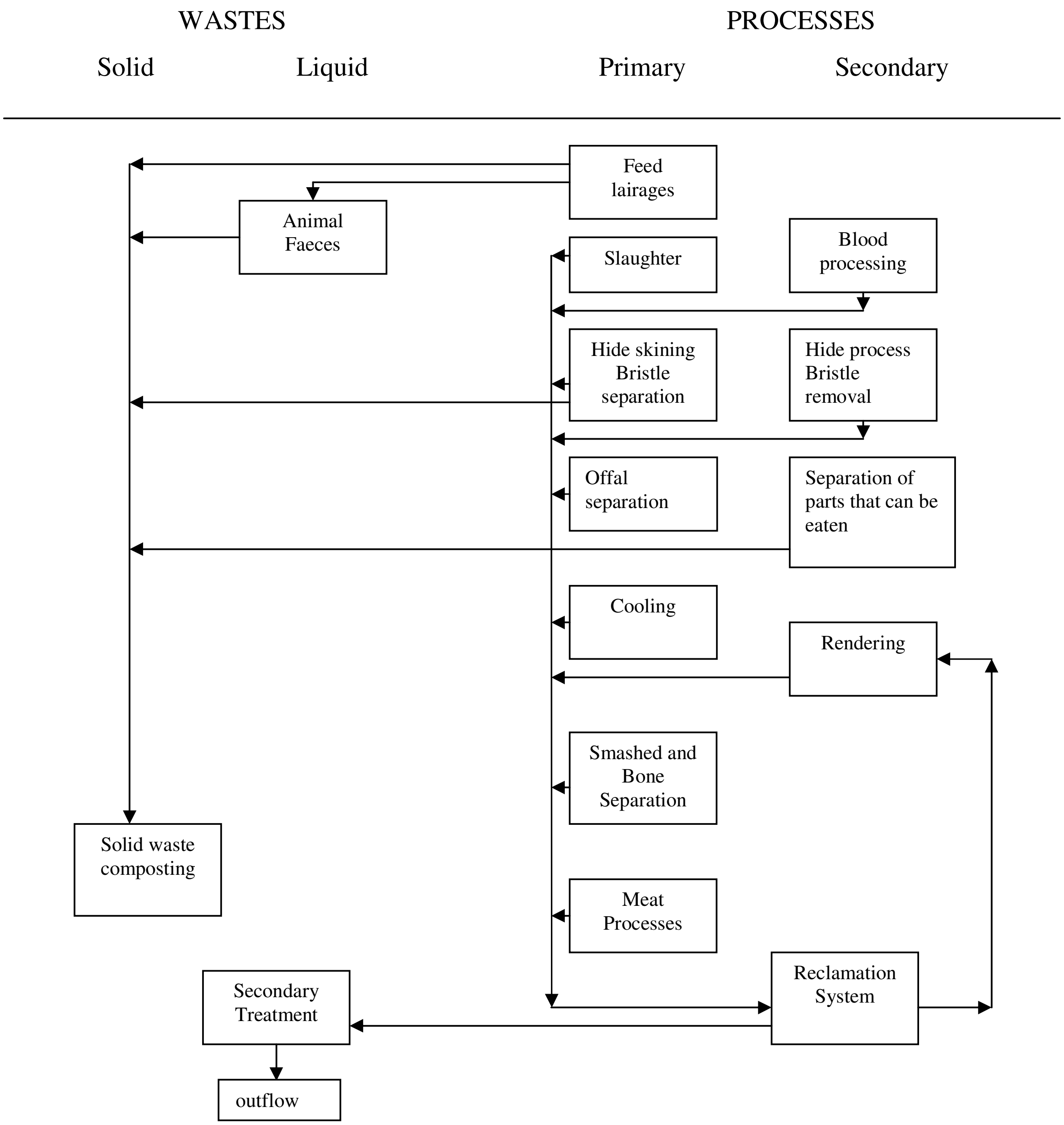

Figure 4.2 Scheme of the red meat process (Dursun & Özen, 1999)

4.1.1.12 General cleaning

In the meat industry, general cleaning and hygiene are very significant. The equipments must be selected carefully; the working people must be attended to the health rules (Günter, 1959).

4.1.2 Rendering Process

Rendering converts meat, poultry and fish byproducts into marketable goods for agricultural and industrial use. Rendering involves cooking, separating and drying processes where edible (fit for human consumption) and inedible (not suitable for human consumption) animal derivatives are made into useful commodities. Edible rendering facilities process fatty animal tissue into edible fats and proteins. The inedible rendering plants produce tallow and grease, which are used in livestock and poultry feed, soap and production of fatty acids. Rendering process may be on-site or off-side at processing plant. The independent renders gather raw materials from small slaughterhouses, supermarkets and butcher shops where the on-site processors receive offal and other goods directly from plant operations. Rendering processes are constituted from the following parts:

4.1.2.1 Raw Matter Distribution

The raw matters that to be used in the rendering process, generally, come from the meat packing processes, the meat process industry, the dead animals in lairages. It is important that the raw matters are collected and evaluated in terms of that the problems in facility are prevented (Bornes, Forster, Hrudey, 1992).

4.1.2.2 Smashing (breaking)

The great flow raw matters are smashed and decreased to small dimensions. In this way, the yield of cooking process increases. The wastewater that comes from this level includes the water that comes from cleaning processed and the matters that to be poured (Bornes, Forster, Hrudey, 1992).

4.1.2.3 Cooking

The cooking;
a) the phase separation and to melt oils
b) to get oil from the tissue
c) to decrease, moisture of raw matters is applied.

4.1.2.4 Oil process

It is process that the oils that to be gotten with the grid, the centrifuge and the filter process are separated from the solids.

4.1.2.5 The waste load

The waste load is defined in Table 4.1.

Table 4.1 Waste loads (Bornes, Forster, Hrudey, 1992)

Parameters	**Avarage value**	**Interval**
Flow m^3/tone r.m*.	3.26	0.47-20.0
Raw material m/day	94	3.6-390
BOD kg/r.m.	2.15	0.1-5.83
Suspended solids kg/r.m.	1.13	0.03-5.18
Cl kg/tone r.m.	0.193	0.08-2.56
TP kg/tone r.m.	0.044	0.003-0.280
Ammonium nitrogen	0.299	0.08-0.74

*r.m.: raw material

4.2 Waste Control in the Meat Processing Industry

4.2.1 General Matters

The aim of the waste control in the process is reduce the bulk of wastewater and pollution load. It is seen that the meat integrated facilities which to made high quality production can be produce low quality outflow. In the meat integrated facilities, in some areas, there is not necessary that qualified (high in quality) water use. While the product standard quality is protected the random water is used and the organic matters mix to sewer system. However, these proteins and oils are losen (disappeared). Low quality products can occur with that these products are reused. It is very significant the optimization of product quality, minimum source and minimum product loss. When water using is made the minimization, the waste quantities that will treat are decreased. Therefore, operating expenses decrease. The second aim, it is that waste load is decreased. The high economic advantages can be provided with that organic matters reuse in high degree (Dursun & Özen, 1999).

It is necessary that the water quantity which to be used is known. And this aim, current gauge and pressure gauge are put. It is necessary that the pressure is arranged (Dursun & Özen, 1999).

If there is biological treatment in the facilities, the detergents that can be dissolved as the biological are used. But, the detergent increases the matters in the emulsion simultation in water. Therefore, it is not wanted the detergent using.

4.2.2 Red Meat Production

4.2.2.1 Lairages

A wastewater current flow occurs that will not control with that the rain and snow waters arrive to the surface. Therefore, it is advised that the upper of the lairages are closed. In this way, clean rain waters do not mix with dirty wastewaters. In the cleaning of the lairages, dry cleaning method must be used. In this way, it is saved from the water (Sweeten, 1996).

4.2.2.2 Slaughterhouse

The waste load is decreased with that the bloods are operated and are used again. The last washing waters include BOD load in the high quantity (Schraufnagel, 1962).

4.2.2.3 Blood process

The waste load can be decreased with heating and evaporation.

4.2.2.4 Hide process

In this process, there is not necessary that quality water is used.

4.2.2.5 Boiler tank

The sludge can collect in the floor (foundation) of these tanks. A pipe is put from the floor to upper part for removal of this sludge.

4.2.2.6 Tripe process

The raw waste load can be decreased with the tripe is sent to rendering and the matters in the offal are cleaned with dried cleaning.

4.2.2.7 Offals

Before the rendering, the waste load increases that offals are washed. Load is decreased with this level disappearing.

4.2.2.8 Intestines

The intestines include high rates oil. The waste load is decreased with the fats are evaluated.

4.2.2.9 Meat process

In this process, the highest waste load constitutes at the end of improving process. The solutions including sugar and salt combine with the organic matters. Therefore, the waste load increases. It must be prevented this solution unnecessary using. In this ways, wastes can decrease.

4.2.2.10 Rendering

The pollutant source of this process is tank's waters. For the waste decreasing these waters are evaporated.

4.2.2.11 Cleaning

The cleaning process causes high waste load. Dry cleaning process can decrease the waste load.

4.2.2.12 Decreasing the water using

a) use the otomatic control valves in the places water providing to lairages
b) use the otomatic closing valves in the animals washing
c) make in specific times offals washing
d) use the planned water using
e) use the dry cleaning process

4.2.2.13 Waste separation

Feaceses: They come from lairages. These wastes removal can be made with the grids and the precipitation.

Blooding wastes: The blood that to include a little water is valuable.

Oils: They come from slaughter, rendering, and the meat process.

Oils in low level: They come from slaughterhouse, bristle removal, offal separation and hide washing. They are collected with DAF and oil conservatives.

Waste involved in the health: The wastewater that humans used and process wastewater must be separated.

4.2.2.14 Clean waters

They are cooling waters and evaporating water. They are very little quantity.

4.2.3 Rendering Process

4.2.3.1 Raw material transporting

In this area, the drainage system is used. The uncontrol discharge is prevented to sewer system with this system. The low bulky and great strong wastes are collected, and they are sent to cooking units. The great bulky and low strong wastes such as bristles, blood etc. is passed from the grid, and they are coagulated and are collected. The drainage system is used in here, on the other hand, the blood do not reuse (Meat processing).

4.2.3.2 Cooking

Cooking process must be succeeding continuous. The vapor lines are projected for transported matter.

4.2.3.3 General cleaning

Before the washing with the hot water everywhere must be swept as dried.

4.2.3.4 Reuse of products

The equipments such as grids and precipitation tank that solid waste and oil reuse will be applied must be projected. The vapor is cooled at 50°C and it can be provided that oils reuse.

4.2.3.5 Waste separation

At the end of the rendering, we can run into the wastes in many different characteristics. For the clean water using again, it is necessary that this water is collected with separated systems.

The washing water that includes the oils and solid matters is passed from grids and then, oils must be treated.

4.3 Wastewater Characterization of Meat and Meat Products Industry

4.3.1 The Pollution Parameters in Wastewater

The meat and meat products industry includes many activities such as alive animals, meat products, various foods, fodders, etc. If the wastewaters that constitute in the slaughterhouse and meat integrated facilities are discharged to the receiver environments they are not treated or the treatment completely are applied, these environments will constitute the unwanted results. In general, the meat industry includes the animal wastes. These wastes have got the organic property in the nature. The characteristics pollutants of the industry are classified with the effects that they make over the waters (Carawan, 1999).

4.3.1.1 Biological Oxygen Demand (BOD)

There are specific quantity oxygen demands of organic matters that can be smashed by microorganisms at aerobic atmosphere. This oxygen is used in the respiration activities of microorganisms. The organic matters that can be decomposed as the biological are the characteristics of meat industry wastewaters (Metcalf & Eddy, 2003).

BOD is the basin conseption parameter of the projected biological treatment systems for the meat industry. Because, BOD is the indication of substrat and nutrition matter, and BOD affects the microorganisms' activities in the biological treatment. In the wastewaters of this industry, the heterotroph microorganisms that to constitute with animal process is thick (Metcalf & Eddy, 2003).

4.3.1.2 Suspended Solid Matters

Suspended solid matters do not dissolve in the water and they are carried whit the water. Suspended solids occur from many organic and inorganic matters. After the biological treatment, suspended solid matters in the out flow are united with flocs and unprecipitation microorganisms (Günter, 1959).

4.3.1.3 Oils and Grease

Oil and grease are the main elements of biochemical group as known lipid. The meat and meat products wastewaters include the oils in high quality.

Olis form the foam ower the wastewater and they do not dissolve in the water. Because of these characteristics, some problems occur in the sewer system and treatment plant. Oil causes that the pipes are plugged (clogged), and it can damage to pump station and grids. Therefore, oil must be controlled continuous. The oils in animal characteristic can be decomposed as biological. But, great BOD levels occur.

4.3.1.4 Ammonium Nitrogen

Nitrogen in ammonium form is found in meat and rendering wastewater. Proteins are transformed to aminoacids and ammonium generally. Ammonium affects the aquatic life and fish as directly toxic effects. pH is effective parameter in ammonium constituting (Carawan, 1999).

4.3.1.5 Hydrogen Ion Concentration (pH)

The matters that to get and give easily the hydrogen ion can change pH level of water. Meat and rendering wastewaters are sensitive against the sudden pH variations. Generally, pH levels are about 7. But, when the chemical matters are added, pH levels are extreme. Example, pH is acidic for that proteins precipitation provides (Carawan, 1999).

4.3.1.6 Pathogenic Microorganisms

Pathogenic microorganisms are harmful for people and animal healths. These micoorganisms are run into frequently in the rendering wastewaters. Salmonella causes to food poisons, and this microorganism can be found in this wastewater. Generally, bacteria quantity in this wastewater is very great. A small part of these bacteria have got the pathogenic characteristic. It is very difficult that the pathogenic microorganisms remove (Atımtay, 2003).

4.4 Making Systematic Controls for Meat and Meat Products Industry

These controls are difficult in every country. In America, special effluent standards of industry are determined. In our country and Europe, the discharge standards are determined with control statutes. Table 4.2 gives the regulations related to meat industry discharge standards.

Table 4.2 Water pollution control statutes (Official Gazette; 2004).

		2 hours	24 hours
PARAMETERS	Unit	Composite Sample	Composite Sample
BOD	mg/l	-	40
COD	mg/l	250	160
Oil & Grease	mg/l	30	20
pH	-	6-9	6-9

4.5 Treatment Methods of Meat and Meat Products Industry

In this part, the physical, chemical and biological treatment processes that will be applied in the meat industry wastewater treatment are explained.

4.5.1 Equalization

The optimum benefit can be provided from treatment processes with that flow bulky and loads of wastewaters are balanced. If the treated waters are discharged to sewer system in the city, the problems that will occur with equalization are made minimise (Atımtay, 2003).

Flow equalization provides that treatment processes are arranged as to daily average flow. In this way, the facility is protected from sudden changes in the wastewater flow. The tank that has got the specific holding bulk and stable outflow current must be projected for equalization of current. The needed bulk is determined as too current of the wastewater. Generally, doing investigations for 24 hours are adequate (Atımtay, 2003).

In many case, it is not adequate that only flow is balanced. It is necessary that waste loads are balanced. The load and flow are different each other. But, equalization is more productive with mixed process that to be made.

4.5.2 The Rough Solid Matters Removal

Generally, the rough solid matters are removed with the various type grids. The criterion in the solids removal is the dimension of particles.

4.5.3 Stable Grid

The using areas of the classical stable grids in this industry fairly limited. Because oils and solid matters easily block over this grid. If 3-4 stable grids are continual used, the bristle, the feather removal can be made. The model that to be used very much is oblique grid. This oblique grid constitute from fibers.

4.5.4 Moving Grids

Because of the problems that to constitute in the using these grids, in the meat industry, generally, these kind grids are not used.

4.5.5 Revolving Grids

These kind grids can be applied successfully in wastewater that to be high solid matter content.

4.5.6 Solid Matters and Oils That Can Be Precipitated Removal

4.5.6.1 Precipitation Tank

The precipitation tanks have got a specific holding period. The solids that to fall down collect on the floor, and the oils that to float collect over the tanks. For the oils reuse, this tank is used. The sludges that to collect in the floor of these tanks must be removed (Carawan, 1999).

4.5.6.2 Air Flotation

In the meat industry, dissolved air flotation (DAF) is the method that to be preferred very much. In this process, air/solid rate is the significant parameter (Carawan, 1999).

4.5.6.3 Electrolytic Coagulation and Flotation

In this process, the treatment occurs from two levels. The first level is electro coagulation and the second level is electro filtration.

In the first level, clash between the electro coagulation and particle and the micro blisters are increase. This process occur at about 1-3 second period.

In the second level, the holding period is between 20-30 second. The gas blisters increase in this process.

In the wastewater that to include the high pollution load, two levels must be applied. Pollution removal yield of this process is great. But, chemical matter quantity that to be used is very great.

4.5.7 Dissolved Organic Carbon Removal

The dissolved colloid organic matters can be removed with that some chemical matters are added. The meat industry wastewaters include the dissolved colloid organic matters and high quantity dissolved organic matters. Most of these matters are decomposed as the biological. Therefore, the biological methods are used in these wastewaters treatment (Carawan, 1999).

4.5.8 Reclamation Protein

The great part of organic matters in the meat industry wastewater is proteins. It is possible that these proteins are reclaimed as reuse in the process. Generally, protein reclamation is in four levels.

1. with help of chemical matters
2. with the ion exchange resins
3. as the biomass in activated sludge systems
4. with ultrafiltration

4.5.9 Anaerobic Processes

In the anaerobic processes, organic wastes are decomposed by the anaerobic and facultative bacteria at high temperatures (20-35°C). Anaerobic decomposition is in 2 levels.

In the first level, the carbonhydrate, oils and proteins are trasformed the organic acid and alcohol by the acid bacteria. In the second level, methane and carbondioxide are brought by the methane bacteria. In this process, pH must be 7-8.5, the temperature must be 25-35°C.

4.5.10 Aerobic Processes

The adequate air is provided to the system for that the oxygen needs of loads are provided in the aerobic processes. During the treatment process, it is necessary that the continuous aerobic conditions are provided.

4.5.11 Disinfection

The meat and meat products industry can include significant quantity pathogenic microorganisms. In the effluent of the meat integrated facilities, *Brucella,* *Salmonella, Shigella* that can be encountered are the microorganisms (Metcalf & Eddy, 2003).

It is necessary that the bacterial protein, pathogenic viruses, parasite eggs, cyst are removed.

In the sterilization, it is provided that all microorganisms that to be or not to be pathogenic dies. The bacterial disinfection yield is defined with that coliforms or fecal coliforms are determined. It is necessary that very high standards are provided for outflow using in the agriculture. Because, the pathogens that to be alive continue their life on the soil and plants and can augment (Günter, 1959).

For the disinfection, the chemicals that to be used very much are chlorine and ozone. Chlorine decreases quantities of some organic compounds, manganese ions, and iron ions. At the end of ozonation, the oxygen occurs as final product. Ozone is more expensive matter than chlorine.

CHAPTER FIVE
MATERIALS AND METHODS

5.1 Introduction to Pilot Plant

MIGROS TURK T. A.Ş. TAN-ET Integrated Meat Plant was selected as a pilot plant in this study. The plant is located in Buca, Izmir City. The process flow scheme of this plant is given in Figure 5.1.

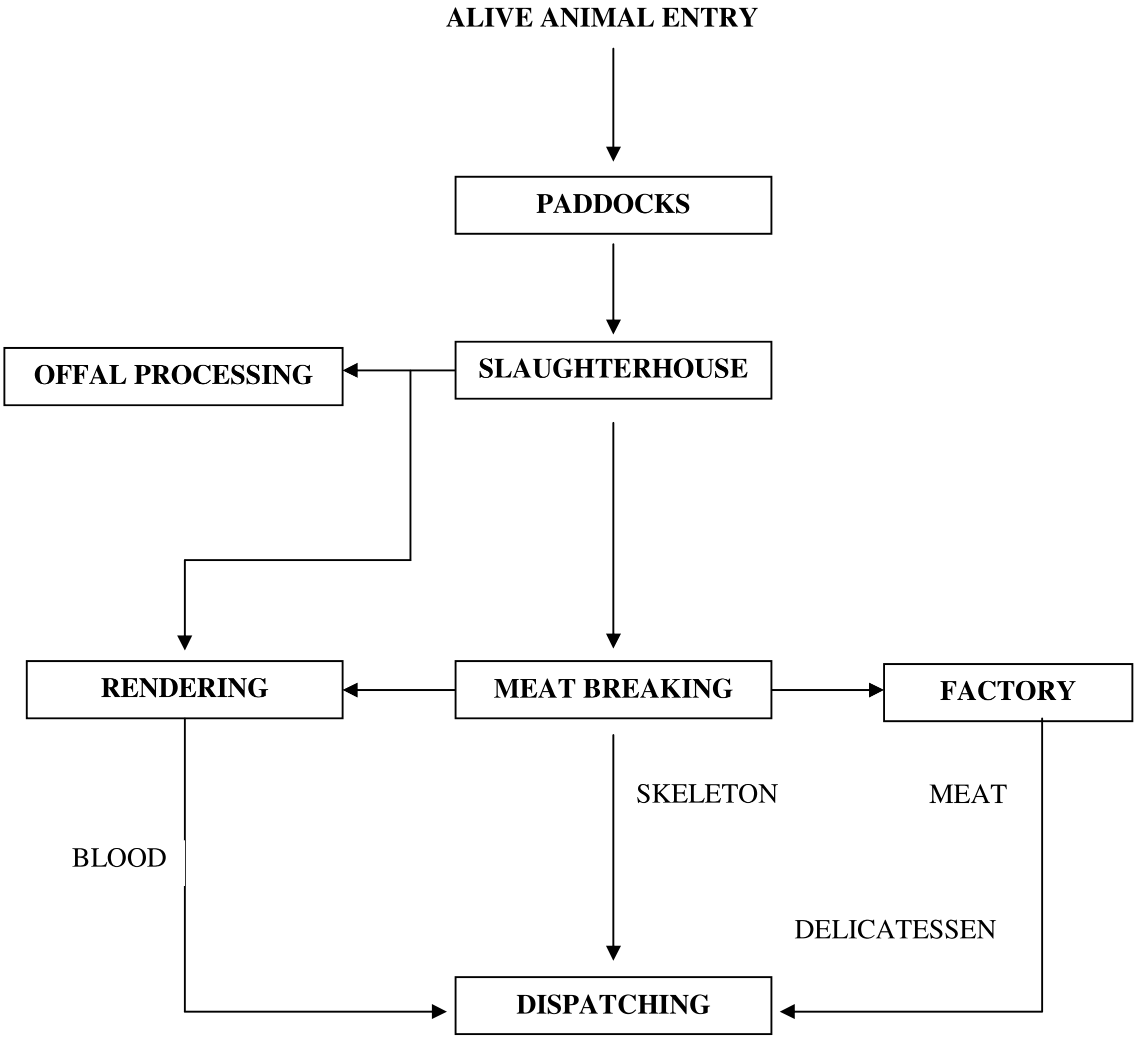

Figure 5.1 MIGROS TURK T. A.S. TAN-ET integrated meat processing industry production flow scheme

The daily wastewater flow is about 800 m³/day and produced wastewater is treated before discharging. Groundwater is used as process water. Blood from slaughterhouse is not introduced to the treatment plant. It is collected in channels and blood flour, which is used as animal feed, is produced. The blood on the floor of the establishment is washed away and the water goes to the treatment plant. In addition, the showering in some parts of the slaughterhouse produces wastewater. Other than industrial wastewater, domestic wastewater from Buca Pond, whole sale fish market, some close places to the plant and the factory also flow to the plant.

MIGROS TURK T. A.S. TAN-ET Integrated Meat Processing Industry is located on Tahtalı catchment area. Therefore, reclaimed water can not be reused for groundwater recharge purposes.

The flow scheme of the wastewater treatment plant is given in Figure 5.2.

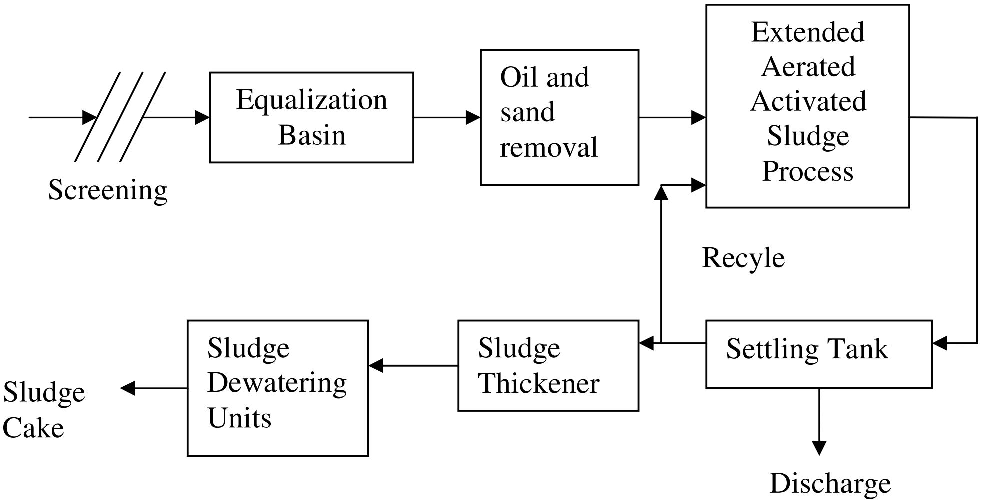

Figure 5.2 MIGROS TURK T. A.S. TAN-ET integrated meat processing industry wastewater treatment plant scheme

5.2 Analytical Methods

In order to determine the properties of meat processing industry, wastewater samples were taken from the influent of the treatment plant of this factory. Reusability evaluations of treated meat processing industry's wastewater were done using effluent of the treatment plant.

In characterization experiments, biological oxygen demand (BOD_5), chemical oxygen demand (COD), suspended solid (SS), oil-grease, total nitrogen (TN), ammonium nitrogen (NH_3-N), pH, conductivity, temperature, sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), boron (B), dissolved solid matter, alkalinity, hardness, sulphate (SO_4^{-2}), chlorine, iron (Fe^{2+}), manganese (Mn^{2+}), heavy metals, TOC, fecal coliforms, total coliforms, silica, salinity, and turbidity analysis were taken into consideration for both influent and effluent wastewater samples. All of the measurements in this study were done in triplicate.

All analyses were done according to Standard Methods (American Public Health Association (APHA), 2005). Na^+, Mg^{2+}, Ca^{2+}, and K^+ concentrations were analyzed using an ICP-QMS (Perkin Elmer-Optima 2100DV). Total nitrogen and ammonium nitrogen were analyzed by using spectroquant cell test obtained from Merc. TOC analyses were done by DOHRMANN DC-190 high temperature analyzer. pH, salinity, and conductivity were measured by WTW model 340i multi analyzer.

CHAPTER SIX

RESULTS AND DISCUSSION

6.1 Characteristics of Influent and Effluent Wastewater

Characteristics of influent and effluent of the treatment plant of the MIGROS TURK T. A.Ş. TAN-ET Integrated Meat Processing Plant are given Table 6.1.

Table 6.1 MIGROS TURK T. A.S. TAN-ET integrated meat processing industry wastewater treatment plant influent and effluent water specifications

Parameters	Influent	Effluent
pH	7.45	7 ± 0.5
Salinity	‰ 0.1	≤ ‰ 0.1
Conductivity	1.43 dS/m	1.5 ± 0.1 dS/m
Na^+	112.900 mg/L	150 ± 20 mg/L
Mg^{++}	301.40 mg/L	300 ± 20 mg/L
Ca^{++}	72.15 mg/L	90 ± 10 mg/L
K^+	25.43 mg/L	45 ± 15 mg/L
Suspended solid	176 mg/L	15 ± 5 mg/L
Dissolved solid	848 mg/L	1030 ± 30 mg/L
Boron	0.115 mg/L	0.4 ± 0.1 mg/L
Sulphate, SO_4^{3-}	394 mg/L	85 ± 5 mg/L
Chlorine	---	38.995 mg/L
Turbidity	120JTU	10 JTU
Iron, Fe^++	0.5273 mg/L	0.5 ± 04 mg/L
Manganese, Mn^++	0.000291 mg/L	0.1 ± 0.05 mg/L
Total nitrogen	40 mg/L	80 ± 40 mg/L
NH_3-N	3.05 mg/L	1.5 ± 0.5 mg/L
NO_3-N	6.85 mg/L	30 ± 10 mg/L
Total phosphorus	5.38 mg/L	5.5 ± 1.0 mg/L

COD		696 mg/L	200 ± 10 mg/L
BOD$_5$		500 mg/L	150 ± 50 mg/L
Faecal coliform		300 unit/100mL	270 ± 20 unit/100mL
Total coliform		300 unit/100mL	250 ± 50 unit/100mL
Oil-Grease		$0.0004*10^{-8}$ g	$0.0003*10^{-8}$ g
Silica		152 mg/L	120 ± 50 mg/L
Temperature		17°C	18 ± 1°C
Colour		375 platinum cobalt	80 platinum cobalt
Heavy Metals	**Zn**	0.0245 mg/L	0.03 ± 0.01 mg/L
	Cr	0.002067 mg/L	0.0015 ± 0.001 mg/L
	Cu	0.003928 mg/L	0.003 ± 0.002 mg/L
	Al	---	0.0075 mg/L
	Ni	0.002879 mg/L	0.002 ± 0.001 mg/L
	Mo	0.005174 mg/L	0.004724 mg/L
	As	0.04005 mg/L	0.04 ± 0.02 mg/L
	Co	0.003718 mg/L	0.004172 mg/L
	Pb	0.003942 mg/L	0.016 mg/L
	Li	0.1907 mg/L	0.2848 mg/L
	Cd	---	< 0.01 mg/L
	K	25.43 mg/L	45 ± 10 mg/L
SAR		1.31	1.7 ± 0.2

The daily wastewater flow of MIGROS TURK T. A.S. TAN-ET Integrated Meat Processing Industry is about 800 m³/day and it can not be adequate as groundwater recharge, process water and agricultural irrigation in large areas. But, it can be used in the landscape irrigation in plant or in small agricultural areas irrigation in around the plant. Also, the treated water can be stored and it can be diluted with fresh water. And, treated water can be used in agricultural irrigation again.

Also, treated water can be used with cleaning aim in plant or as process water in area not required much more water.

6.2 The Evaluation of Industrial Reuse

For an existing or proposed industrial facility, a cost effective wastewater management system that conforms to all related regulations should be developed. Water conservation and reuse programs affect the feasibility of available wastewater management alternatives. The implementation of in-plant controls applies to almost all types of industries and is usually one of the most cost-effective methods of industrial wastewater management. Some applications of in-plant controls include waste reduction, water conservation/recycle, and process modifications.

In the industrial facilities, reclaimed wastewater can be used for cooling water, boiler-feed water, process water, parts washing and cleaning water, dust suppression, and fire fighting purposes. Required water quality is various for each application. Therefore, each reuse options will be discussed separately.

6.2.1 Cooling Water

The detailed knowledge about cooling water is given in Section 2.2. As summary, the needed precautions should be taken in preparing cooling water such as corrosion, residue, and microbial growth. Table 6.1 shows recommended cooling water specifications (Guidelines for water reuse) and the properties of the effluent of the treatment plant.

As seen in Table 6.1, some parameters in the effluent are not suitable for cooling water. These unsuitable parameters are shown as italic and bold. In order to decrease the COD and BOD levels a two-step biological treatment can be applied. For the other unsuitable parameters, before the secondary treatment coagulation and flocculation can be done. Rapid sand filtration and activated carbon adsorption can be applied to remove dissolved suspended solids. In order to obtain cooling water from the effluent, the flow scheme given in Figure 6.1 is recommended.

Table 6.2 Cooling water recommended specifications and treatment plant effluent values

Parameters	**Recommended Limit Value**	**Effluent**
Cl^{-1}, mg/L	500	45 ± 10
Total Dissolved Solids, mg/L	500	***1030 ± 30***
pH	6.9-9.0	7 ± 0.5
COD, mg/L	75	***200 ± 10***
Total Suspended Solids, mg/L	100	15 ± 5
BOD, mg/L	25	***150 ± 50***
NH_4^+-N, mg/L	1.0	***1.5 ± 0.5***
PO_4^{-3}, mg/L	4	***5.5 ± 1.0***
SiO_2, mg/L	50	***120 ± 50***
Al^{+3}, mg/L	0.1	0.0075
Iron, mg/L	0.5	0.5 ± 0.4
Mn^{+2}, mg/L	0.5	0.1 ± 0.05
Ca^{+2}, mg/L	50	***90 ± 10***
Mg^{+2}, mg/L	0.5	***300 ± 20***
SO_4^{-2}, mg/L	200	85 ± 5

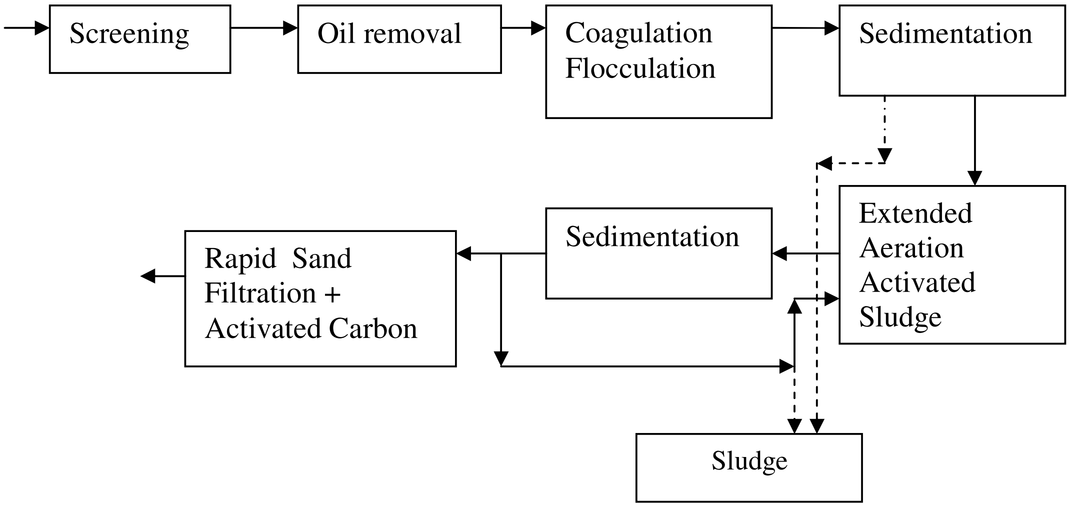

Figure 6.1 Recommended flow scheme for achieving cooling water

As a result, chemical treatment units, which are coagulation, flocculation, and sedimentation, should be added before the existed biological treatment units. At the end of the treatment plant, rapid sand filtration and activated carbon adsorption units should be supplemented.

6.2.2 Boiling Water

Biological treatment processes should be improved for the sufficient COD and BOD_5 reduction. Coagulation and flocculation can be applied for the removal of heavy metals and softening of water. Reverse osmosis can be used for the obtaining of the highest quality water. One of the disinfection methods like as UV, chlorine, ozone can be chosen. UV is a very expensive disinfection method. Chlorine is one of the anion in water that creates problems. Therefore, ozone is the most suitable reagent for disinfection.

Table 6.3 Boiler water recommended specifications and treatment plant effluent values

Parameters	**Low Pressure (<150 psig)**	**Medium Pressure (150-700 psig)**	**High Pressure (>700 psig)**	**Effluent**
Silica, mg/L	30	10	0.7	***120 ± 50***
Aluminum, mg/L	5	0.1	0.01	0.0075
Iron, mg/L	1	0.3	0.05	***0.5 ± 0.4***
Manganese, mg/L	0.3	0.1	0.01	***0.1 ± 0.05***
Calcium, mg/L	--	0.4	0.01	***90 ± 10***
Magnesium, mg/L	--	0.25	0.01	***300 ± 20***
Ammonia, mg/L	0.1	0.1	0.1	***1.5 ± 0.5***
Sulphate, mg/L	--	--	--	***85 ± 5***
Chlorine, mg/L	--	--	--	***45 ± 10***
Dissolved Solids, mg/L	700	500	200	***1030 ± 30***
Copper, mg/L	0.5	0.05	0.05	0.003 ± 0.002
Zinc, mg/L	--	0.01	0.01	0.03 ± 0.01
pH	7-10	8.2-10	8.2-9	7 ± 0.5
Suspended Solid, mg/L	10	5	0.5	***15 ± 5***
COD, mg/L	5	5	1	***200 ± 10***

If the treated wastewater is going to be used in a boiler, then the treatment should be determined according to the values mentioned in table above. When we look at the values of wastewater for high pressure, it can be seen that most of the parameters are above the required values. In order to use wastewater in high pressure boiler, there is need for advanced treatment technologies. For no residue to occur silica, aluminum, calcium and magnesium salts have to be controlled. Depending on the type of boiler, filtration, carbon absorption and nitrogen removal methods can be applied. For better quality water obtaining, reverse osmosis can be used.

Recommended treatment plant flow scheme to obtain high quality water for high pressure boiler is given in Figure 6.2.

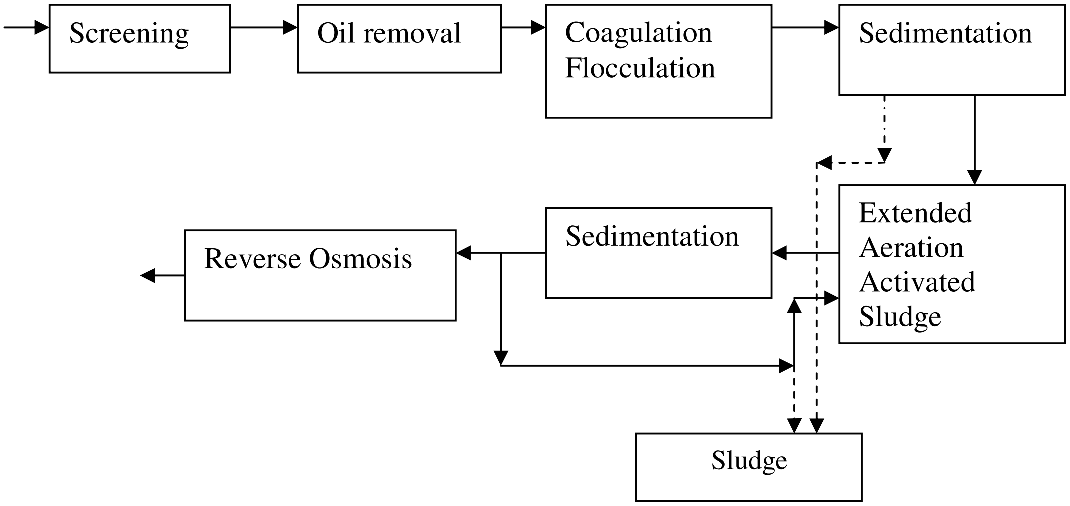

Figure 6.2 Recommended flow scheme for achieving boiler-feed water

Consequently, in order to obtain high pressure boiler-feed water from the effluent, chemical treatment units, which are coagulation, flocculation, and sedimentation, should be added before the existed biological treatment units. Because the high pressure boiler needs a high quality water, reverse osmosis unit should be used at the end of the plant.

6.2.3 Process Water

The need for reclamation of streams is identified and the approach also ascertains that only the minimum amount of water is to be regenerated or treated before discharge. The systematic system analysis approach ensures that all important mass- and energy flows are taken into account, and scenarios for optimization are developed including the use of process integration and energy- and water pinch analysis techniques. A systematic approach was developed in order to use treated wastewater as process water. This systematic approach is shown in Figure 6.3 (Andersen, 2002). It can be applied to any industry.

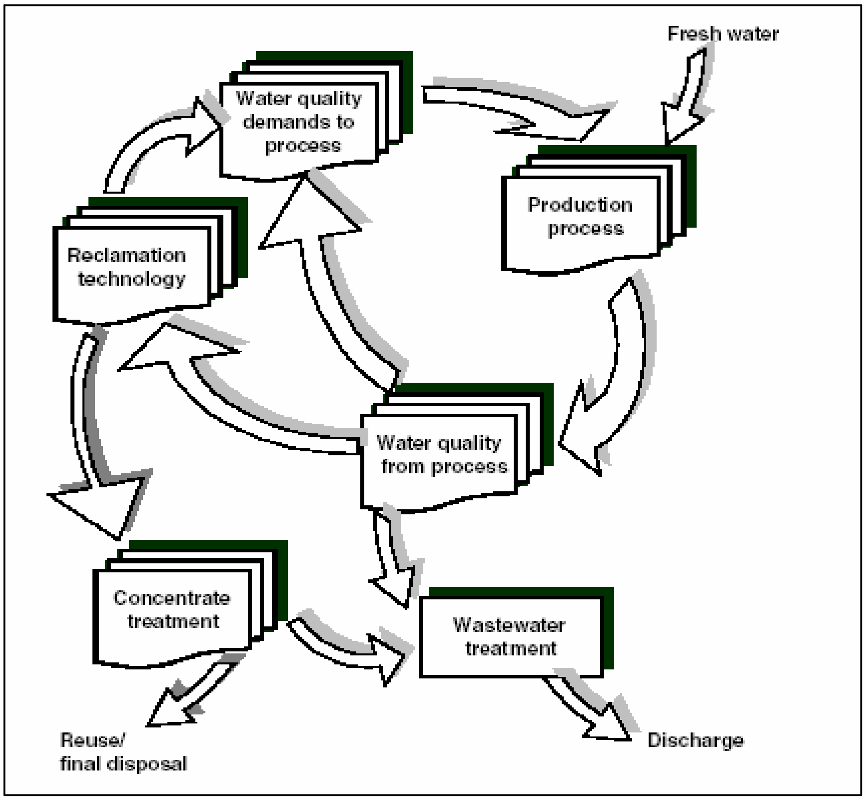

Figure 6.3 Concept for system analysis and design through process integration (Andersen, 2002)

The required process water quality depends on the production. Because MIGROS TURK T. A.S. TAN-ET Integrated Meat Establishment is food industry, the water quality has to the same at every point and should not allow microbiologic problems. In the establishment, in concordance with HACCP (Hazard Analysis and Critical Control Point) the water is analyzed chemically and biologically on a regular basis. The HACCP system is internationally accepted as the system of choice for food safety management. In meat plants HACCP plans will focus on control measures that can reduce the likelihood of contamination of meat from microbiological hazards, such as Salmonella, *E.coli O157* and Campylobacter, during production (Food industries).

In case of using the treated wastewater as process water treatment should be done until very clean and fresh water quality is acquired. The treatment steps taken for boiler water should be taken for process water as well.

6.3 The Evaluation of Agricultural Reuse

The data given in Table 6.1 and Table 3.3 were compared. According to this table, conductivity, sulfate, boron, suspended solids and pH parameters make the water “Class I- very good” for irrigation. However, BOI_5 and fecal coliform parameters make the water “Class IV- usable with caution” for irrigation. In this case, it is necessary to improve the existing system for organic waste and disinfect the water in concordance with microbiological aspects.

In order to get rid of organic waste a two-step activated sludge system or anaerobic process can be used in the biologic treatment step. After the traditional activated sludge step, following the anaerobic treatment, the disinfection process begins. Then, the wastewater acquired will be reusable. In a study that looked into meat establishment wastewater treatment biological method usage, the data showed that the anaerobic hybrid reactor usage for COD treatment varied between 62% and 91% and the biogas methane content produced during anaerobic breaking up is 70%. Considering these results, Figure 6.4 shows suggested treatment plant flow scheme for obtaining Class I water. Chlorine application can be used for disinfection although chlorine is one of the anions in irrigation that create problems. Because of this reason, UV or ozone can be used for disinfection instead of chlorine.

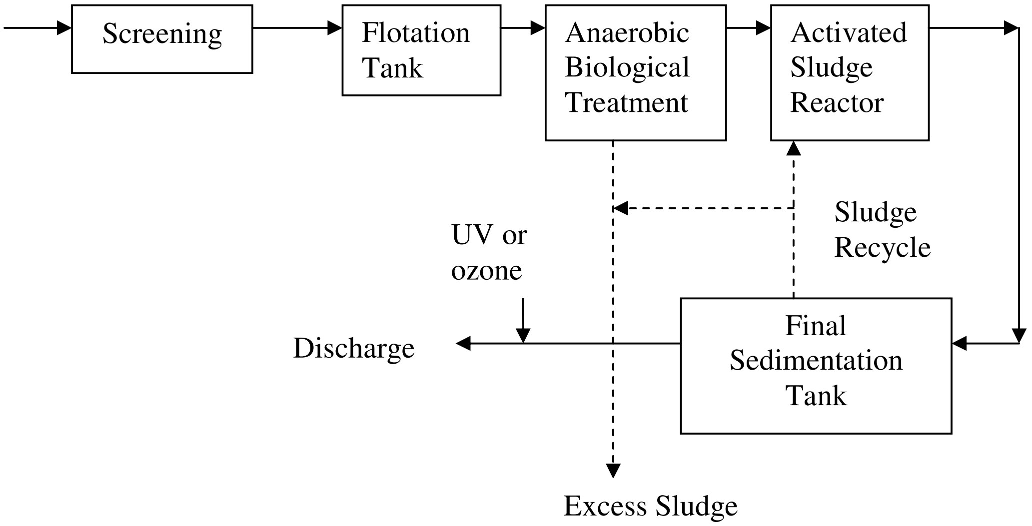

Figure 6.4 Recommended flow scheme for agricultural reuse

The most important stage in the usability assessments of the wastewater is to determine the soil constitution. According to the soil constitution the most suitable irrigation is determined. The most suitable irrigation is drip or trickle irrigation in order to prevent water loss and enable water access to the roots of the plants. The choice of plant for this type of irrigation is also important. It is not recommended to water produce that are going to be consumed raw with treated wastewater. Instead, woods, grass, etc. and plantation irrigation with trade plants such as cotton, linen, etc. should be the choices.

6.4 The Evaluation of Groundwater Recharge

The selected pilot plant is located on Tahtalı catchment area. Therefore, reclaimed water can not be discharged to the underground. Although the groundwater recharge with reclaimed water is not possible, suitability of reuse of effluent for this aim was also evaluated. The high quality of reclaimed water, whose properties must be same to potable water, for groundwater recharge must be used. The characteristics of potable water depending on the Turkish Standard Institution (TSE) are given in Table 6.4.

Table 6.4 Drinking water standards and effluent water value of wastewater treatment plant

Parameters	**TSE**	**Effluent**
Turbidity	25 NTU	10 NTU
Coliform bacteria	<1 unit/100ml	250 ± 50 unit/100ml
Al	0.2 mg/L	0.0075 mg/L
As	0.05 mg/L	0.04 ± 0.02 mg/L
Ba	0.3 mg/L	n.m.*
Cd	0.01mg/L	< 0.01 mg/L
Cr	0.05 mg/L	0.015 ± 0.1 mg/L
F	1.5 mg/L	n.m.
Pb	0.05 mg/L	0.016 mg/L
Hg	0 mg/L	n.m.
NO_3	50 mg/L	30 ± 10 mg/L
Se	0.01 mg/L	n.m.
Ag	0.01 mg/L	n.m.
Sb	0.01 mg/L	n.m.
Cl	600 mg/L	45 ± 10 mg/L
Colour	20 mg/L	80 platinum cobalt
Cu	3 mg/L	0.003 ± 0.002 mg/L
Fe	0.2 mg/L	0.5 ± 0.4 mg/L
Mn	0.05 mg/L	0.1 ± 0.05 mg/L
pH	6.5-9.2	7 ± 0.5
SO_4	250 mg/L	85 ± 5 mg/L
Total dissolved solid matter	1500 mg/L	1030 ± 30 mg/L
Zn	5 mg/L	0.03 ± 0.1 mg/L
Ca	200 mg/L	90 ± 10 mg/L
Mg	50 mg/L	300 ± 20 mg/L
K	12 mg/L	45 ± 15 mg/L
Na	175 mg/L	150 ± 20 mg/L

*n.m.: not measured

Biological treatment processes should be improved for the sufficient COD and BOD_5 reduction. Coagulation and flocculation can be applied for the removal of heavy metals and softening of water. Reverse osmosis can be used for the obtaining of the highest quality water. One of the disinfection methods like as UV, chlorine, ozone can be chosen. UV is a very expensive disinfection method. Chlorine is one of the anion in water that creates problems. Therefore, ozone is the most suitable reagent for disinfection.

6.5 The General Comments

With respect to the effluent water values of the MIGROS TURK T. A.S. TAN-ET Wastewater Treatment Plant, the reclaimed water can not be directly reused. Almost for all reuse applications, additional organic matter removal, water softening units, and advanced treatment process, especially reverse osmosis, should be applied to obtain adequate quality water. In Figure 6.5, the recommended reclamation facility flow scheme is given for all applications. The dissolved air flotation (DAF) unit was chosen for oil removal. Extended aerated activated sludge unit should be applied to remove both organic materials and nutrients. Disinfection with UV or ozone can not be used if the membrane processes are applied. However, in order to take a guarantee the high quality reclaimed water obtaining, disinfection is also shown in the figure.

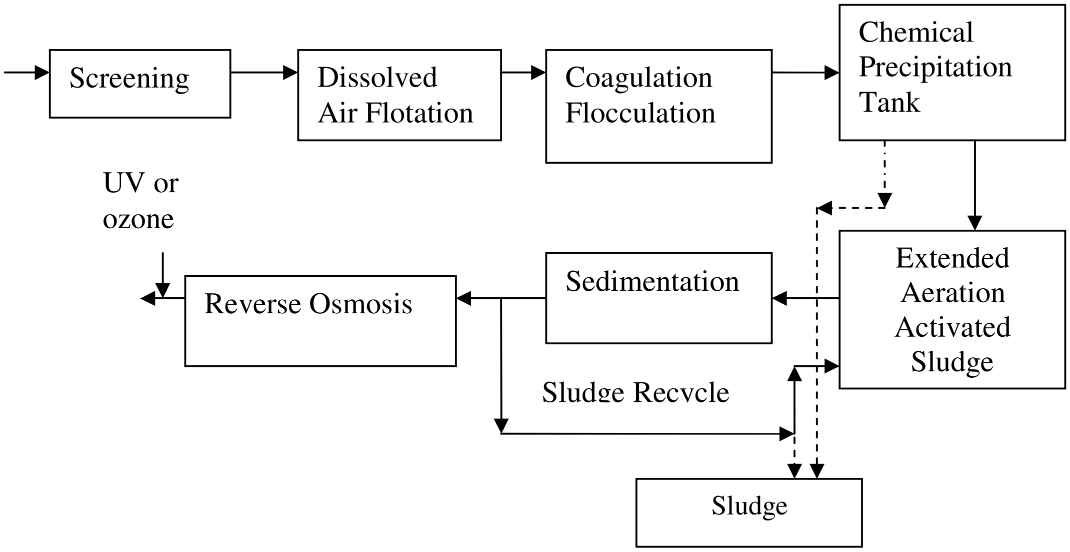

Figure 6.5 Recommended flow scheme for all reuse applications

CHAPTER SEVEN
CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion

The effluent of the wastewater treatment plant of MIGROS TURK T. A.S. TAN-ET Integrated Meat Processing Plant was evaluated depending on the required water quality for some reuse applications. According to evaluations, conclusion remarks from this study could be given as follows:

- The effluent can not be directly reused for agricultural usage, groundwater recharge, industrial cooling water, boiler water or process water.
- In order to reuse of the effluent, some additional treatment processes are necessary.
- In general, for all the applications, there is need for additional organic material removal and water softening procedures.
- To achieve good quality reclaimed water, one of the suitable membrane systems must be chosen.
- The coagulation and flocculation process following by sedimentation unit should be established before biological treatment unit for the removal of trace materials and the softening of water.
- In order to polish the effluent, one of the membrane process, preferably reverse osmosis, should be used.
- Depending on the used membrane process, disinfection may not be required. In all applications, microbiological pollution is the most important parameter. The most appropriate disinfection methods should be used for pathogen microorganism removal. Chlorination is the most economic solution so it is very much preferred. Though, it might have negative effects on health. For this reason a more costly solution UV treatment can be used as the most appropriate disinfection method. In the economical point of view, ozone is more suitable than UV.

7.2 Recommendation

- Water shortage problem depending on the global warming, continuous population growth, and rapidly industrialization has become a very important problem. Our present limited water is also being forced. Instead of discharging the treated wastewater, water reclamation and reuse options should be taken into consideration.
- In this thesis, the reuse alternatives of the meat processing industry were evaluated. This kind of study should be carried out with different industrial wastewater.
- Cost analysis should be carried out in addition to investigation of reuse alternatives.

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