Water treatment plant design from water data review

Water and Wastewater Treatment
Sergio Arenas Gayoso

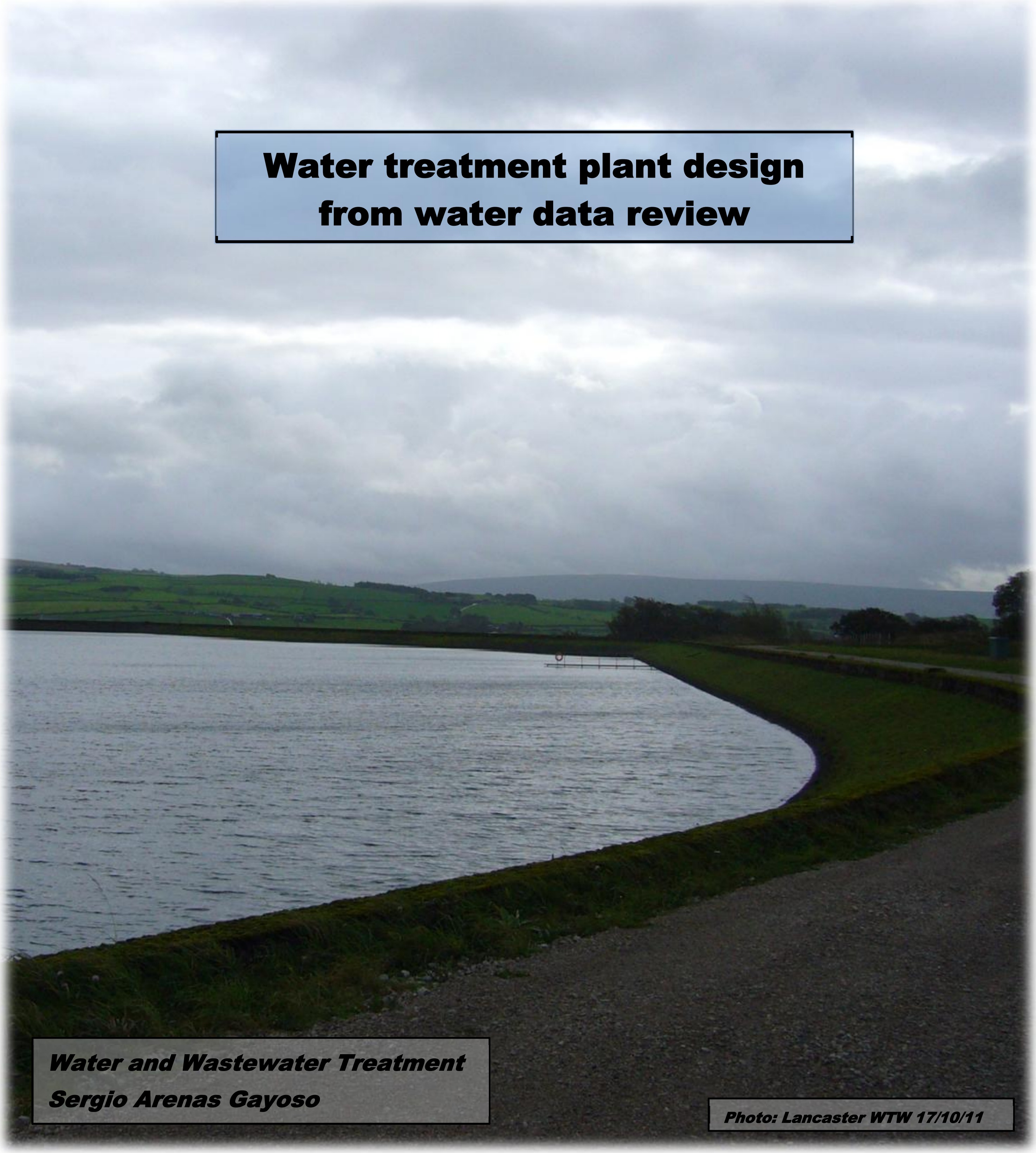


Photo: Lancaster WTW 17/10/11

Index

Number of words (excluding references): 4860

Introduction

The present work tries to evaluate and determinate a water treatment plant from a water quality data provided.

The characterization of the source water as well as the pollutants contained and their possible sources have been carried out.

Using the World Health Organization (WHO) Water Safety Plan methodology, the risk assessment has been undertaken, identifying effective control measures, and describing appropriate monitoring of the water source.

A water treatment plant has been designed which will adequately treat the water to meet the conditions for Drinking Water citing the appropriate regulations for the microbiological, disinfection by-products, turbidity, manganese, aluminum and pesticides parameters justifying the choice of each process unit chosen.

Finally, a suitable maintenance and monitoring scheme for the chosen process has been devised.

Review of the water quality data

Pesticides

According to the EU drinking water directive (EUDWD, 1998), the parametric value for total pesticides is 0.5 (µg/l) and as the chart shows, the value is never reached during the three years period. However, the parametric value applied to each individual pesticide (which means organic insecticides, herbicides, fungicides, etc.) is 0.1 µg/l.

Thus, the following pesticides (chart 1) exceed the individual value suggested: Diuron (herbicide), 24D (herbicide), Atrazine (herbicide), Metaldehyde (pesticide against gastropods), Mecoprop (herbicide), and MCPA (herbicide). Classification obtained through FPA (2002).

Furthermore, their concentration (≥1 µg/l), follows a seasonally behaviour, normally between April and October.

Nitrogen

As the charts 2-4 show, nitrate, nitrite and ammonia have exactly the same behaviour. According to the WHO Guidelines for Drinking-Water Quality (WHO, 2011), both nitrate and nitrite as N are not present in significant concentrations (11 and 0.9 mg/l respectively). The ammonia as N it is also under the threshold odour concentration.

There is a peak right at the end of the year 2010 in all of them, however the value reached, do not present problem at all.

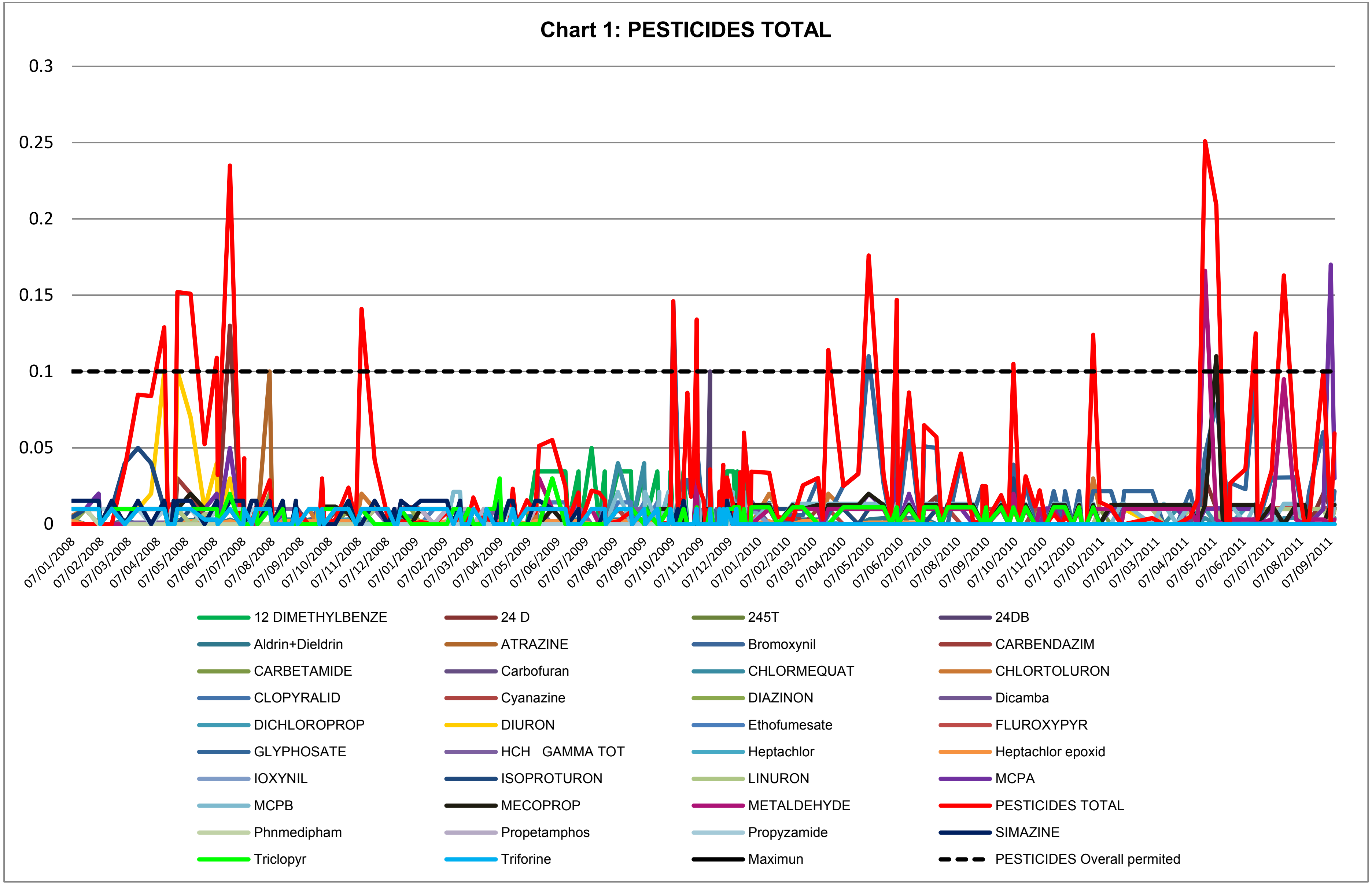


Chart 1: PESTICIDES TOTAL

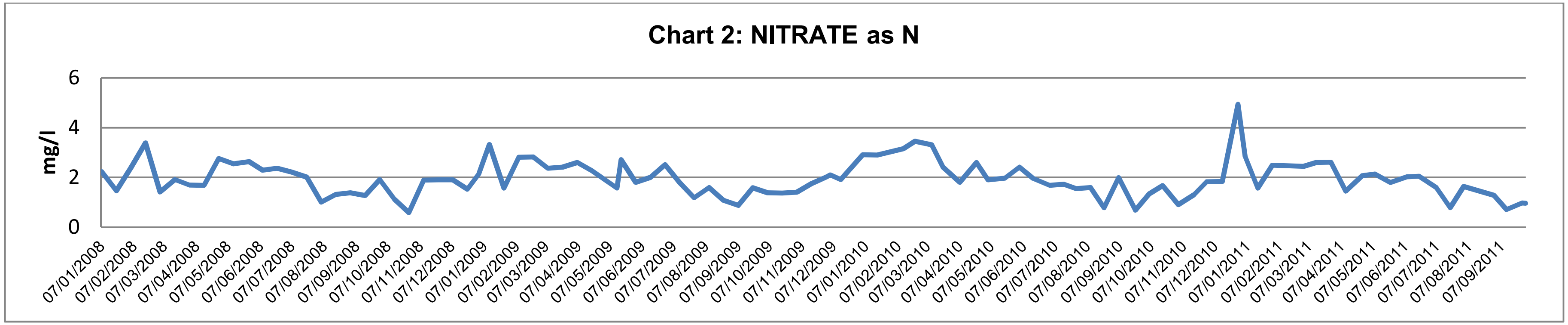


Chart 2: NITRATE as N

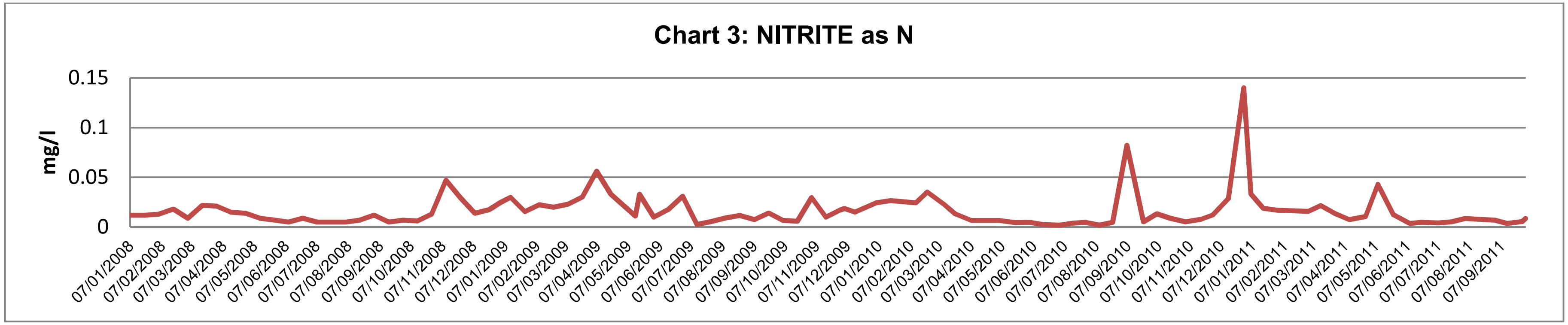


Chart 3: NITRITE as N

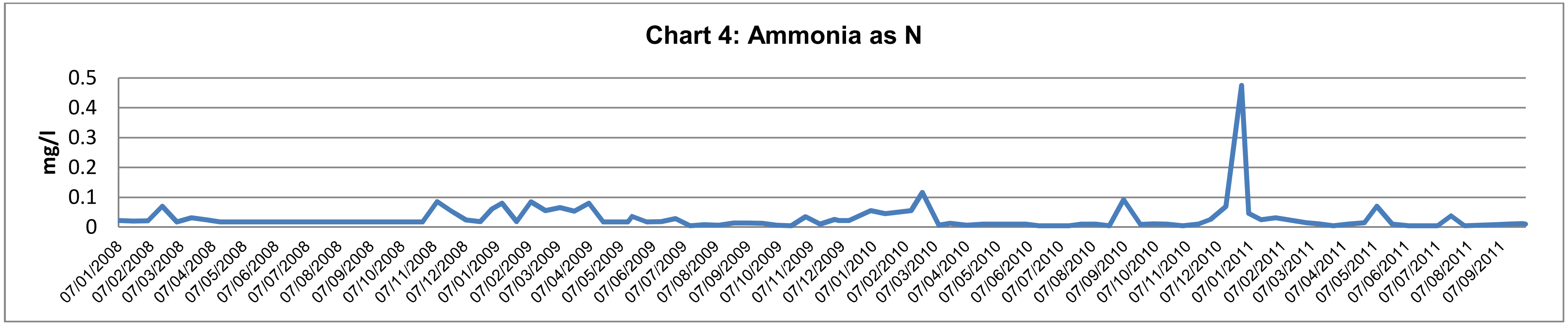


Chart 4: Ammonia as N

Hardness

According to the chart 5, hardness alkalinity, Ca and Mg have the same behaviour along the three years. According to the WHO guideline, both Ca and Mg are under the taste threshold (100-300 mg/l). Hardness acceptability may vary considerably from one community to another; however consumers tolerate water hardness in excess of 500 mg/l, well above the value along the period in this case (it never exceeds 150 mg/l and never goes under 50 mg/l, being the average of 92 mg/l), so should not be problems with the interaction of alkalinity and pH. According to the hardness, water might be considered soft (under 100 mg/l).

Corrosion should not be problem of water mains and pipes in household water systems as it ranges 6.5-8.5 as it is recommended. The average in this case is 7.34.

Conductivity

Conductivity ranges 100-400 μsie/cm. According to the EU directive it should not be higher than 2500 μsie/cm. therefore, the values are considered normal (chart 6). Conductivity behavior does not seem to be affected neither by the nitrogen compounds, Ca, Mg nor metals like Fe, Al or Mn. Only the peak on 29/12/10 in nitrogen compounds, minerals and metals seem to be related to.

Metals

According to the EUDWD and considering charts 7 and 8:

- Mn: the parametric value is 50 μg/l and the average along the period is 52 μg/l. However, the data show figures normally well above this value, especially from 2009. There are three main peaks: in the middle of 2009, at the end of 2010 and right at the beginning of 2011.
- Fe: the parametric value is 200 μg/l. However, its values are well above along the three years period. In fact, it reaches 1000 μg/l four times at the end/beginning of each year.
- Al: the parametric value is 200 μg/l. It follows the same behavior of the Fe and it is also above of 200 μg/l along the period of the data (an average of 226 μg/l).

Microorganisms

According to the WHO (2011), there must not be coliforms presence after the disinfection process. Regarding cryptosporidium, it must be reduced to minimum levels in drinking water (1.3×10^{-5}/l). As the charts 9-11 depict, both *E.coli* and total coliforms as well as *Cryptosporidium*, are presented along the period. Thus, the average for *E.coli*, total coliforms and *Cryptosporidium* presence are respectively: 895 No/100 ml, 7700 No/100 ml and 0.5 No/l .

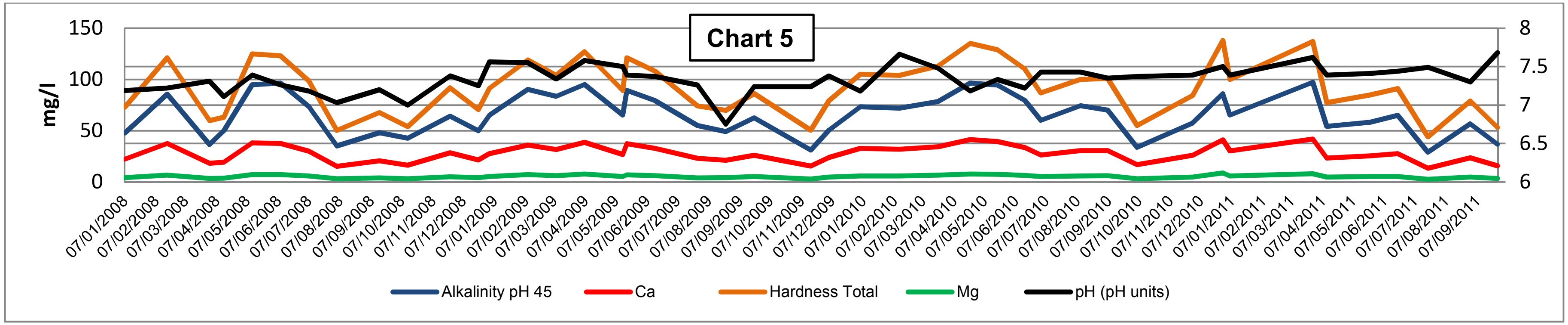


Chart 5
mg/l
150
100
50
0
8
7.5
7
6.5
6
07/01/2008 07/02/2008 07/03/2008 07/04/2008 07/05/2008 07/06/2008 07/07/2008 07/08/2008 07/09/2008 07/10/2008 07/11/2008 07/12/2008 07/01/2009 07/02/2009 07/03/2009 07/04/2009 07/05/2009 07/06/2009 07/07/2009 07/08/2009 07/09/2009 07/10/2009 07/11/2009 07/12/2009 07/01/2010 07/02/2010 07/03/2010 07/04/2010 07/05/2010 07/06/2010 07/07/2010 07/08/2010 07/09/2010 07/10/2010 07/11/2010 07/12/2010 07/01/2011 07/02/2011 07/03/2011 07/04/2011 07/05/2011 07/06/2011 07/07/2011 07/08/2011 07/09/2011
Alkalinity pH 45
Ca
Hardness Total
Mg
pH (pH units)

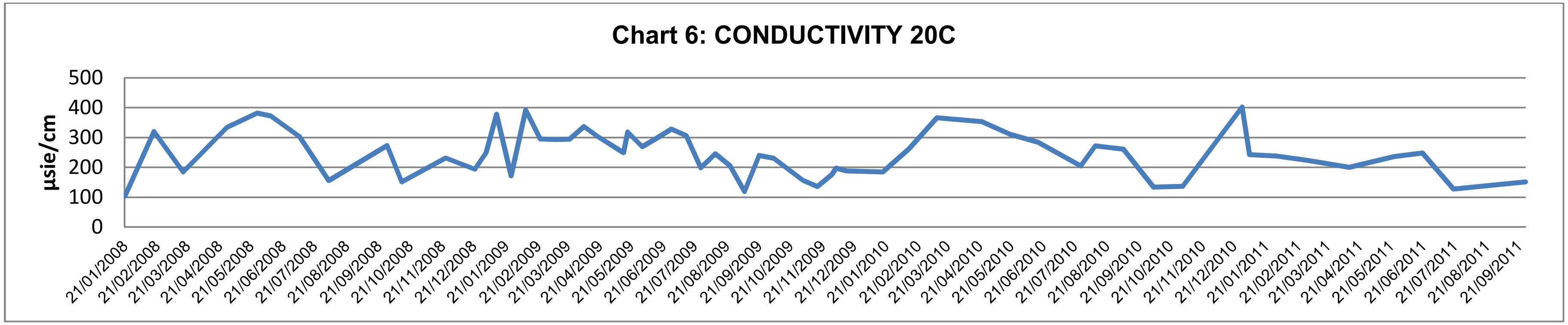


Chart 6: CONDUCTIVITY 20C
µsie/cm
500
400
300
200
100
0
21/01/2008 21/02/2008 21/03/2008 21/04/2008 21/05/2008 21/06/2008 21/07/2008 21/08/2008 21/09/2008 21/10/2008 21/11/2008 21/12/2008 21/01/2009 21/02/2009 21/03/2009 21/04/2009 21/05/2009 21/06/2009 21/07/2009 21/08/2009 21/09/2009 21/10/2009 21/11/2009 21/12/2009 21/01/2010 21/02/2010 21/03/2010 21/04/2010 21/05/2010 21/06/2010 21/07/2010 21/08/2010 21/09/2010 21/10/2010 21/11/2010 21/12/2010 21/01/2011 21/02/2011 21/03/2011 21/04/2011 21/05/2011 21/06/2011 21/07/2011 21/08/2011 21/09/2011

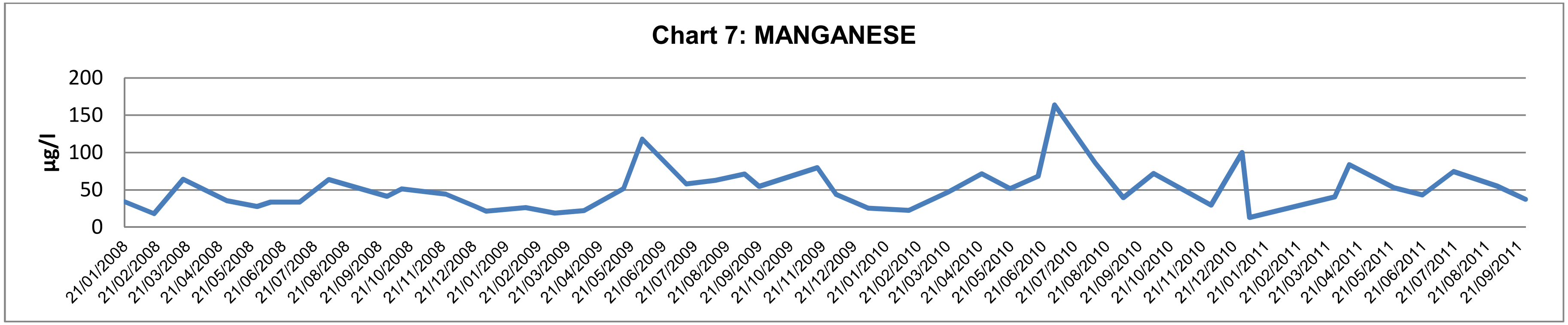


Chart 7: MANGANESE
µg/l
200
150
100
50
0
21/01/2008 21/02/2008 21/03/2008 21/04/2008 21/05/2008 21/06/2008 21/07/2008 21/08/2008 21/09/2008 21/10/2008 21/11/2008 21/12/2008 21/01/2009 21/02/2009 21/03/2009 21/04/2009 21/05/2009 21/06/2009 21/07/2009 21/08/2009 21/09/2009 21/10/2009 21/11/2009 21/12/2009 21/01/2010 21/02/2010 21/03/2010 21/04/2010 21/05/2010 21/06/2010 21/07/2010 21/08/2010 21/09/2010 21/10/2010 21/11/2010 21/12/2010 21/01/2011 21/02/2011 21/03/2011 21/04/2011 21/05/2011 21/06/2011 21/07/2011 21/08/2011 21/09/2011

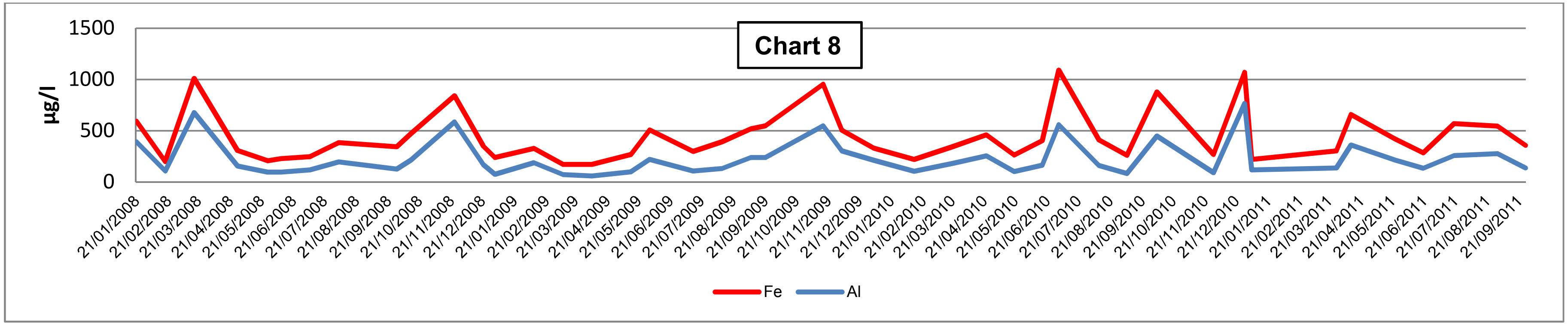


Chart 8

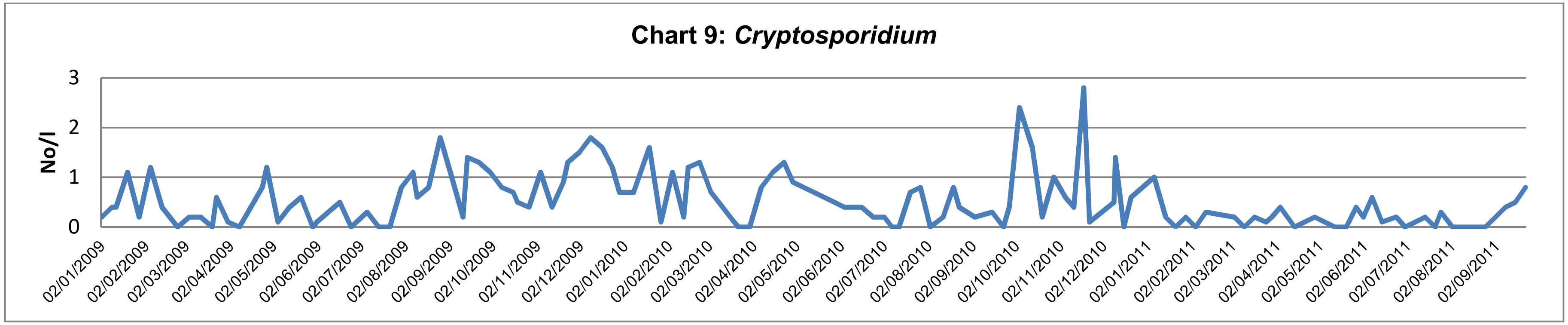


Chart 9: *Cryptosporidium*

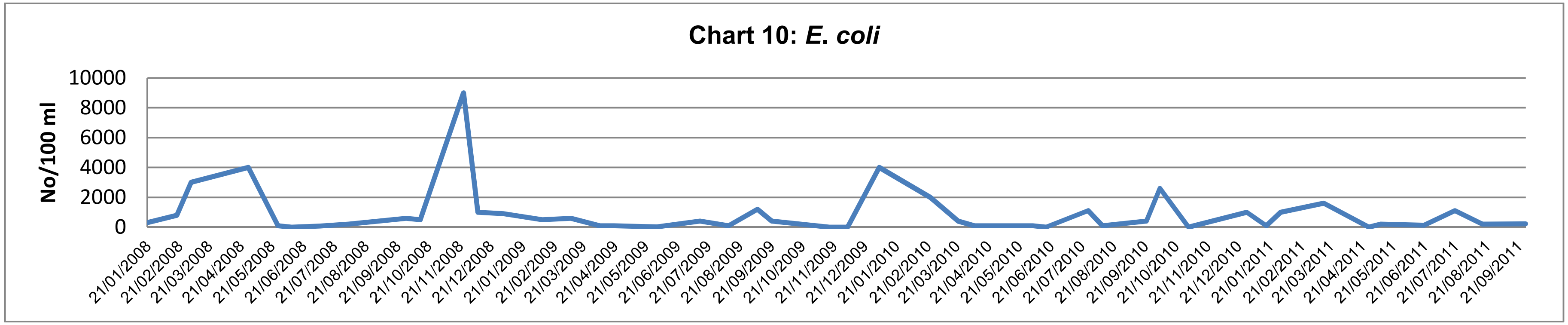


Chart 10: *E. coli*

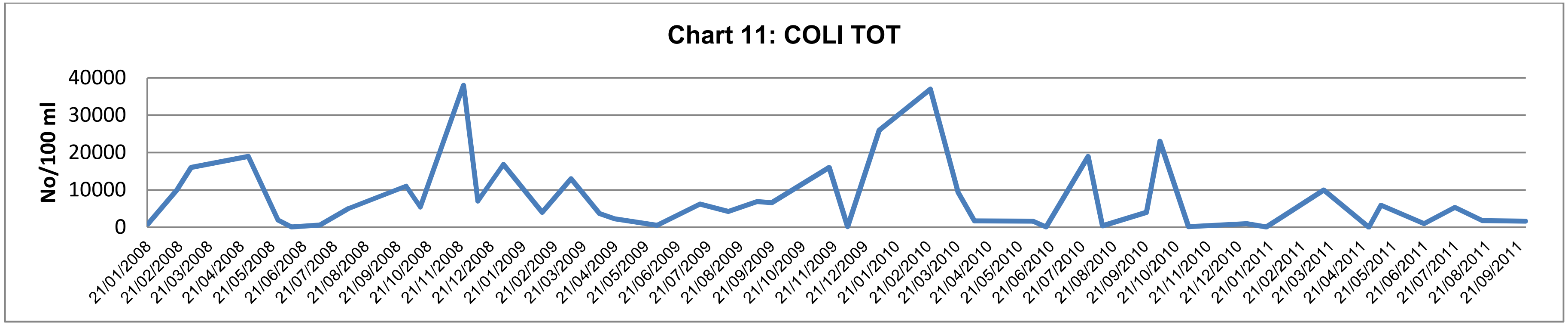


Chart 11: COLI TOT

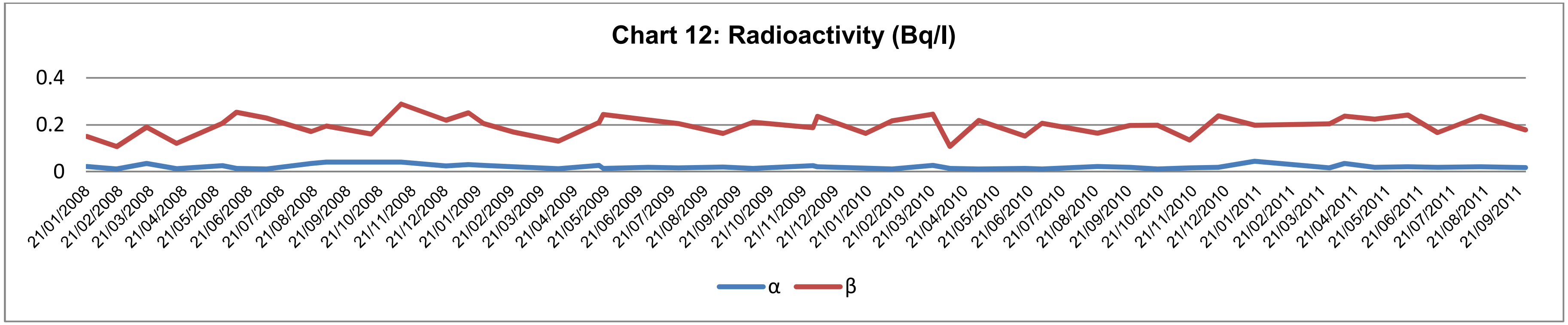


Chart 12: Radioactivity (Bq/l)

Radioactivity

If the results of the analysis of drinking water are lower than 0.5 Bq/l for total alpha radioactivity and 1 Bq/l for total beta radioactivity, then additional analysis are no required (ICRP, 1991). As the chart 12 shows, total alpha radioactivity never reaches 0.1 Bq/l and the highest value for total beta radioactivity throughout the period is 0.29 Bq/l.

Turbidity

According to WHO (2011), if levels are below of 10 NTU, the water is considered clear. The average throughout the period of sampling is 9 NTU (chart 13), even considering an unusual peak in November of 2009 which reaches almost 100 NTU.

Colour

According to the EUDWD (1998), the standard for colour is 20 Hazen (a level at which there is no visible sign of colour). The chart 14 shows how the levels are constant during the three years period, but normally above of 20 Hazen. The presence of aluminium at concentrations in excess of 100–200 µg/l may cause deposition of aluminium hydroxide floccules and the exacerbation of discoloration of water by iron. Colour is strongly influenced by the presence of iron and other metals (WHO, 2011).

TOC

Apparently, there is a peak every November-December of each year (chart 15). There is not established a parametric value for TOC, however the EUDWD says there should not be abnormal changes once the water has been treated.

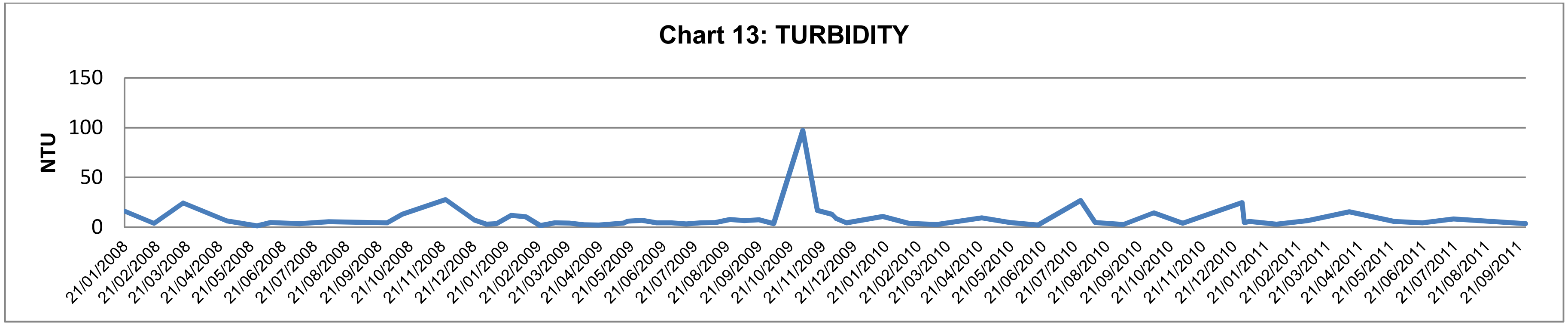


Chart 13: TURBIDITY
NTU
150
100
50
0
21/01/2008
21/02/2008
21/03/2008
21/04/2008
21/05/2008
21/06/2008
21/07/2008
21/08/2008
21/09/2008
21/10/2008
21/11/2008
21/12/2008
21/01/2009
21/02/2009
21/03/2009
21/04/2009
21/05/2009
21/06/2009
21/07/2009
21/08/2009
21/09/2009
21/10/2009
21/11/2009
21/12/2009
21/01/2010
21/02/2010
21/03/2010
21/04/2010
21/05/2010
21/06/2010
21/07/2010
21/08/2010
21/09/2010
21/10/2010
21/11/2010
21/12/2010
21/01/2011
21/02/2011
21/03/2011
21/04/2011
21/05/2011
21/06/2011
21/07/2011
21/08/2011
21/09/2011

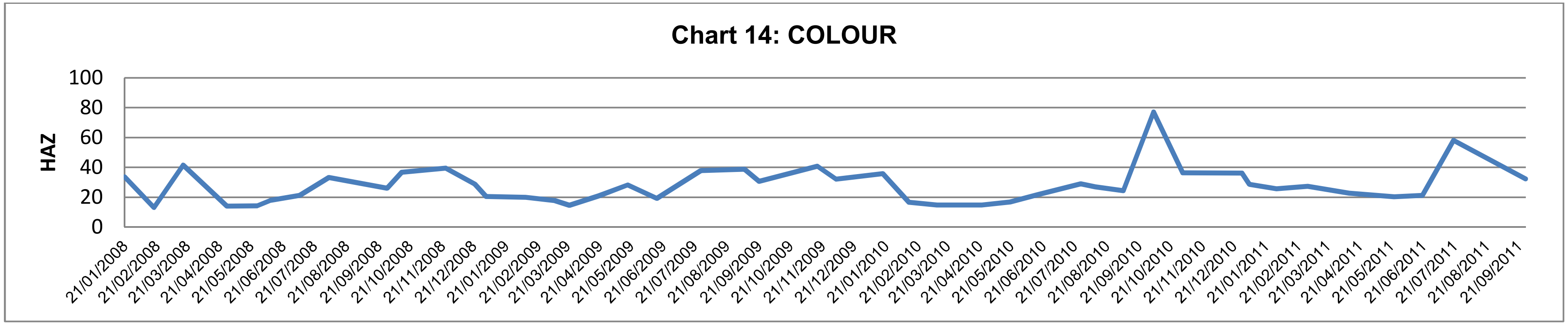


Chart 14: COLOUR
HAZ
100
80
60
40
20
0
21/01/2008
21/02/2008
21/03/2008
21/04/2008
21/05/2008
21/06/2008
21/07/2008
21/08/2008
21/09/2008
21/10/2008
21/11/2008
21/12/2008
21/01/2009
21/02/2009
21/03/2009
21/04/2009
21/05/2009
21/06/2009
21/07/2009
21/08/2009
21/09/2009
21/10/2009
21/11/2009
21/12/2009
21/01/2010
21/02/2010
21/03/2010
21/04/2010
21/05/2010
21/06/2010
21/07/2010
21/08/2010
21/09/2010
21/10/2010
21/11/2010
21/12/2010
21/01/2011
21/02/2011
21/03/2011
21/04/2011
21/05/2011
21/06/2011
21/07/2011
21/08/2011
21/09/2011

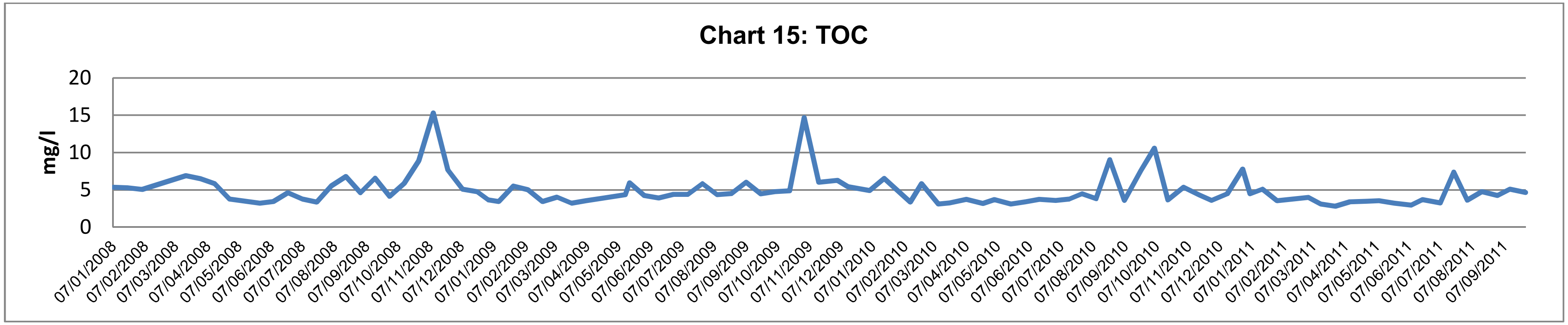


Chart 15: TOC
mg/l
20
15
10
5
0
07/01/2008
07/02/2008
07/03/2008
07/04/2008
07/05/2008
07/06/2008
07/07/2008
07/08/2008
07/09/2008
07/10/2008
07/11/2008
07/12/2008
07/01/2009
07/02/2009
07/03/2009
07/04/2009
07/05/2009
07/06/2009
07/07/2009
07/08/2009
07/09/2009
07/10/2009
07/11/2009
07/12/2009
07/01/2010
07/02/2010
07/03/2010
07/04/2010
07/05/2010
07/06/2010
07/07/2010
07/08/2010
07/09/2010
07/10/2010
07/11/2010
07/12/2010
07/01/2011
07/02/2011
07/03/2011
07/04/2011
07/05/2011
07/06/2011
07/07/2011
07/08/2011
07/09/2011

Characterization of the source water

According to the above, the characterization of the source water will be carried out depending on the present pollutants, trying to give reasonably explanation of their possible sources.

Regarding pesticides, even though both annual variation and levels along the period are low for most of the pesticides, it seems to be a seasonal variation with some pesticides (chart 1). Thus, apparently there are peaks between the spring-summer season and end of autumn, which could coincide with spring and winter cereals. Besides, the total of pesticides variation is more obvious. It may be a reason to think about surface water located in an area either with agricultural practices or road, railway refurbishment works (FPA, 2002; Palma *et al*, 2009).

Overall, N levels (as nitrate/nitrite and ammonia) are very low throughout the years (charts 2-4) except a peak produced in one determined day. Groundwater normally have high levels of these components because they are highly mobile (Canter, 1997; Bergström and Kirchmann, 1999), so again, one could say that surface water would be the source in this case.

However, presence of metals like Fe or Mn are more common in groundwater (Kim *et al*, 2008), especially in mine areas. Yet, in surface water these metals may be in high levels if an eutrophication process is been carried out (Tankéré *et al*, 2000). Even though eutrophication is mainly due to N and P, it would coincide with the presence of agricultural practices, being the main source of pollution.

Undoubtedly, the most determinant factor in order to characterize the source water is the presence of microorganisms and especially the high levels of total coliforms (chart 11) as they are more common in surface water (Medema *et al*, 1998).

The presence of coliforms indicates faecal water, which is extremely common in sewage water. However, taken into account all the parameters along with the presence of *Cryptosporidium*, is every likelihood the final source was a mixed farming, with crops and livestock which would explain the presence the faecal water and therefore, the presence of coliforms and *Cryptosporidium* (WHO, 2011). Thus, to sum up, the data might come from either a river or lake (surface water) where there could be an incipient eutrophication process and where, presumably, there are agricultural and stockbreeding practices in the area.

Water safety plan methodology

According to the WHO (2009), a semi-quantitative method is chosen to evaluate the water safety plans (WSP's).

Table1. Semi-quantitative risk matrix approach (from Deere et al, 2001)

		Severity or consequence			
		Insignificant or no impact - Rating: 1	**Moderate aesthetic impact Rating: 2**	**Major regulatory impact Rating: 3**	**Catastrophic public health impact Rating: 4**
Likelihood or frequency	**Likely / Once a week Rating: 4**	**4**	**8**	**12**	**16**
	Moderate / Once a month Rating: 3	**3**	**6**	**9**	**12**
	Unlikely / Once a year Rating: 2	**2**	**4**	**6**	**8**
	Rare / Once every 2-3 years Rating: 1	**1**	**2**	**3**	**4**

Risk score	**<4**	**4-7**	**8-11**	**>12**
Risk rating	**Low**	**Medium**	**High**	**Very high**

Table2. Output of hazard assessment and risk assessment using semi-quantitative approach

Process Step	Hazardous event (source of hazard)	Hazard type	Likelihood	Severity	Score	Risk rating	Basis
Source	Cocktail of pesticides from agricultural uses	Chemical	3	3	9	High	Potential introduction of toxic Chemicals (concentrations in finished water above WHO Guideline values)
Source	Cattle defecation in vicinity source of potential pathogen ingress + atmospheric phenomenon (rain)	Microbial	4	3	12	Very high	Potential illness from pathogens from cattle, such as *Cryptosporidium*
Source	Cattle defecation in vicinity source of potential pathogen ingress + atmospheric phenomenon (rain)	Microbial	4	3	12	Very high	Potential illness from pathogens from cattle, such as Coliforms or *E. Coli*
Source	Geology of the area/river + atmospheric phenomenon (rain) and infiltration + agriculture pollutants (P-N-eutrophication)	Chemical	3	3	9	High	Potential introduction of toxic metals (concentrations in finished water above WHO Guideline values of Fe and Mn)
Source	Farm machinery use (fuel, oil)	Chemical	1	2	2	Low	Potential introduction of toxic Chemicals (concentrations in finished water WHO Guideline values of petrol derived)
Source	Cocktail of chemists and some other components which lead to changes in aesthetic	Organoleptic	3	2	6	Medium	Possible change in water properties which may result in costumers rejection

Table3. Risk prioritization and control measures

Hazardous event	Control measure	Validation of control measure	Reassessment of risk post-control
Presence of a mix of pesticides	To applied the correct dosage/crop To adopt good farming practices Control measures (legislation)	High as the risk decrease considerably	Low with appropriate operational monitoring (LAOP)
Presence of *Cryptosporidium*	Improve water filtration technique Boil water (last resource)	Between low and medium as it takes long time and may be expensive	LAOP
Presence of coliforms	Improve water filtration technique Boil water (last resource) Iodine water Tertiary disinfection	The more retention time the higher efficacy	LAOP
Presence of high level of Fe and Mn	To reduce the use of pesticides or improve the application method In-situ: Vyredox Ionic exchange	Medium-high: depending on the efficiency of use Low: expensive and complex Very high: total removal	Low-medium depending on the control measure and with AOP
Presence of benzene and components derived from petrol	Use of more efficient machinery To avoid the use of machinery or reduce the time of use in the proximity of the source wherever possible Improve the machinery maintenance	High as the frequency is very low	Low-medium depending on the good practices of the farmer
Low organoleptic water quality	To control the issues above Use of adsorption techniques and methods	Medium-high depending on the adsorption capacity	LAOP

Table4. Long- and short-term monitoring requirements and corrective actions

Process Step	Critical limit	What	Where	When	How	Who	Corrective action
Source	Pesticides concentration leaving plant must be <0.1 µg/l	Pesticides residual	At entry point to distribution system (EPDS)	Weekly on-line	Chromatography	Water Quality Officer (WQO)	Activate pesticides non-compliance protocol (NCP)
Source	*Cryptosporidium* leaving plant must be $\leq 1.3 \times 10^{-5}$/l	*Cryptosporidium* residual	Dept. of Agriculture Site Inspection	Daily	On site at Dept. of Agriculture	Catchment/ Watershed Liaison Officer	Meet with landholder in breach and discuss incentive programme
Source	Coliforms concentration leaving plant must be 0	Coliforms residual	Council offices Site inspection	Daily	On site at Dept. of Agriculture	Catchment/ Watershed Liaison Officer	Meet with landholder in breach and discuss incentive programme
Source	Fe and Mn concentration leaving plant must be <200 and 50 µg/l respectively	Fe and Mn residual	EPDS	Weekly on-line	Metal analyser	WQO	Activate metals NCP
Source	Benzene and petrol derived concentration leaving plant must be <10 µg/l	Benzene residual	EPDS	Weekly on-line	Petrol derived analyser	WQO	Activate petrol derived NCP
Source	Organoleptic characteristics must be acceptable to consumers and no abnormal change	Possible customers rejection	EPDS	Daily on-line	Sensory analysis	WQO	Activate organoleptic features NCP

Water treatment plant design

Coliform removal by the conventional treatment process

Conventional water treatment includes a series of processes (coagulation, flocculation, clarification through sedimentation, filtration and disinfection) that when applied to raw water sources contribute to the reduction of microorganisms of public health concern (Geldreich, 1996).

One of the major barriers to water reclamation and reuse is concerns regarding the health risk of exposing public to treated wastewater and associated chemical and microbial contaminants (Schaefer *et al*, 2004).

Coliforms concentrations can be removed by primary, secondary, and tertiary effluents. On average, high concentrations of total and faecal coliforms can be removed by primary treatment, which may include coagulant addition prior to primary clarifiers. Other operating factors can also contributed to the increased coliforms removal such as the return of activated sludge to the primary clarifiers. Return of activated sludge to the primary clarifiers may have enhanced adsorption and subsequent settling and removal of coliforms (Zhang and Farahbakhs, 2007). With the secondary treatment, high removal of total and faecal coliforms may be done (Lucena *et al*, 2004), as well as in the tertiary treatment process.

Coliform removal by membrane bioreactors

On the other hand, Coliforms may be removed by membrane /membrane bioreactor systems (MBR) as Zhang and Farahbakhs (2007) tested.

Nominal and absolute pore sizes of the membranes can be between 0.04 and 0.1 mm. The absolute pore size is the minimum diameter at which 100% of particle or marker of a certain size is removed and typically describes the largest pore size on the membrane surface. Both nominal and absolute pore sizes are therefore important in determining microbial removal of membranes. Since coliform bacteria are larger than the absolute pore size of the membranes (0.6-1.2 mm in diameter by 2-3 mm in length) no coliform bacteria are expected in the permeate from the intact membranes.

The MBR system had higher removal efficiencies for all indicator organisms than the secondary treatment of conventional process, and it had similar or better removal efficiencies than the conventional treatment plus tertiary treatment and disinfection. This indicates that the MBR system can, not only replace the biological treatment processes, but it also eliminate the need for further effluent polishing (sand filtration) as well as disinfection. This is significant since not only chlorination/dechlorination is costly, but also produces large quantities of disinfection by-products (DBP), many of which are suspected carcinogens. In general, the MBR system produced better or comparable effluent quality than that of an advanced conventional treatment process in far fewer steps (Zhang and Farahbakhs, 2007).

Thus, in order to decide what treatment process should be chosen, MBR would be the first option as, compared with the conventional activated sludge process (CAS) process followed by tertiary treatment (RBC, sand filtration, and chlorination), the MBR system achieve better faecal coliform removal by more than 1 log unit and because the MBR process can achieve better microbial removal in fewer steps than a CAS process with advanced tertiary treatment.

Cryptosporidium

Studies have demonstrated that *Cryptosporidium* removal throughout all stages of the conventional treatment process is largely influenced by the effectiveness of coagulation pre-treatment (Dugan *et al*, 2001). *Cryptosporidium* oocysts, like *Giardia* cysts, are organisms that can be physically removed from water supplies by conventional particle separation processes including chemical coagulation-flocculation, clarification (sedimentation), and granular media filtration (Bellamy *et al*, 1993). Efficient protozoan cyst removal can be achieved by properly functioning conventional filters when the water is effectively treated through coagulation, flocculation and settling prior to filtration (Shaw *et al*, 2000). Water treatment plants using granular activated carbon (GAC) and rapid sand filters were more likely to have effluent samples positive for cysts and oocysts than those plants using dual- or mixed media filters (LeChevallier *et al*, 1991).

Pressure-driven membrane processes (microfiltration [MF], ultrafiltration [UF], nanofiltration [NF], reverse osmosis [RO]) are playing an important role in drinking water production in the US and in Europe. These processes are being employed in water treatment for multiple purposes including control of disinfection by-products (DBPs), pathogen removal, clarification, and removal of inorganic and synthetic organic chemicals (Jacangelo *et al*, 1997).

MF membranes have the largest pores, ranging from 0.1 to 10 mm, and the highest permeability so that a sufficient water flux is obtained at a low pressure. MF is an efficient process to remove particles that may cause problems in further treatment steps. Applications of MF membranes in water treatment include clarification, pre-treatment and particle and microbial removal (Jacangelo *et al*, 1997).

UF membranes have smaller pore sizes (0.002–0.1 mm); therefore the permeability is considerably lower than in MF and higher pressures are needed. Current applications of UF membranes in water treatment include particle and microbial removal. Physical sieving is considered as the major mechanism of removal of protozoan cysts.

So, for this case study, MF would be chosen as, from the energy/environmental and cost point of view, UF requires more energy and therefore would be more expensive. Besides, UF would be more practical in case of the necessity of removing small viruses, which is not a problem in this water. Furthermore, both technologies are good for minimizing turbidity.

Disinfection by-products

The use of chlorine for drinking water disinfection has virtually eliminated most waterborne diseases resulting from drinking water ingestion (USCDC, 1997). However, chlorination forms a number of disinfection by-products (DBPs), which are of potential concern. Some of these DBPs have cancer risks as well as other acute and chronic effects to human health (King and Marrett 1996). A number of DBPs have been investigated, including trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs), and haloketones (HKs).

The four THM species (chloroform, bromodichloromethane, dibromochloromethane and bromoform), dichloroacetic acids, trichloroacetic acids, trichloroacetonitrile, bromate and chlorite have been reported to have carcinogenic effects to human health. In addition, the nitrogenous DBPs, such as N-nitrosodimethylamine (NDMA) and other unknown DBPs may also pose a potential cancer risks to human health. If chlorine (for primary disinfection) is followed by chloramine (for residual protection), NDMA, regulated DBPs and other DBPs may be formed. However, THMs and HAAs will be much less in these cases. The amounts of DBP formation may be characterized based on the types and combinations of disinfectants used. (Chowdhury *et al*, 2009).

Table5 shows a good comparison among the most common disinfectants used. It will help to choose the best disinfectant for this case.

Table5. Basic information of disinfectants

Issue		**Chlorine**	**Chloramine**	**Chlorine dioxide**	**Ozone**	**Ultraviolet radiation**	**Reference**
Application		Most common	Common	Occasional	Common	Emerging use	USEPA (2006)
Cost		Lowest	Moderate (>chlorine)	High	High	Extremely high	Clark *et al* (1994)
Disinfection Efficiency	**Bacteria (*V. Chloreae*, Coliform, *E. Coli*, etc.)**	Excellent	Good	Excellent	Excellent	Good	MWH (2005), Sadiq and Rodríguez (2004)
	Viruses (Polio virus, Rota virus, etc.)	Excellent	Fair	Excellent	Excellent	Fair	
	Protozoa (*G. Lamblia*, etc.)	Fair to poor	Poor	Good	Good	Excellent	
	Endospores	Good to poor	Poor	Fair	Excellent	Fair	
Organisms Regrowth		Unlikely	Unlikelyy	Likely	More likely	More likely	MHW (2005)
Limits on free residual		5 mg/l	5 mg/l	0.3-0.5 mg/l	-	-	WHO (2011)
By-products	**Regulated**	4 THMs HAAs	Traces of THMs and HAAs	Chlorite	Bromate	None	WHO (2011)
	Unregulated	Many	Many: cyanogen halides, NDMA	Many: chlorate	Biodegradable organics	None known	Richardson (2005)
Oxidation		Strong	Weak	Selective	Strongest	None	Chlorine Chemistry Council (2003)
Odour and taste removal		Excellent	Good	Excellent	Good to poor	None	
Stability		Stable	Stable	Unstable	Unstable	Unstable	

So, taken into account the water characteristics in this case and after the table information, the use of chlorine shapes up as the best alternative in comparison with the others DBPs, as it can deal with all the issues with the lowest cost. However, further analysis will be carried out in this study.

Turbidity

Turbidity removal is carried out by coagulation/flocculation, settling and filtration.

A wide variety of chemicals exist for use in clearing raw water of suspended solids in coagulation/flocculation processes. It is known that the effectiveness of these coagulants has a complex dependency on the nature of the raw water, being affected by such things as temperature, pH, and especially the specific proportions of organic, inorganic, and biological particles that constitute the suspended solids. Furthermore, it is typically found that combinations of coagulants can be used to achieve much higher performance and process efficiency, but this performance again depends on the complex nature of the water source (Innosol, 2010).

Because of this complexity, no systematic criteria can be applied across all drinking water treatment facilities, so coagulant selection must be addressed by each facility according to its own circumstances.

Due to the water conditions in this case, Hydrolyzing Metallic Salts would be the best option as Pre-Hydrolyzed Metal Salts and Synthetic Cationic Polymers normally require an on-site production process as well as there is a historical lack of instrumentation for determining relative amounts especially for the use of polymers.

Among the Hydrolyzing Metallic Salts, Aluminum sulphate, $Al_2(SO_4)_3$ (better known as alum) is preferred to ferric salts (even though Al has high concentrations in this case) since they are less efficient for removing organic suspended solids and also they work better with high pH values (>8.5). In this case, the pH is suitable for the aluminum and allows fast mixing (Innosol, 2010).

In order to accelerate the flocculation process or strengthen the floccules to make it easier to filter, various additives can be used to aid in the coagulation and flocculation process.

Synthetic Cationic Polymers seem to be a good option in this case because they are more suitable with metallic coagulants. Natural polymers and inorganic coagulants are normally less efficiency and some of them work better with ferric salts (Innosol, 2010).

Thus, poly-DADMAC may be a solution as little is required to produce large floccules, rapid precipitation and low turbidity residue. Furthermore, it might improve process performance and economy when used properly.

Since pre-treatment is necessary for this case, best option for filtering is the use of rapid sand filters. A filtrate quality is possible that has less than 1 NTU, however, due to the necessity of removing *Cryptosporidium*, MF will be the option for removing microorganisms and turbidity.

Manganese

Mn along with Fe are in high concentrations in this water analysis. Thus, the suggested technique for removing Fe and Mn is a combination of three processes which are carried out in a simple filter system after the disinfection process: 1) ion exchange as an initial phase, where the dissolved manganese is fixed on the zeolite surface, 2) the subsequent oxidation of manganese on the surface of the medium, which allows the formation of an oxide film (MnO_x (s)) and 3) the removal of dissolved manganese by adsorption on the oxide film formed before. This film has high affinity for Mn^{2+} and Fe^{2+} (CYTED-XVII, 1996). It should be enough to reduce Mn levels in critical periods.

Aluminium

Removal of Al can be carried out by several methods such as cation exchange resin, reverse osmosis and electrodialysis. Processes such as coagulation, sedimentation and filtration (combined) are moderately effective in Al removal (Srinivisan *et al* 1999).

Othman et al (2010) achieved high percentages of Al removal by using two chelating resin, Iontosorb Oxin (IO) and polyhydroxamic acid (PHA), which could be incorporated to the same filter for removing Mn and Fe. Both chelating resin achieved 93% and 98% of Al removal being 20 minutes the optimum stirring time. However, it may increase the complexity and the price of the treatment system.

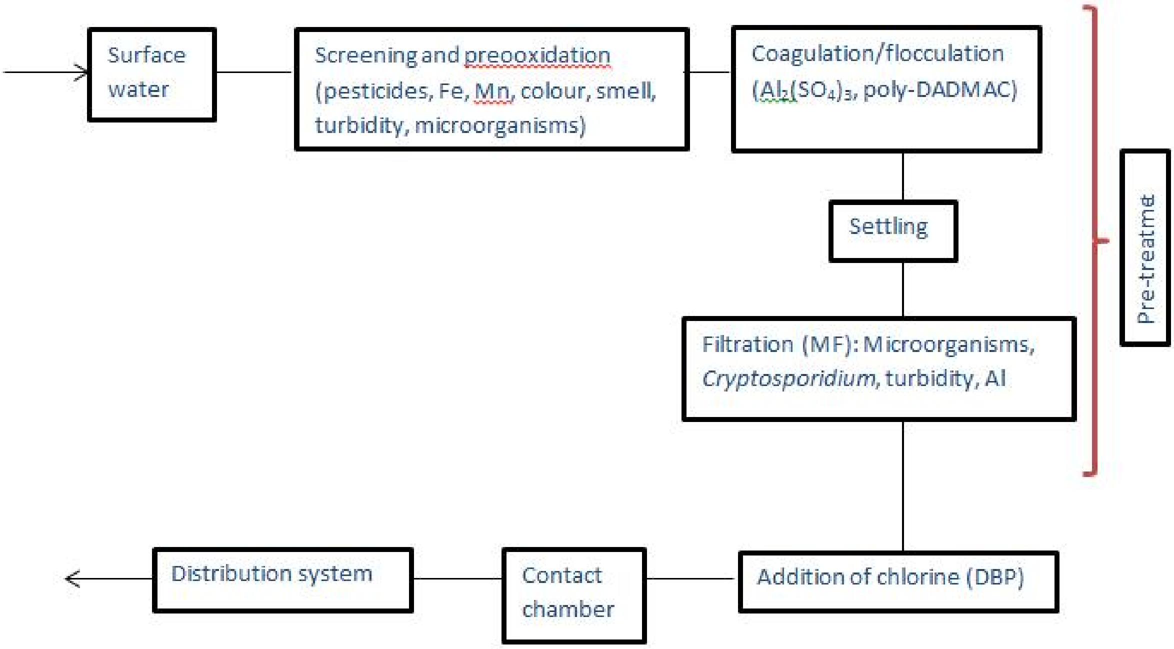
Pesticides

Increasingly, water treatment plants are applying ozone in the prior oxidation step instead of chlorine or NaClO due to the numerous advantages that this presents, in spite of its higher economic cost. Ozone has a high oxidant power and, in principle, does not generate hazardous organohalogenated by-products, such as THMs (Von Gunten, 2003). Moreover, colour, smell, and dissolved iron and manganese can be removed via ozonation and coagulation may be improved (Koga *et al*, 1992).

According to Ormad et al (2008), Preoxidation by ozone is an efficient treatment for degrading the majority of the pesticides present and their combination with coagulation does not improve removal efficiencies of pesticides. Activated carbon adsorption is also an efficient treatment for the majority of studied pesticides. When this treatment is combined with preoxidation by ozone, all of the pesticides they studied (about 44) were efficiently degraded. However, granular activated carbon (GAC) is expensive and may not worth it in this case.

Final design

Considering the above, the final design chosen is shown in the image below. It would be compound of a pre-treatment (pre-oxidation (with ozone), coagulation/flocculation, sedimentation/settle, filtration (MF) and perhaps the use both of GAC and resins for removing Al could be applied but it would depend on the efficiency of the water treatment without them) and finally a final step of disinfection by adding chlorine before the storage and the distribution system. Ozone and MF are expensive system but they are very effective and avoid the use of some other system which may complicate the treatment operation. So, in a long term, it is believed to be the best option.



Maintenance and monitoring scheme

ISSUE	MAINTENANCE	MONITORING
OZONE	-To be used in with a free halogen residual, which shall be maintained in the water at all times operation -Maintenance of the O_3 generating equipment shall be detailed in the premise's operations manual -Employees involved in the operation of O_3 generating equipment shall be trained in the operation and maintenance of the equipment.	-O_3 concentration in the aquatic facility water body shall not exceed 0.1 mg/l -Refresher training of O_3 equipment operation and maintenance procedures shall be conducted a minimum of once every six months (AQW, 2011).
COAGULATION	Alum application rates and the total coagulant applied in terms of alum equivalent mg/l need to be tracked by the supervisory control and data acquisition (SCADA) system (AWWA, 2010)	
FLOCCULATION	-The best strategy is to add it near to the main source of the problem. -PolyDADMAC shall be delivered in suitable container. -For storage purposes, it shall be store in cool-dry place -It shall be kept away from oxidants and strong acids. -Under proper storage conditions, polyDADMAC shall be stable for at least 12 months.	-Test method ANSI/NSF standard 60; EN 1408: 1998standard 60. -Not to exceed 25 mg/l with a carryover of not more than 50 µg/l of polyDADMAC into the finished water (SAJH, 2002).
MICROFILTRATION	-Aeration and backpulsing: membranes are to be backpulsed with water and air scour intervals of 15-30 min to reduce membrane fiber fouling wastewater deconcentration every two to three hours -Extended backpulse cleaning: 1/d an extended backpulse maintenance clean are to be conducted automatically with NaClO to control biofouling on the membrane surface and eliminate potential regrowth in the permeate piping. -Recovery cleaning: 1/m using NaClO and citric acid (Feldman *et al*, 2009).	-Planar ultrasonic transducers may be mounted on each cross-flow cell for continuous monitoring. -Real-time monitoring is necessary for improving the understanding and control of spatially defined fouling mechanisms involved (Kujundzic *et al*, 2011).
CHLORINE	-It need to be stored in steel containers -Safety precautions must be exercised during all phases of treatment regular operation and maintenance. It involves disassembling and cleaning the various components, once every 6 months. -Valves and springs should also be inspected and cleaned annually.	-A routine operation and maintenance schedule should be developed and followed according to manufacturer's instructions. -Control equipment must be tested and calibrated as recommended by the equipment manufacturer (Solomon *et al*, 1998).
FIRE PROTECTION	These include building fire suppression sprinkler systems and firefighter systems at waterfronts (salt water or brackish water (UFC, 2005).	
HEALTH AND SAFETY	-People who handle chemicals in related maintenance activities can attend safety education classes (UFC, 2005). -Refer to the COSHH for additional information.	
WATER SAMPLE FREQUENCY AND TESTING REQUIREMENT	For pH, alkalinity, conductivity, inhibitor and calcium hardness is suggested a frequency of 2/W for medium plants (100-350 kW) and 1/d for large plants (>350 kW) (UFC, 2005).	

Conclusion

This work has evaluated and determined a water treatment plant from a water quality data provided.

The water has been characterized as being surface water as the main pollutants were pesticides, metals (Fe, Mn and Al), some petrol derived and microorganisms, especially Cryptosporidium and coliforms. The main source may be farming practices and the presence of livestock.

The risk assessment and the identification of effective control measures, describing appropriate monitoring of water, have been undertaken under the conditions of the WHO Water Safety Plan methodology.

Finally a water treatment plant, composed of pre-treatment (ozone, coagulation/flocculation, sedimentation and microfiltration) and disinfection with chlorine, has been designed in order to meet the conditions for Drinking Water citing the appropriate regulations for the microbiological, disinfection by-products, turbidity, manganese, aluminium and pesticides parameters. Even though ozone and MF are expensive, they are the best option in the long term in this case.

A reasonable justification and a suitable maintenance and monitoring scheme for the chosen process, has been given.

References

AWWA, 2010. Operational Control of Coagulation and Filtration Processes. Manual of water supplies practices M37. 3rd Edit, American Water Works Association, pp. 180.

AQW, 2011. Appendix 4 – requirements for ozone water treatment systems. Available at: <http://www.public.health.wa.gov.au/1/69/1/Search.pm> [Accessed 07 January 2012].

Bellamy, WD, Cleasby, JL, Logsdon, GS, Allen, MJ, 1993. Assessing treatment plant performance. J. AWWA, 85, pp. 34-38.

Bergström, LF, Kirchmann, H, 1999. Leaching of total nitrogen from nitrogen-15-labeled poultry manure and inorganic nitrogen fertilizer. J. Environ. Qual. 28, pp. 1283-1290.

Canter, LW, 1997. Nitrates in Groundwater. CRC Press LLC, Boca Raton, USA, pp. 15.

Chlorine Chemistry Council, 2003. Drinking water chlorination: a review of disinfection practices and issues. Chlorine Chemistry Council, Arlington, VA.

Chowdhury, S, Champagne, P, McLellan, PJ, 2009. Models for predicting disinfection byproduct (DBP) formation in drinking waters: A chronological review. Science of the Total Environment 407, pp. 4189-4206.

Clark, RM, Adams, JQ, Lykins, BW, 1994. DBP control in drinking water: cost and performance. J Environ Eng.; 120(4), pp. 759-82.

CYTED-XVII, 1996. Agua Potable para comunidades rurales, reuso y tratamientos avanzados de aguas residuales domésticas. Capítulo 04: remoción de hierro y manganeso en fuentes de agua subterráneas para abastecimiento público, pp. 37. Available at <http://www.bvsde.paho.org/bvsair/e/repindex/repi84/vleh/fulltext/acrobat/agua.pdf> [Accessed 02 January 2012]

Deere D, Stevens M, Davison A, Helm G, Dufour A., 2001. Water quality: guidelines, standards and health-assessment of risk and risk management for water-related infectious disease. Management Strategies. Fewtrell L, Bartram J, Eds, London, World Health Organization, IWA Publishing, pp. 257-288.

Dugan, NR, Fox, KR, Owens, JH, Miltner, RJ, 2001. Controlling Cryptosporidium oocysts using conventional filtration. J. AWWA 93, pp. 64-77.

EUDWD, 1998. The Drinking Water Directive (DWD), Council Directive 98/83/EC. Available at <http://ec.europa.eu/environment/water/water-drink/index_en.html> [Accessed 07 December 2011].

Feldman, EM, Crossley, IA, Ruge, R, 2009. Minimize microfiltration membrane maintenance. Consider best practices for cleaning and waste disposal. Opflow, practical ideas for water operators. American Water Works Association. Available at: <http://www.hazenandsawyer.com/uploads/files/Membrane_maintenance.pdf> [Accessed 07 January 2012].

FPA, 2002. List of Agricultural Pesticides. Available at: <http://www.wpro.who.int/hse/pages/agriculturallist.html> [Accessed 22 December 2011].

Geldreich, EE, 1996. Creating microbial quality in drinking water. In: Geldreich, EE (Ed.), Microbial Quality of Water Supply in Distribution Systems. CRC Press LLC, Boca Raton, FL, pp. 39-101.

ICRP, 1991. 1990 recommendations of the ICRP. Annals of the ICRP. Oxford, Pergamon Press (International Commission on Radiological Protection Publication 60), 21(1.3)

Innosol, 2010. Available at: <http://www.dgrsol.com/tempWater/municipalWater/drinkingWater/coagulants.php> [Accessed 04 January 2012].

Jacangelo, JG, Adham, SS, Laine, JM, 1995. Mechanism of Cryptosporidium, Giardia, and MS2 virus removal by MF and UF. J. AWWA 87, pp. 107-121.

Jacangelo, JG, Rhodes Trussell, R, Watson, M, 1997. Role of membrane technology in drinking water treatment in the United States. Desalination 113, pp. 119-127.

Kim, K, Kim, H-J, Choi, B-Y, Kim, S-H, Park, K-H, Park, E, Koh, D-C, Yun, S-T, 2008. Fe and Mn levels regulated by agricultural activities in alluvial groundwaters underneath a flooded paddy field. Applied Geochemistry, 23, pp. 44-57.

King WD, Marrett LD, 1996. Case-control study of bladder cancer and chlorination by products in treated water (Ontario, Canada). Cancer Causes Controls, 7, pp. 596-604.

Koga, M, Kadokami, K, Shinohara, R, 1992. Laboratory-scale ozonation of water contaminated with trace pesticides. Water Sci. Technol. 26(9-11), pp. 2257-2260.

Kujundzic, E, Greenberg, AR, Fong, R, Hernández, M, 2011. Monitoring Protein Fouling on Polymeric Membranes Using Ultrasonic Frequency-Domain Reflectometry. Membranes, 1, pp. 195-216.

LeChevallier, MW, Norton, MW, Lee, RG, 1991. Giardia and Cryptosporidium spp. in filtered drinking water supplies. Appl. Environ. Microbiology. 57, pp. 2610-2616.

Lucena, F, Duran, AE, Morón, A, Calderón, E, Campos, C, Gantzer, C, Skraber, S, Jofre, J, 2004. Reduction of bacterial indicators and bacteriophages infecting fecal bacteria in primary and secondary wastewater treatments. J. Appl. Microbiol. 97 (5), pp. 1069-1076.

Medema, GJ, Schets, FM, Teunis, PFM, Havelaar, AH, 1998. Sedimentation of free and attached Cryptosporidium oocysts and Giardia cysts in water. Appl. Environment Microbiology, 64 (11), pp. 4460-4466.

MWH, 2005.Water treatment: principles and design. NJ, USA: John Wiley & Sons.

Ormad, MP, Miguel, N, Claver, A, Matesanz, JM, Ovelleiro, JL, 2008. Pesticides removal in the process of drinking water production. Chemosphere 71, pp. 97-106.

Othman, MN, Abdullah, MP, Abd, YF, 2010. Removal of Aluminium from Drinking Water. Sains Malaysiana, 39(1), pp. 51-55.

Palma, P, Kuster, M, Alvarenga, P, Palma, VL, Fernandes, RM, Soares, AMVM, López de Alda, MJ, Barceló, D, Barbosa, IR, 2009. Risk assessment of representative and priority pesticides, in surface water of the Alqueva reservoir (South of Portugal) using on-line solid phase extraction-liquid chromatography-tandem mass spectrometry. Environment International 35, pp. 545-551.

Richardson, SD, 2005. New disinfection by-product issues: emerging DBPs and alternative routes of exposure. Global Nest, Int J, 7(1), pp. 43-60.

Sadiq, R, Rodriguez, M, 2004. Disinfection byproducts (DBPs) in drinking water and predictive models for their occurrences: a review. Sci Total Environ; 321, pp. 21-46.

SAJH, 2002. Specification for Poly (Diallyldimethylammonium Chloride) or Polydadmac Used For Potable Water Supply. Quality Assurance Department. Available at: <http://www.saj.com.my/Spec/SPECIFICATION%20FOR%20POLYDADMAC1.pdf> [Accessed 06 January 2012].

Schaefer, K, Exall, K, Marsalek, J, 2004. Water reuse and recycling in Canada: a status and needs assessment. Can.Water Resour. J. 29 (3), pp. 195-208.

Shaw, K, Walker, S, Koopman, B, 2000. Improving filtration of Cryptosporidium. J. AWWA 92, pp. 103-111.

Solomon, C, Casey, P, Mackne, C, Lake, A, 1998. Chlorine Disinfection. National Small Flows Clearinghouse. Available at <http://www.nesc.wvu.edu/pdf/WW/publications/eti/Chl_Dis_gen.pdf > [Accessed 06 January 2012].

Srinivisan, PT, Viraraghavan, T, Subramanian, KS, 1999. Aluminium in drinking water: An overview. Water SA, 25(1), pp. 47-56.

Tankéré, SPC, Stathama, PJ, Priceb, NB, 2000. Biogeochemical Cycling of Mn and Fe in an Area Affected by Eutrophication: The Adriatic Sea. Estuarine, Coastal and Shelf Science, 51, pp. 491-506.

UFC, 2005. Industrial water treatment operation and maintenance. Available at: <http://www.wbdg.org/ccb/DOD/UFC/ufc_3_240_13fn.pdf> [Accessed 04 January 2012].

USCDC, 1997. Summary of notifiable diseases; morbidity and mortality weekly report. CDC surveillance summaries: surveillance for waterborne disease outbreaks-USA.

USEPA, 2006. National primary drinking water regulations: stage 2 disinfectants and disinfection by products rule: final rule. Fed Register, 71 (2).

Von Gunten, U, 2003. Ozonation in drinking water. Part I: Oxidation kinetics and product formation. Water Res. 37, pp. 1443-1467.

WHO, 2009. Water Safety Plan Manual. Step-by-step risk management for drinking-water suppliers. Available at: <http://www.who.int/water_sanitation_health/publication_9789241562638/en/index.html> [Accessed 28 December 2011].

WHO, 2011. Guidelines for drinking-water quality. World Health Organization, 4th ed. Available at: <http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/> [Accessed 06 December 2011].

Zhang, K, Farahbakhs, K. 2007. Removal of native coliphages and coliform bacteria from municipal wastewater by various wastewater treatment processes: Implications to water reuse. Water research, 41, pp. 2816-2824.