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Comparative Study of New Configurations of the Water Line of Municipal WWTP to Improve its Energy and Environmental Sustainability

Estudi Comparatiu de les Noves Configuracions de la Línia d'Aigües d'EDAR Municipals per a una Millor Sostenibilitat Energètica i Ambiental

Xavier Aguilera i Mengual

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Universitat de Barcelona

Dos campus d'excel·lència internacional

B:KC Barcelona Knowledge Campus

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“La riquesa, no és estar podrit de diners i viure sols per fer-ne més, desesperat. Que en uns grans magatzems no hi ha una secció on poder comprar tranquil·litat”.

“*La Riquesa*”, La Trinca

“Suposo que això és com diuen al Soho: half a loaf is better than no bread”

Bibiana Ballbé, Polònia

“Al *tanto* que va de canto”

Popular knowledge

My special thanks to my tutor and supervisor, Joan Dosta. Thanks for his patience, his suggestions and ideas in connection to my deepest fulfilled expectations for the topic for this research.

Thanks –as well- to all the people who aimed me and gave me support to carry out the crazy ideas which –perhaps- ended up not being so crazy. To all of you, my sweet thanks!

Tack så mycket, Kokoro.

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1. SUMMARY

The present project is mainly based on a research in the new methodologies and trends to make a WWTP either a system in which a series of separation operations are proposed to create new cycles for the recuperation of the different components or species that are influents to the WWTP, or propose existent technologies for the future WWTP in special space conditions in order to achieve a substantial reduction of energetic costs, but in this case, the unitary operations are not focused in the reusing of compounds arriving on to the WWTP.

When referring to the term "cycles" the idea laying behind is that to avoid the currently release of N_2, Mg^{2+} and several P species to the surrounding environment of the WWTP -which may cause a slow but silent eutrophication- and thus, reuse the by-products produced to be used in other industries or even for agricultural. Fresh water can also be reused as a result of an osmosis process for separation from the waste water treatment flow. A realistic approach is performed on a well-known scenario, Barcelona and the surrounding areas.

When referring to the terms "reduction of energetic costs" these are related to the enhancement of current techniques and implementation of new practices to reduce the costs of several line processes involved in the wastewater treatment as well as the enhancement of electricity production.

Finally, a holistic vision of the enhancement processes is given to understand the need for these changes and the soonest implementation as possible.

2. RESUM/RESUMEN

Aquest projecte és principalment basat en la recerca de nous processos i tendències per a fer en una EDAR o bé una sèrie d'operacions de separació que proposen crear nous cicles de recuperació per a components o espècies [químiques] que són afluents a l'EDAR o bé, proposar tecnologies existents pel futur de les EDAR en condicions especials d'espai per tal d'aconseguir substancials reduccions de costos energètics, però que en aquest cas, no van associades a la reutilització de compostos que arriben a l'EDAR.

Quan hom es refereix al terme "cicles", la idea que rau darrera és la d'evitar l'actual alliberament de nitrogen atmosfèric, catió magnesi i espècies de fòsfor al medi ambient del voltant de l'EDAR, -que pot causar una lenta i silenciosa eutrofització- i, aleshores, reutilitzar aquests subproductes generats per tal de poder ser usats en d'altres indústries o fins i tot a l'agricultura. L'aigua dolça també pot ser reutilitzada com a resultat d'un procés de separació per osmosi, procedent de la línia del flux d'aigua residual. Es desenvolupa un enfocament real dut a terme en un escenari conegut, Barcelona i les àrees circumdants.

Quan hom es refereix a termes "de reducció de costos energètics", aquests es relacionen a la millora dels processos de les actuals tècniques i la seva implementació amb noves pràctiques per tal de reduir els costos de diverses línies del procés involucrades en la depuració de les aigües residuals, així com també una millora de la producció d'energia elèctrica.

Per acabar, es dóna una visió holística sobre la millora dels processos per tal d'entendre la necessitat per aquests canvis i la seva implementació el més aviat possible.

Este proyecto se basa principalmente en la búsqueda de nuevos procesos y tendencias para aplicar en una EDAR o bien una serie de operaciones de separación que proponen crear nuevos ciclos de recuperación para componentes o especies [químicas] que son afluentes a la EDAR o bien, proponer tecnologías existentes para el futuro de las EDAR en condiciones especiales de espacio para conseguir sustanciales reducciones de costes energéticos, pero que en este caso, no van asociadas a la reutilización de compuestos que llegan a las EDAR.

Cuando uno se refiere al término “ciclos”, la idea que yace detrás es la de evitar la actual liberación de nitrógeno atmosférico, catión magnesio y especies de fósforo al medio ambiente, -que puede suponer una lenta y silenciosa eutrofización- y, entonces, reutilizar estos subproductos generados con tal de ser usados en otras industrias o hasta en la agricultura. El agua dulce también puede ser reutilizada como resultante de un proceso de separación por osmosis, de la línea de flujo de agua residual. Se desarrolla un enfoque real llevado a cabo en un escenario conocido, Barcelona y sus áreas circundantes.

Cuando uno se refiere a los términos “de reducción de costes energéticos”, éstos se refieren a la mejora de los procesos de las actuales técnicas y de su implementación con nuevas prácticas con tal de reducir de las diferentes líneas de proceso involucradas en la depuración de las aguas residuales, así como también una mejora en la producción de energía eléctrica.

Para acabar, se da una visión holística sobre la mejora de los procesos para entender la necesidad que requiere de estos cambios y que su implementación sea lo más pronta posible.

3. INTRODUCTION

In this first introductory chapter the main lines of motivation for this project are described as well as the factors that note the necessity for a shift in the perception of the treatment of wastewater and its posterior disposal.

3.1. SCARCITY OF NATURAL RESOURCES

It is not a new trend observed worldwide that natural resources are neither accessible to everybody nor ever-lasting. In this line, developing new policies, technologies and conceptions for the best use of material resources, use of energy and as well waste reuse is a determining step in the future development of human society and economy.

It has already been spread out that fossil fuels will not last longer than several decades. And that the world climate is changing because of the release of gases that overheat the atmosphere. Actually, countries worldwide meet together to set up protocols for reducing the carbon dioxide emissions (Kyoto summit protocol), enhancing the development for greener energies and focus on a minor dependence on oil so as to reduce the greenhouse effect gases.

Understanding that developing new processes and technologies should be the main focus of science is crucial to conceive a sustainable and continuous economic growth.

3.1.1. Water scarcity

Water is one of the most precious liquids and compounds on earth. It is known that water is the liquid of life, as almost every single life unit develops in water media. The water resources present in the earth depend basically on both the rain and the existence of rivers or reservoirs so that local authorities are able to perform drinking water processes to make water suitable for drinking requirements or any other requirement for further use.

Water scarcity does not even depend on the country in which people live. Draughts can both affect developing countries with fatal consequences and developed countries as well. In 2007-2008 a terrible draught in Catalunya made the Government of Generalitat take extraordinary measures such as temporary drinking water limitations and even acquiring water from abroad transported by huge ships to provide the population with the basic daily amounts of water needed [1].

In fact, the Barcelona Metropolitan Area (despite being in a Mediterranian area with such few rain circumstances) counts on a huge amount of water which might be available for human use. This is the groundwater from aquifers, such Llobregat aquifer and Besòs aquifer. However, this groundwater mass is currently contaminated by marine (salty water) intrusion, meaning that the water quality is not suitable enough for human intake.

In addition, there is a potential use from seawater. This is the desalinization process via RO, but the problem for this process is that the amount of energy required is not affordable in standard situations and is mainly regarded as an emergency key to avoid draught consequences.

3.1.2. Future fertilizer scarcity

The fertilizer industry is a very important sector dedicated to the extraction and processing of natural (some of them non-renewable) resources to enhance the agricultural yields necessary. Intensive agriculture is needy of fertilizers to be allowed to produce as much fruits and vegetables to sustain the population levels. Actually, it exists a correlation between the implementation in the chemical industry of the Haber-Bosch process to synthetize ammonia from atmospheric Nitrogen and Hydrogen and the increase of worldwide population. This fact explains that thanks to cheaper costs for ammonia production and the more quantity of it, more fertilizers based on Nitrogen were produced, agricultural yields were enhanced and, therefore, more people were able to eat, grow up and breed, so in terms of population growth, the increase is an exponential curve.

It would seem that the fertilizer industry is forever-lasting in terms that Nitrogen is a very accessible resource in the atmosphere and Hydrogen is as well easy to be obtained from water, but it happens that there is another very important fertilizer which is Phosphorous and this is not a renewable source.

It is now interesting to have a quick view over the Nitrogen cycle:

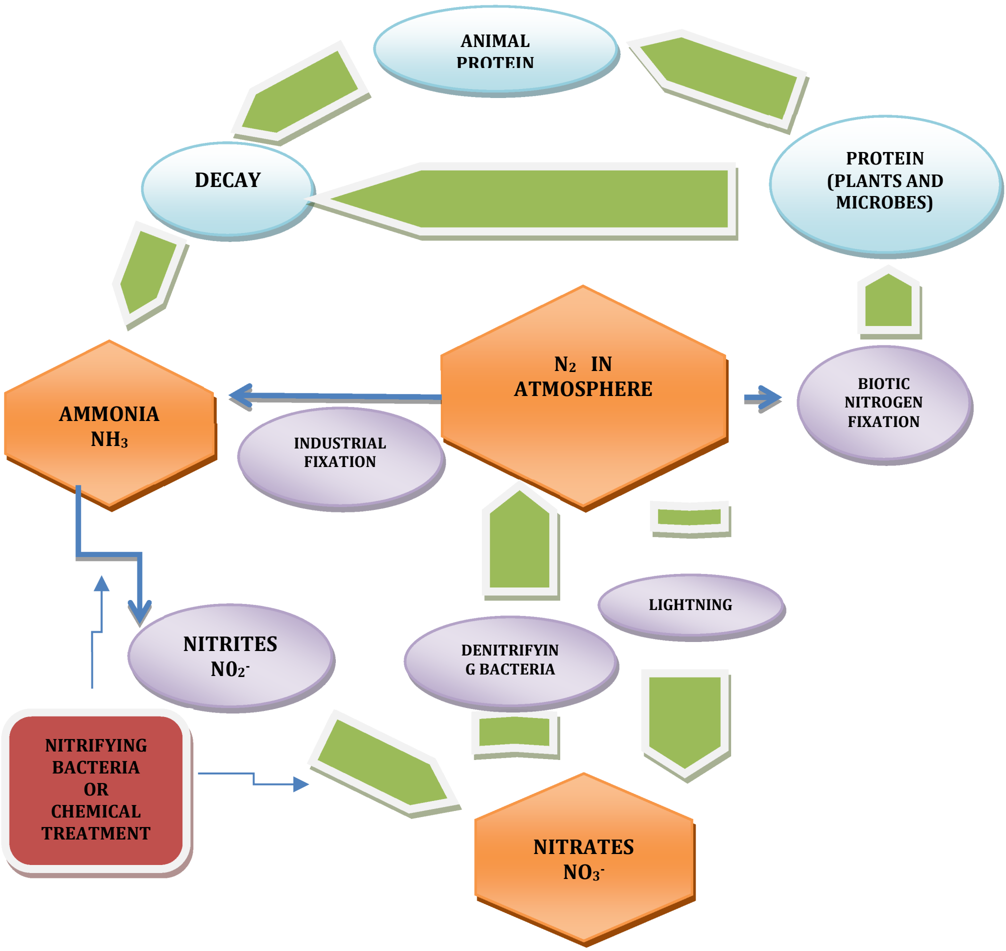

Figure 1.- Cycle of Nitrogen. Own creation.

The idea from the figure is such that all forms of Nitrogen are eventually connected thanks to the cyclic uses of Nitrogen. This means that by natural means, Nitrogen fixation if performed via bacteria and incorporated to plants in a cycle that continues with the decay into ammonia and an eventual conversion into Nitrogen gas via nitrifying and denitrifying bacteria. On the other hand, the vast majority of the Nitrogen for fertilizer uses comes from the conversion of Nitrogen gas by industrial fixation into ammonia (chemical fixation and chemical treatment) to eventually be converted into Nitrates. Nitrates are either incorporated to plants or in the very last term reduced into Nitrogen gas again by denitrifying bacteria.

Once that the cycle is overviewed, it is important to ask if there is any other “route” so as to avoid the loss of nitrates into Nitrogen gas and re-convert these nitrates into ammonia again. Actually, it is easier if all the protein decay which leads to be converted into ammonia might be kept as ammonia itself. This clue question is critical to develop the rest of this project.

In comparison, the Phosphorous cycle:

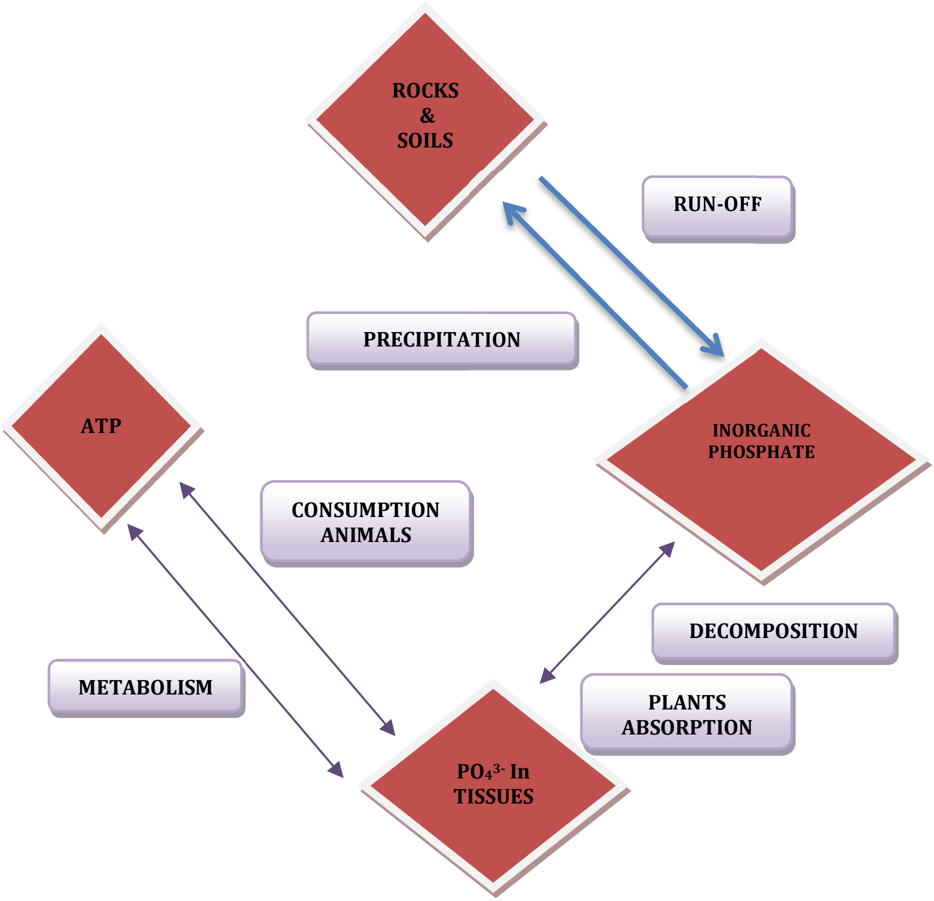

Figure 2.- Cycle of Phosphorous. Own creation.

In contrast with the Nitrogen Cycle, in the Phosphorous cycle there are not very well defined roles in the conversion and re-distribution of Phosphorous. In terms of source of Phosphorous, the only known source for industrial exploitation is the mining of Phosphorous rocks which are now estimated to be a threatened resource with a limited lifetime of 100-1000 years provided that the extraction rate is kept at the same levels as they are now. Unfortunately, the world population is expected to increase dramatically for the following centuries, so it is not a so-long period of time for the natural Phosphorous-rock stock.

Once again, the reader should ask him/herself if the arrows indicated in blue (which represent the main stock of Phosphorous) could be re-designed or re-conceived to enhance the Phosphorous recovery and recycling.

In addition to the cycle-view, it is also very interesting to remark that worldwide there is a constant flow (exchange) of food (cereals, mainly) which create a certain eutrophization in a very smooth and indirect manner. When commercializing cereals, in fact, countries trade with plants and seeds which contain, at the same time, Nitrogen and Phosphorous, among other minerals on their tissues. When massive exportation occurs, in that country, there is an impoverishment of minerals, so the country should create or buy more fertilizers to compensate the loss. When a country acquires cereals (for example) it is also acquiring minerals and nutrients that the population, eventually will excrete. When this occurs, minerals and "fertilizers" are released to the environment (first, to the sewage, on the last term to the environment). It is in this

To give a visual example of this, there is the visual world map of the wheat trade.

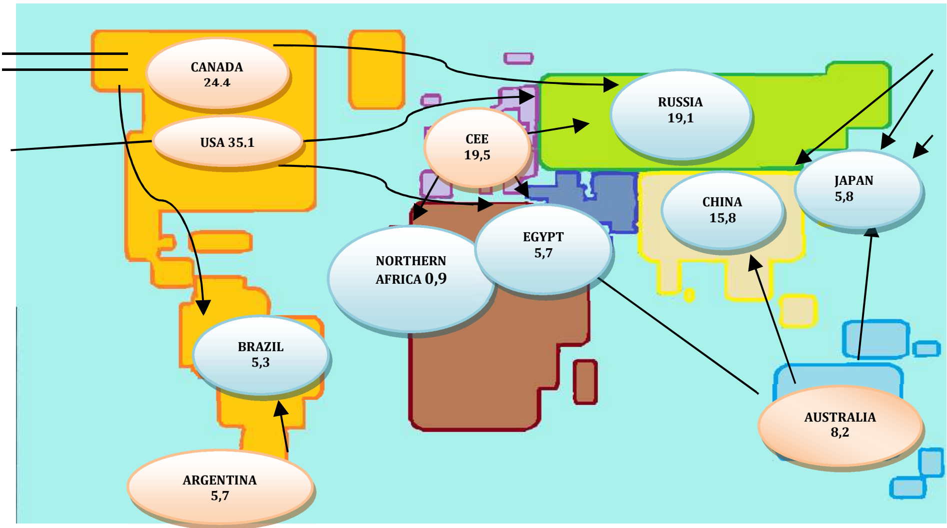

Figure 3.- Wheat trade in the world. Adapted [2].

In the last figure, in orange there are the precedence countries in the wheat trade. In blue, there are the countries receiving wheat trade. Numbers refer to the millions of tons exported or imported. There is a tendency for disequilibrium in which it is shown that emerging economies have to “buy” cereals from the developed countries. The rich countries can produce their own fertilizers to grow again and again the cereals but the accumulation of nutrients happens in the poorest countries (except for Japan, where the geography and space limitation may influence the decision/need to buy cereals from abroad).

3.1.3. Future fossil fuel scarcity

Fossil fuels are the main energy source for the most of human activities. The clue for that is the high combustion heat they have. As stated before, fossil fuels are the main energetic source for transportation (e.g. including transportation of cereals and food in general). The energy for transportation which is now almost 100% dependent on fossil fuel, will be in a medium-long term threatened because of the disappearance of oil. It is interesting in terms of the global production of food, the increasingly high costs for transportation will lead to more local economies in producing food. In this sense, it will be, of course, crucial for every country (or agricultural region) to be able to have the enough Nitrogen and Phosphorous to use as fertilizers. Otherwise, the costs to obtain food will increase dramatically and lead the agricultural economy and food supply to a crisis.

There is a tendency to obtain energy from waste (e.g. Avfall Sverige [3]) as well as to improve the systems and water or sludge lines in WWTP [4] to be able to take as much profit from the waste as possible. This new visions have been driven because of the awareness of companies, Governments and other public sectors to re-design the conception of Recycling, Reusing and Minimizing waste disposal.

3.2. CLOSING CYCLES

The importance of “closing cycles” is meant in terms of recycling whatever it is produced. Recycling is not just in terms of the last three figures, to make the nutrients (N, P) to be at entire disposition of the agricultural industry, it is, in addition, the conception of give value to that what is consider at a first instance, as waste, something not desired but if properly separated, can be of a fundamental importance for a sustainable development. Closing cycles is, as well, to promote a new vision for the two cycles shown above to improve the energetic necessities (in terms of electricity but in terms of energy for transportation too). In this line, in this project several ideas are mentioned to develop these new processes and – what is also of equal importance – to concern the public of the potential and the need for these new processes/technologies for a better future.

3.3. REMOVAL FOR EMERGING CONTAMINANTS

The evolution of medicine, in many fields has led to an evolution in the pharmacological industry. This means that a wide range of medicines and drugs are now available to the public in general. However, taking medicines does not mean that the medicine is incorporated to the body. Instead, the general activity of medicines and drugs is to perform a certain function and then be released away from the body.

What this statement comes to say is that in WWTP, it is found a very wide range of different compounds, the majority of which are pollutants, but the concentration of them is often too low to be able to perform any affordable process to remove them. Nevertheless, it exists nowadays a series of possible pathways to eliminate these pollutants. This pollutants are organic compounds so it has been studied the beneficial effects of certain microbes which enhance the removal of these undesirable compounds when it comes the time for disposal of WWTP effluents.

4. JUSTIFICATION

The importance for the research taken into account in this project is due to the future necessity to integrate the new promising processes associated to depuration in WWTP. There are two basic ideas. The first idea is that the substances (influents) arriving to the plant may be profitable and potentially reused for several purposes for outside the WWTP. Nitrogen, Magnesium and Phosphorous may form a mineral called struvite [5] which is used as a fertilizer. Pure fresh water can be separated by osmosis at full scale for further usage in close industries. The second idea is to enhance the already existing technology in the wastewater treatment towards a more self-energetic focus in the WWTP design.

These new visions which may sound obvious are not implemented or maybe are not implemented to a certain extension for which to make the process of wastewater treatment more sustainable and less energy-demanding. What is obvious is revised and through simple calculations intended to be justified to be studied thoroughly in the future and, finally, implemented. In addition, this work is embedded on the concern and optimization for those processes which may lead to the better profit of existent resources to develop the culture of the less-dependence on natural non-renewable resources such as the raw mineral source of Phosphorous.

5. OBJECTIVES

The main objectives for this research and study are the following stated below:

- To concern the Reader about the possible new procedures and technologies can open and provide the WWTP for a more environmentally-friendly operation.
- To point out the need for these new methodologies in WWTP in regard to the reuse of limited natural resources and the reduction of energetic costs for production of other industrial-derived products if the recovery from the WWTP is achieved.
- Be able to quantify some of the most important economic repercussions of the application of the mentioned new processes.
- In addition, mention and propose new methodologies for emerging pollutant removal and give an example of an integrated treatment to achieve it.

6. STATE OF ART

In this chapter it will be detailed the information available found from the bibliographical sources:

6.1. OVERCOMING WATER SCARCITY

6.1.1. Recycling water and Water Regeneration

Draught is a climatic episode which is a serious and real threat around the world. The most sensible areas exposed to potential draught are those under a warm climate, with high population density and with little precipitation (or water income). It is wise, then, to be aware of the potential of a WWTP for providing "freshwater" if combining processes with a water regeneration plant or system (WRP).

6.1.1.1. Water for flushing and other activities for the city.

The idea of taking profit of the existing water that arrives (as wastewater) to a WWTP is the one of removing the hazardous substances, bacteria, virus, etc., so that the water is then able to be used again. This concept of "reusing" again the water is called "water regeneration" and in Spain there is existent legislation about it. Regenerating water is to provide the water coming from a wastewater treatment with the minimum quality so as to be employed for further uses. The existing law is clear about the capabilities and limitations of regenerated waters [6].

Forbidden uses according to RD 1620/2007:

- Human consumption (except for catastrophe declaration)
- Process water in food industry
- Sanitary or health care installation use.
- Leisure use in which water is in direct exposition with human body (such bathing activities, etc.)
- Ornamental fountains in public areas.
- Any other uses that the sanitary authorities may consider as a risk for public health or threat for the environment.

Possible uses for regenerated water according to RD 1620/2007:

- Urban use (WC, fight against the fire, street flushing, car washing, etc.)
- Agricultural use (water may be in contact with the plants) gardening and ornamental plants and flowers.
- Industrial use (except for food industry)
- Leisure activities (golf fields, ponds, etc.)
- Environmental uses (forest watering, aquifer recharge by percolation or direct injection, etc.)

So, via an RTP it would be possible (according to the law) to use regenerated water for flushing the toilets, among other uses. It is mentioned the toilet use because it is a very important use of water at home because of the amount of water used in flushing.

In addition, it is very important to mention that regenerated water for toilet flushing needs of new infrastructure in terms of municipalities being able to collect regenerated water and distribute is separately from the ordinary freshwater so that these two different waters are never in contact. This main obstacle is probably the reason why regenerated water it is not more popular nowadays in household. This use requires of the proper infrastructure (new pipe network specially designed for regenerated water) and the awareness of the people who uses it at home.

It is also important to state that the controversy of regenerated water use is still on discussion. For the general public it may be shocking to understand that water may be reused from wastewater sources or origins. That is the reason why legislations (in general around the world) are still so strict and reluctant for the uses of regenerated water in contact with human body.

6.1.1.2. Water for aquifer regeneration

It is already a reality in the Barcelona Metropolitan Area the use of regenerated water for aquifer regeneration. In fact, the industries settled in Barcelona during the first halve of the 20th century and an important part of the second halve, used a lot of groundwater extracted from wells. This situation was continuous in the past and it was not until the 70s when the vast majority of these industries moved away that the aquifer piezometric level started recovering its natural position. In fact new constructions in Barcelona and surrounding areas suffered in the 90s floods because when they were built the groundwater level was so low that engineers didn’t realize of it. Once the level was slowly increasing, flooding episodes were more and more frequent.

As a result of the overexploitation of the Llobregat-Besòs aquifer in Barcelona, seawater entered in the aquifer. Nowadays, in the Llobregat WWTP part of the regenerated water is used as artificial barrier to recover and recharge the aquifer and avoid the saline intrusion from seawater, making the salt water out [7].

Anyway, for other situations of aquifer status, it is also a good option to inject the regenerated water for any case of draught menace, in connection to the need in dry zones to be provided with “extra” reservoirs just in case of extreme necessity. In addition, the injection in aquifers is one of the possible uses which the law permits in relation to regenerated water uses.

6.1.1.3. Forward Osmosis Treatment (FOT)

Forward Osmosis is the use of the thermodynamic driving force of osmosis to separate via a semipermeable membrane the wastewater into two different effluents: (a) more concentrated wastewater and (b) less concentrated osmotic fluid (which initially presents a high concentration in compounds so as to create a very high osmotic pressure and divert through the membrane pure water to equal or to compensate the osmotic pressure difference of both fluids.

In this line, there exist studies in relation to Forward Osmosis (it is called forward Osmosis to be differentiated from the popular RO, because in here, the principle is to use the natural tendency and driving force so that the separation is spontaneous and requires little energy intake [8].

The clue in this technique is to use an osmotic fluid capable of be regenerated at low cost. In this case, almost pure water is obtained from diluted osmotic fluid, and so osmotic fluid is again able to be used in the FO process.

The advantage of this process is that there is no need to put extra energy on the system to perform the pure water separation. The main disadvantage is that the technique is relatively new and the yields obtained in laboratory experiments (so these are experiments carried out at very low flows) still are relatively inefficient if compared with yields that full-scale plants would require. In laboratory experiments performed at 25ºC, using a synthetic draw solution (concentrated osmotic fluid) consisting of NH_4HCO_3 4M, and feed solution (influent solution to separate the water from) consisting of NaCl 0.5M the results obtained are the following:

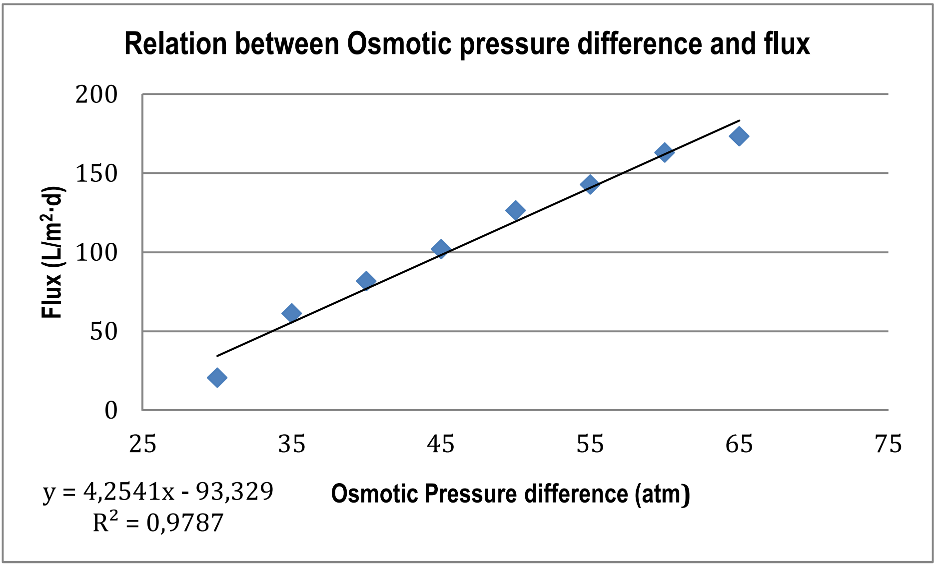

Figure 4.- Graphic in which is shown the relation between osmotic pressure difference and flux per unit of are of membrane. Adapted [8].

6.2. NUTRIENT RECOVERY

6.2.1. The potential of nutrients

As seen in the cycles for both Nitrogen and Phosphorous, because of metabolic activity and through human excretion, wastewater is rich in N and P. It is estimated that 1m^3 of wastewater contains 50gr of N (total Nitrogen), 10gr of P (total Phosphorous) and, overall, 100gr of fertilizers which may be potentially used for agriculture [4]. In fact, it is easy to perform a quick analysis on urine to check visually its content of insoluble phosphorous compounds. Just by adding a few drops of concentrated Sodium Hydroxide solution into a tube with a little sample of urine and as well with Magnesium Sulphate it may be seen that there is a formation white cloud that, with time is deposited in the bottom of the tube. This solid is the precipitated salts of $Mg_3(PO_4)_2$ because it is the most probable solid to be formed in terms of ions present in the solution (solubility product) and because of the strong polarity of Mg^{2+}. The important idea to underline is that when Magnesium ion is added, the solids formed in the solution are more, so in terms of nutrient recovery, just by a simple experiment it can be quickly showed that

Phosphorous solid precipitation is enhanced by Magnesium co-precipitation rather than by increasing pH, because it only precipitates with the Magnesium present in the same solution. This idea is essential to understand Struvite recovery.

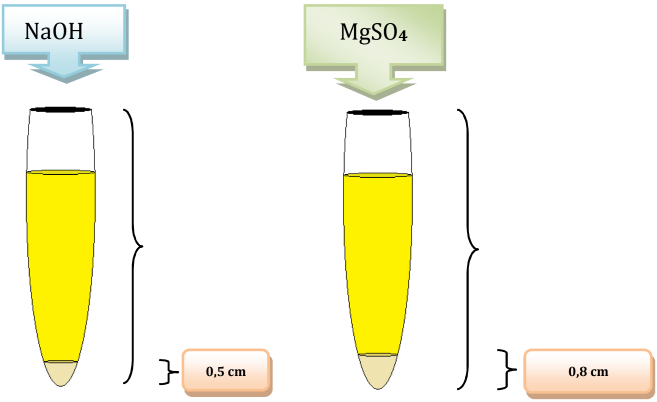

Figure 5.- Representation of the comparison in precipitation of Phosphorous species

6.2.1.1. Direct use

Nowadays wastewater (or regenerated water) can be used for agricultural uses. There is a reason for that. The high amount of nutrients that already treated wastewater (or regenerated water) may contain make this water source a quite enough attractive nutrient source as well. The best use for wastewater is the nearest to the WWTP and the RWP because the longer the pipe network, the more problems with fouling there might happen.

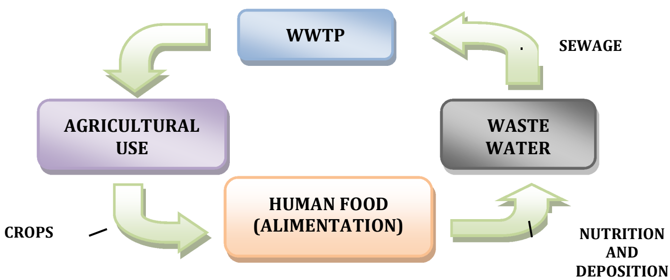

Figure 6.- Cycle for reusing nutrients present in wastewater

6.2.1.2. Nitrogen recovery

Nitrogen recovery is already practiced in several WWTP in USA. The recovery consists of a series of unitary operations comprehending air stripping of ammonia from digester supernatant and steam stripping of ammonia as well from digester supernatant [9].

Air stripping consists of splitting up the ammonia dissolved and present in the sludge line supernatant stream by means of an air current. The requirements is that ammonia must come out of the dissolution by excess of the present of air, thus, the main stream must be in conditions of producing the ammonia gas to be split up. This is to say that the pH of the wastewater stream must be around 11 to provide basic media to form ammonia. The pH requirements are supplied by $Ca(OH)_2$. The main problem of this stripping by air current is that the Calcium Hydroxide amounts are huge (with the cost repercussion) and, in addition, the pH conditions enhance the precipitation of this mineral in the pipes of the system (fouling).

Steam stripping of the digester supernatant is another technique that may achieve more recovery yields than air stripping (steam stripping achieves a 88% of recovery of total ammonia in supernatant if a gas-to-liquid ratio is maintained around 300 to 1) but the cost of operation is very high because the stripping column should be maintained at a very high temperature to keep the steam as gas. In addition, the influent ammonia concentration must be on the order of 500 to 600mg/L. Once ammonia is separated, it is crystallized with sulphuric acid.

6.2.1.3. Struvite recovery from digester supernatant

Struvite is Magnesium Ammonium Phosphate Hexahydrate with the following chemical formula: $MgNH_4PO_4 \cdot 6H_2O$. It is a white crystal powder but can form any kind of size of crystal. It is highly soluble at acidic pH and very insoluble in alkaline pH [10].

Struvite recovery is not a more sophisticated method than already explained above. The additional improvement in comparison with the Nitrogen recovery is that via Struvite recovery Phosphorous is removed from the supernatant as well as Nitrogen, so one more nutrient (and a very important one and difficult to remove from WWTP) is separated. In addition, Struvite has been studied since many years because of the problems that tends to produce in WWTP because of the precipitation at any unexpected corner and the worst fouling effects it may derive from that [11].

The normal water line in a WWTP may be such like:

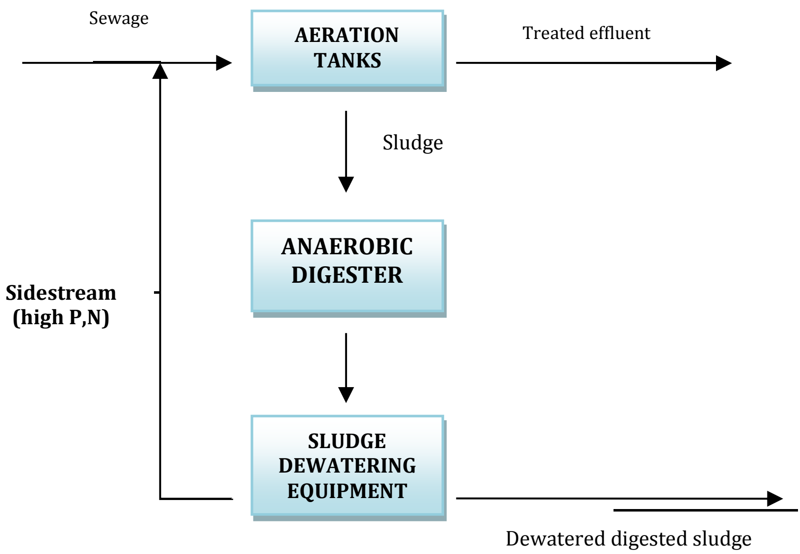

Figure 7.- Typical configuration for a secondary treatment and the sludge treatment

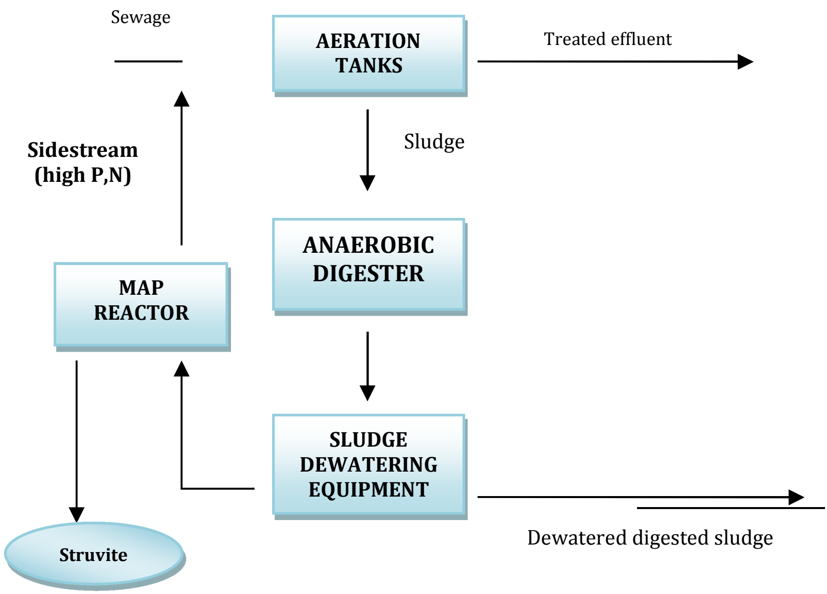

Figure 8.- Modified configuration to introduce Struvite recovery (MAP)

The key factors for Struvite precipitation are such like:

- Compromise in the optimum pH for struvite recovery: as the pH increases, the concentration of orthophosphoric species increases as well, while concentration of free magnesium and free ammonia (ammonium ion) decrease.
- The content of P in the supernatant from the sludge dewatering is very high (700-800mg/L), then, it is one of the critical points to perform P removal by co-precipitation with Magnesium ion.

It is important to comment that the struvite recovery is performed over the supernatant sidestream because, in this way, Phosphorous and Nitrogen recirculation is avoided and because after mechanical dewatering of digested sludge, the concentration of nutrients is high enough to precipitate them. In this terms, the recovery yield of Phosphorous (it would be the limit reagent because of its lowest concentration) from the sludge digester supernatant is considered to be around 94% [11]. For the co-precipitation, it is needed Magnesium Hydroxide so that the pH of the supernatant is slightly increased and, as well, it is a source of Magnesium to enhance the precipitation stage.

However, with the incorporation of the struvite recovery, the water line is modified as shown in Figure 8, with the addition of the MAP reactor stage to perform the precipitation phase.

Note that both figures (figure 7 and figure 8) have been adapted from the original source [11].

An already studied model for an Struvite precipitation reactor may be the following [11].

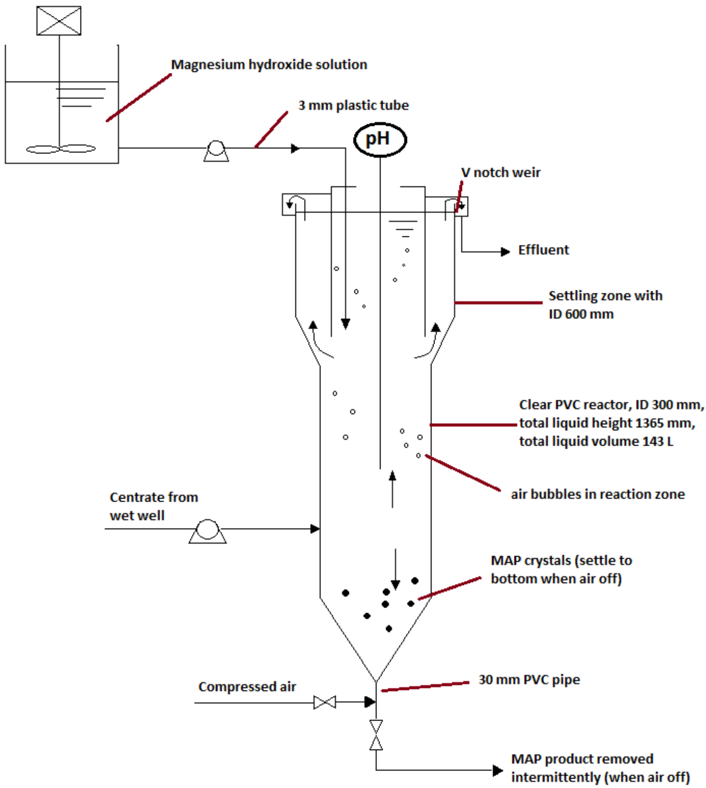

Figure 9.- Configuration for the Struvite precipitation reactor (MAP). Adapted [11]

6.3. ENERGETIC DEMAND OF WWTP

6.3.1. Basic design in WWTP

6.3.1.1. Intensive WWTP in front of Soft Treatments

Technology in WWTP is divided into intensive (hard) treatments or extensive (soft) treatments. Hard treatments are characterized by requiring large amounts of energy to perform the wastewater treatment, while needing a relatively few space for installations. However, soft treatments (or technologies) do not require such amount of energy to operate (because this technologies use the natural depuration capabilities of biological systems and organisms) but, instead, they require huge extensions of land to treat water.

In this line of other possible solutions for those WWTP which position is nearby an important superficial mass of water is the Green Filter. Green filters are soft technologies which enable wastewater treatment by the filtering in a porous media such as the soil.

Wetlands are also a soft treatment which is based in the retention by several mechanisms of the pollutants of water and then mineralized slowly mostly by biochemical processes.

Lagoons and ponds are as well an attractive means for treating wastewater but, unfortunately, the treatment is not carried out in the soil, but in the water media, so this treatment is not as interesting for the removal of the emerging pollutants, which are more easily removed in contact with the soil particles where certain bacteria mineralize special new contaminants.

In contrast with the intensive treatment methods, soft methods do not often allow the possibility to recover nutrients because it is not an industrial-installation so facilities to control the process are less available. Thus, pollutants or nutrients are mineralized and then released to the environment transformed into a non-hazardous substance.

6.3.1.2. Enhancing the biogas production

One method that is currently spreading in biogas production from WWTP sludge is to destroy the cell membrane of bacteria coming from the secondary treatment in order to release the organic and inorganic substances from inside the cell so that bacteria in digester can easily reach the nutrients from the death cells. This breaking the cell membrane can be achieved by mechanical means by projecting the sludge at a very high pressure through a jet and against a solid surface so that when cells impact to the solid wall they explode releasing the content.

6.4. NEW POLLUTANTS

Due to the advance in medical treatments, pharmaceutical companies have created persistent medicines and drugs that are persistent in water. In the past these compounds could not even be neither quantified nor detected because of the low concentration in which they are present in wastewater.

6.4.1. Polycyclic Aromatic Hydrocarbons (PAH) [12]

PAH are not always necessary present in wastewater, but are a kind of compound which can be eliminated by soil mineralization thanks to bacteria. These bacteria are called Mycobacterium and Sphingomonas and are present in soils contaminated by PAH. However, the activity of these bacteria is very slow compared with the activity these bacteria show in artificial conditions (laboratory studies). The objective of certain studies has been to determine the best ratio of organic carbon, N and P to achieve a better kinetics in the degradation of PAH. Results show that the best ratio is (C/N/P) (in mg) 120/14/3 or (in moles) 100/10/1.

7. Hypothesis, Calculations and Discussion of Results

In the present chapter, a series of hypothesis in connection with the previous studied information are designed in order to achieve the changes and modifications to enhance the functioning of WWTP.

- *The cristallisation and precipitation of Struvite is a Unitary Operation in which nutrient recovery can be achieved within the WWTP sludge line (after the supernatant has been separated).*

Table 1.- Struvite recovery mass and molar balance according to data in literature [11]

Total flow in the plant		
	Literature	El Prat
Q (m3/d)	300000	420000

Total flow of sludge (sludge + supernatant)		
	Literature	El Prat
Qss (m3/d)	55000	77000
[N] (mg/L)	700	700

[P] (mg/L)	70	70
[N] (kg/d)	38500	53900
[P] (kg/d)	3850	5390

Percentage of recovery (literature)		
	Literature	El Prat
%	94	
[N] (kg/d)	36190	50666
[P] (kg/d)	3619	5066,6

MW	
NH_4^+(g/mol)	18
PO_4^{3-}(g/mol)	95
Mg^{2+}(g/mol)	24,3
H_2O(g/mol)	18

Mole flow		
	Literature	El Prat
NH_4^+(kmol/d)	2010	2814
PO_4^{3-}(kmol/d)	38	53
Mg^{2+}(kmol/d)	38	53
H_2O(kmol/d)	38	53

Struvite Mass Flow ($MgNH_4PO_4 \cdot 6H_2O$)		
	Literature	El Prat
(kg/d)	9321	13000

The present table can show via simple calculations the viability of considering Struvite recovery. For a WWTP like the one in El Prat, the result is almost 13 ton of struvite each day.

The costs of exploitation have not been calculated neither have been considered the costs of construction for the struvite precipitation reactors.

- *The Forward Osmosis Unitary Operation can produce fresh water from several lines of the process within the WWTP.*

In any treatment plant, before using any sophisticated membrane such as RO membranes (and now FO membranes) it is essential that the fluid that will be in contact with that membrane is previously treated. The recommended treatments are either microfiltration or ultrafiltration. Microfiltration is the process which presents a lower costs and allows good enough quality for the effluent to then go through the RO process, so for the FO process the same criteria will be adopted to avoid membrane fouling. Actually, both membranes work by osmosis, no matter if it is Forward (or Direct) or Reverse.

It is interesting to have a look at appendix number one in which Table 4 contains information in relation to the wastewater quality before and after the microfiltration process. Note that it is supposed that the influent wastewater has already gone through a primary and secondary process prior arriving to the microfiltration (it is not raw wastewater).

Note that the process for FO has a series of limitations. The experiments conducted by the authors showed that the flow for both the draw solution and feed solution were of about 2L/min. In terms of industrial application of this technology it means that the total flow diverted to the FO process should be split up into multiple minor flows to achieve the same flow.

The present calculations contained in the following table try to give an idea of how feasible it would be to implement the FO to obtain freshwater from wastewater. Some considerations have been made to adapt the calculations to the hypothesis of the authors [8].

The results of calculations are included in Table 2. The main inconvenience for the calculation of FO is that there is not much information about the FO energetic costs, neither the costs for implementation of the processes, nevertheless, from the results in Table 2 – and always according to the laboratory conditions stated by the authors of the article read) show that the feasibility for the process is very limited in terms of the Total Number of Units needed to perform the FO, given the proposed range of the percentage of total wastewater flow which might go through the FO process. It is impossible to carry out this process just by space disposition of the plant. However, the yields of the FO separation are maximum limits. This means that although it is stated that a 10% of the total flow goes through the FO, of course, the effluent from the FO will never be as high as the influent value for the flow. So values in the tables are maximum limits. In addition, osmotic pressure, changes with time so, the further the process goes, the less osmotic pressure difference there is, so it is a process in which the total treated flow will be much less than always expected.

Table 2.- Flow through the FO and TNU required for the process

Hypothetical application of FO to El Prat WWTP (Nominal Flow: 420000m^3/d)				
% Total flow to FO	Q (m^3/d)	Flow to FO (L/min)	Operation Flow (L/min)	TNU of FO
10	42000	29167	2	14583
20	84000	58333	2	29167
30	126000	87500	2	43750
40	168000	116667	2	58333
50	210000	145833	2	72917
60	252000	175000	2	87500
70	294000	204167	2	102083
80	336000	233333	2	116667

- *Other configurations of WWTP (soft technologies or green technologies) can be implemented in serial connection after the main treatment processes so as to improve the quality of the treated wastewater just before the effluent is disposed in the environment.*

Actually, this hypothesis will not have any calculations behind. It is just a matter of common sense. In those cases where there is the possibility to create a green area next to the WWTP, it is a reasonable idea to use facultative ponds or wetlands to ensure a final better quality of the water in order to be disposed into the environment. In addition, wetlands, as their way of depuration is the attached growth and biofilm retention to mineralize the organic pollutants of water, may properly remove the PAH present in wastewater. In addition, wetlands are able to retain pollutants by adsorption on surface of particles in the soil.

- *The wastewater, once treated properly, can adapt its quality to supply the water for WC water flushing in several municipalities around the Metropolitan Area in Barcelona:*

Table 3.- Data and calculations for the viability of regenerated water use for WC water flushing in the Barcelona Metropolitan Area.

Analysis on Prat de Llobregat WWTP		Analysis on Besòs WWTP	
Nominal raw Wastewater Flow [13]		**Nominal raw Wastewater Flow [13]**	
Q (m^3/d)	420000	Q (m^3/d)	525000
Population [14]		**Population [14]**	
BCN (only 35%)	1611822	BCN (only 65%)	1611822
35% of the last	564137	65% of the last	1047684
El Prat	63419	Badalona	219708
Cornellà	86687	Montgat	11055
Esplugues	46667	Sant Adrià	34822
L'Hospitalet	254056	Santa Coloma G.	120029
Sant Joan	32812	Tiana	8221
Sant Boi	83408		
Santa Coloma C.	8060		
Sant Just	16859		
Total inhabitants	1156105	Total inhabitants	1441519
Individual Flushing (estimated)		**Individual Flushing (estimated)**	
Flushing/(day·person)	3	Flushing/(day·person)	3
Volume/Flushing [15]		**Volume/Flushing [15]**	
(L/Flushing)	7	(L/Flushing)	7

Flow for WC flushing (m^3/day)	24278	Flow for WC flushing (m^3/day)	30271
Potential Market Price [4] (€/day)	6069	Potential Market Price [4] (€/day)	7567
Anual Saving in Water (hm^3)	8,87	Anual Saving in Water (hm^3)	11,06
Typical volume of Catalunya's Reservoirs from internal basins (hm^3) [16]		Typical volume of Catalunya's Reservoirs from internal basins (hm^3) [16]	
Riudecanyes	3	Boadella	61
Foix	4	Llosa del Cavall	80
Siurana	12	La Baells	109
Sant Ponç	24	Sau	165
Catllar	59	Susqueda	233

Observation: This hypothesis is conditioned to the future developing of new pipelines to supply the regenerated water to the buildings in order to be used in flushing toilettes (WC). Political will is required.

Note that there has not been calculated the “extra costs” for chlorination of the WWTP efluent for further usage in WC flushing as well as it has been considered that the water quality at the end of the depuration process is good enough for the reutilization in toilets. The potential price for the water is regarded as the market price at which tapwater is sold, meaning that there is an implicit consideration of the drinking water processes within this estimated unitary price. In addition, if the water treated in the RTP had to adapt its quality for new standards, these always would be priced less, otherwise, the process for water regeneration and reuse is no longer feasible. What is important in this step of water regeneration is that the water, itself, is valued again, so in case of draught, its price is even higher than in normal situations and this regeneration process worth it.

In spite of the results in this chapter's calculations, provided that the membrane technology for FO improves in a near future, the new design for a basic WWTP conceived under the regard for environmental friendliness could be such like:

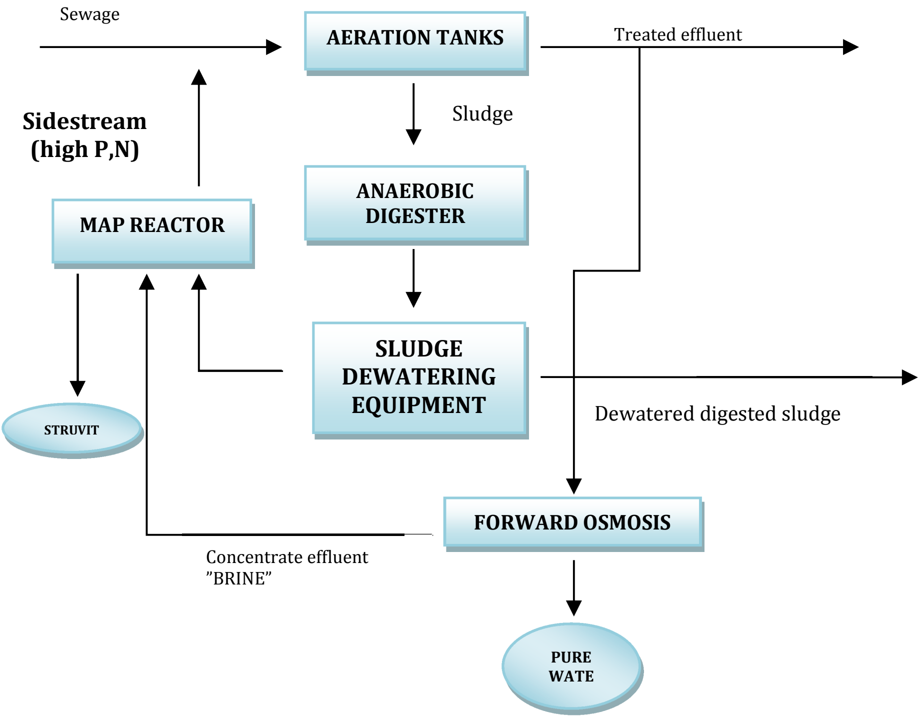

Figure 10.- One possible configuration of WWTP in the future, including FO technology and Struvite recovery

8. CONCLUSIONS

The conclusions that this research and posterior calculations have led to are the following stated below:

- It is possible to conceive and design better processes which may lead to a better profit for reusing of nutrients flowing into the WWTP. In this line, the basic reutilization of water for WC flushing uses would equal the entire water volume of several reservoirs per year.

- The potential for the recovery and reuse of certain minerals and chemical species for certain industrial or agricultural purposes is a real option as well as the permission from the current law to achieve it.

- Struvite precipitation and fresh water separation are feasible to recover and in terms of economic and environmental sustainability are desirable to be carried out.

- Forward Osmosis for pure water extraction separation from already treated wastewater is not

- In the future, and for new WWTP that will be constructed, combining technologies could help reducing the operation costs as well as help integrating WWTP in the environment and, in the case of wetlands, perhaps achieve emerging pollutant removal from the wastewater.

9. REFERENCES AND NOTES

[1] Generalitat de Catalunya: Agència Catalana de l'Aigua. http://aca-web.gencat.cat/aca/sequera/ca/inici.jsp (last accessed June 9, 2014).

[2]. Gérin-Grataloup, A-M. Précis de Geographie. *Éditions Nathan.* 1995.

[3] Avfall Sverige. Swedish Waste Management. http://www.avfallsverige.se/in-english/ (last accessed June 9, 2014).

[4]. Verstraete, W.; Van de Caveye, P.; Diamantis, V. Maximum use of resources present in domestic "used wáter". Bioresource Technology. 100 (2009) 5537-5545.

[5]. Shu, L.; Schneider, P.; Jegatheesan, V.; Johnson, J. An economic evaluation of phosphorous recovery as struvite from digester supernatant. Bioresource Technology 97 (2006) 2211-2216.

[6] Boletín Oficial del Estado. RD 1620/2007: Sobre el uso de las aguas regeneradas http://www.boe.es/boe/dias/2007/12/08/pdfs/A50639-50661.pdf. (last accessed June 9, 2014).

[7] Amphos 21. Scientific and Strategic Environmental Consulting: Estudis Hidrogeològics i Hidroquímics per a l'establiment d'una barrera hidràulica contra la intrusion salina en un aqüïfer costaner (Espanya). http://www.amphos21.com/vistas/paguas.php (last accessed June 9, 2014).

[8]. Yong Ng, H.; Tang, W. Forward (Direct) Osmosis: A novel and prospective process for brine control. Water Environment Foundation, WEFTEC, 4345-4352. 2006.

[9]. Metcalf & Eddy; Tchobanoglous, G. et al. Wastewater Engineering: Treatment and Reuse. 4th International Edition. McGraw Hill. 2004.

[10] Doyle, J. D.; Parsons, S. A. Struvite formation, control and recovery. Water Research 36 (2002) 3925-3940.

[11] Münch, E.; Barr, K. Controlled Struvite Crystallisation for Removing Phosphorous Anaerobic Digester Sidestreams. Water Resources. Vol 35, No. 1, pp 151-159, 2001.

[12] Leys, N. M.; Bastiaens, L.; Verstraete, W.; Springael, D. Influence on carbon/nitrogen/phosphorous ration on polycyclic aromatic hydrocarbon degradation by Mycobacterium and Sphingomonas in soil. Applied Microbiological Biotechnology (2005) 66: 726-736.

[13] Agència Catalana de l'Aigua: Anuari de les estacions depuradores de Catalunya. http://www.aca.cat (last accessed June 9, 2014).

[14] Instituto Nacional de Estadística. INE: Padrón municipal. http://www.ine.es (last accessed June 9, 2014).

[15] Fundació ABERTIS. Estudi del consum d'aigua als edificis de la Regió Metropolitana de Barcelona. http://www.fundacioabertis.org/rcs_est/estudi_complet.pdf (last accessed June 9, 2014).

[16] Agència Catalana de l'Aigua-Idescat. Estat dels embassaments de les conques internes de Catalunya. http://www.idescat.cat/pub/?id=aec&n=212 (last accessed June 9, 2014).

Other sources of information which have been consulted are:

[*]. Dewettinck, T.; Van Houtte, E.; Geenens, D.; Van Hege, K.; Verstraete, W. HACCP (Hazard Analysis and Critical Control Points) to guarantee safe water reuse and drinking water production – a case of study. Water Science and Technology Vol 43 No 12 pp 31-38. 2001.

[*] Agència de Residus de Catalunya. III Jornades tècniques de gestió de sistemes de sanejament d'aigües residuals: Vies de gestió dels fangs d'EDARs: Situació Actual i previsió per a l'horitzó 2007-2012.

http://aca-web.gencat.cat/aca/documents/ca/jornadatecnica003/04_oliva_r.pdf (last accessed June 9, 2014)

10. ACRONYMS

In this chapter, the reader will find a collection of the acronyms used in the development of the present research and calculations for this project.

- RO: Reverse Osmosis.
- ATP: Adenosine TriPhosphate.
- P: Phosphorous species (especially orthophosphoric species when not specified).
- N: Nitrogen species.
- WWTP: Waste Water Treatment Plant.
- WRP: Water Regeneration Plant.
- FO/FOT: Forward Osmosis / Forward Osmosis Treatment
- TNU: Total Number of Units
- MAP: Magnesium-Ammonia-Phosphorous (Struvite)
- TOC: Total Organic Carbon
- BOD: Biological Oxygen Demand
- COD: Chemical Oxygen Demand
- TSS: Total Suspended Solids
- TDS: Total Dissolved Solids
- NTU: Nephelometric Turbidity Unit

APPENDIX

APPENDIX: ADDITIONAL INFORMATION

Table 4.- Quality of wastewater after the microfiltration process [9]

Constituent	MF influent	MF effluent	Average Removal
	(mg/L)	(mg/L)	(%)
TOC	10-31,0	09-16,0	57
BOD	11-32	2-9,9	86
COD	24-150	16-53	76
TSS	8-46	0,5	97
TDS	498-622	490-620	0
Ammonia-N	21-42	20-35	7
Nitrate-N	1-5,0	1-5,0	0
Phosphates	6-8,0	6-8,1	0
Sulphates	90-120	90-121	0
Chloride	93-115	93-116	0
Turbidity (NTU)	2-50	0,03-0,08	99

Note that the results of the table are shown as an example of wastewater quality after a microfitration process because it was available data. It is just for having an idea of magnitudes.