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Implementation proposal of safety plan for reuse of treated wastewater in green areas, Case Study: University City.

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Abstract. In the “Universidad Nacional Autonoma de Mexico (UNAM)” (campus University City), it was performed a diagnosis of treatability infrastructure and quality of treated wastewater which is reused for irrigation of green areas (94% of the population uses this green areas for recreational activities, including food intake). This diagnostic allowed detecting the actions needed in order to achieve a responsible management of treated wastewater. Based on the methodology for water safety plans that have been developed to organize and systematize the management practices applied to drinking water. This study arises a methodological proposal of multiple barriers, for the safe handling of treated wastewater and its reuse for the irrigation of green areas. The proposal includes four essential barriers of control: The first one refers to the evaluation of the wastewater treatment process; the second one, includes a continuous quality monitoring program for the treated wastewater (effluent); the third one, involves a continuous checking of the conditions of storage and distribution of treated wastewater; finally, the last barrier included is a monitoring of bacteriological quality in aerosols for sprinkler irrigation. The implementation of this strategy in the management of treated wastewater will reduce negative health risks, particularly when the population is directly exposed to the treated wastewater. As well as promoting effective policies in the management of wastewater in developing countries, this plan may become an integral part of the solution to stemming the water scarcity crisis.

Key words: health, plans, reuse, safety, treated, wastewater

Introduction.

Population growth and the depletion of water supply sources lead to the need in many countries of reusing wastewater for various purposes: agricultural irrigation, industry, public services and artificial recharge, among others. Several countries have implemented guidelines for treated wastewater reuse in order to promote a more effective and efficient use of available water resources and ensure public health and environmental protection. Also, a variety of approaches have been taken by different agencies to regulate water quality for wastewater reuse systems (Aggelakis et al, 1999). So far, only a few countries worldwide have established claims on wastewater reuse that led to the drawing of specific regulations or guidelines. These guidelines are not enforceable but can be used in the development of a wastewater reuse program (Anggekalis et al, 2001). A criteria is needed that employs a broader approach to encompass treatment standards, treatment process controls and fail-safe systems, application standards and water quality standards suitable for a more comprehensive set of wastewater uses. According to Fawell et al, 2004, framework must consider consistent basis for the development of appropriate and verifiable standards and guidelines at local, regional and national levels. The basis of this proposal considers relevant local issues that have been researched, developed and implemented from 2008 to 2012 through the management project, use and reuse of water in the UNAM ("PUMAGUA") along with the current legislation, to develop the proposed security plan. One of the main variables in wastewater reuse is the characterization of water quality, which is not an abstract exercise, it's occurs in a specific context associated with the proposed use of the water. Therefore, as the practice of treated water reuse is mainly aimed for the irrigation of green areas, and people customs involve direct contact, it is critical develop plans focused on safe handling of treated wastewater. Regarding public health, water quality is an important factor for both human consumption and reuse, in order to avoid impacts on health of the university community.

Authors found only one paper reported in scientific journals referring to implementing a Water Safety Plan (WSP) to the reuse of wastewater for potable purposes; an approach for an indirect potable reuse system in early stage of development (Dominguez et al, 2010).

In 2005, the world health organization WHO proposed security plans addressed to water supply systems for water quality protection in order to achieve the health goals fixed by the National Authority. Green areas and agriculture irrigation are well known as practices for wastewater reuse (treated or not). This paper describes the research undertaken to development a methodological proposal of a security plan, based on multiple barriers for reuse of treated wastewater in green areas in University City.

Methods.

As a part of the project "PUMAGUA", a diagnosis of conditions was performed in terms of wastewater treatment technologies and reuse practices currently in use in the campus University City-UNAM. The main use for the treated wastewater is the irrigation of green areas which are in direct contact with the users. This diagnostic allowed detecting the actions needed in order to achieve the responsible management of treated wastewater. This leads to a methodological proposal of multiple barriers, as a strategy to implement a safety project of treated wastewater management.

This work considers the methodology for WSP that has been developed to organize and systematize the management practices applied to drinking water (Davison et al, 2005). Many different stakeholders are involved, so roles and responsibilities (who does what) need to be clearly defined, along with mechanisms to ensure the active coordination of the various institutions (Choukr-Allah and Hamdy, 2004). The proposed scheme of (WWSP) involved eight major components that are presented in Figure 1. Within the elements of the plan, representative aspects are involved; environmental, social, economic, cultural, technical, institutional, health and reuse (Almasri et al, 2009).

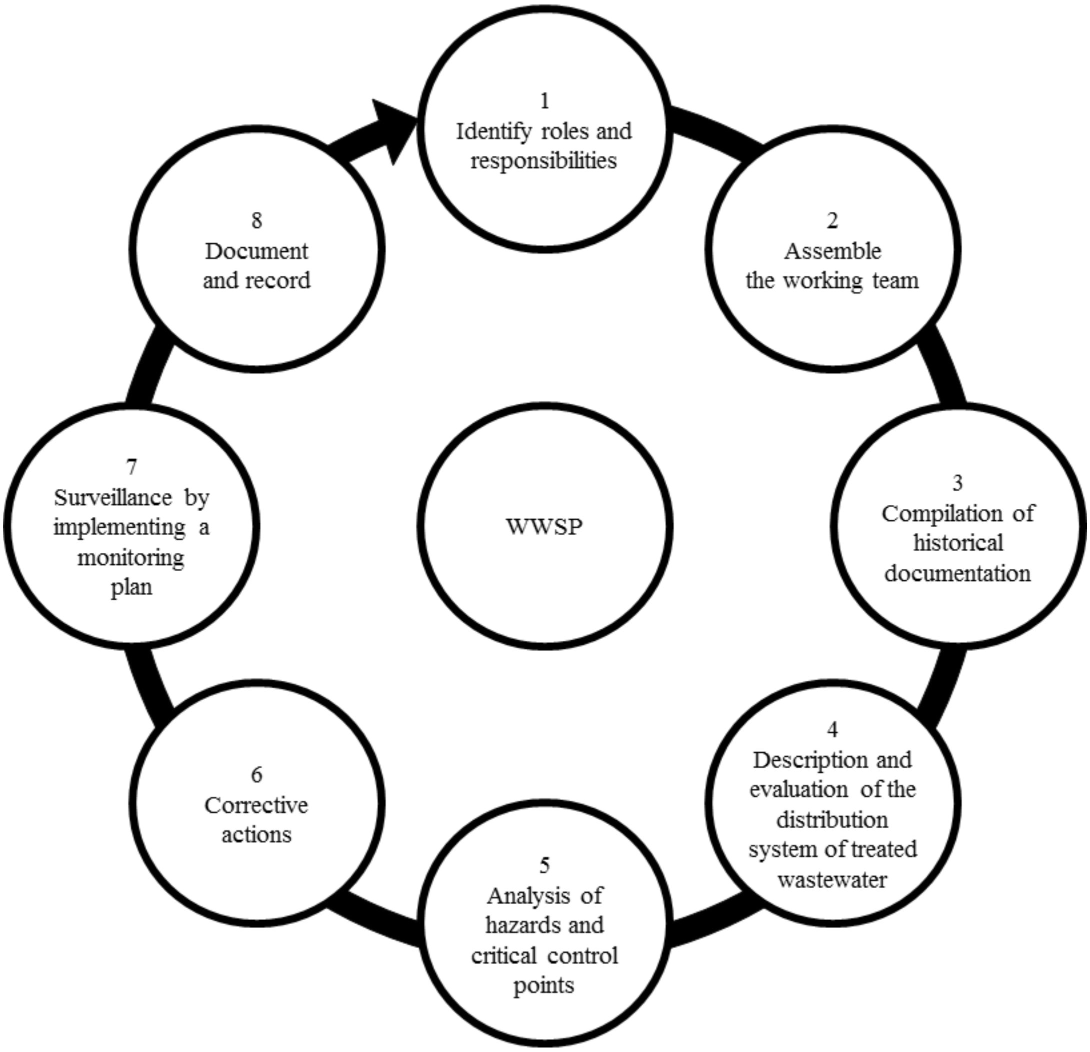

Figure 1 Major stages to implement a WWSP.

For the case study of University City, the following actions, describes the development of specific activities for each stage.

Identify roles and responsibilities.

a) The responsible actors of the treatment, management and distribution of University City treated wastewater were identified.
b) Authorization procedures were arranged in order to perform physical inspections to the treatment facilities, treated wastewater monitoring, requirements reports and emergencies response with the Internal Operating Agency (IOA).
c) People responsible were consulted to obtain the necessary historical information about the distribution system.
d) Other important actors were users. They provided relevant information about the activities performed in green areas and the perception on service quality.

Assemble the working team.

a) As recommended by WHO 2005, it was necessary to form a multidisciplinary team, involving experts to develop WWSP. A team leader was appointed, who leads the management project, use and reuse of water, in the UNAM since 2008. The team included: authorities to implement the necessary changes, personnel involved with the daily operations, personnel with extensive knowledge of the system and scientific experts in various disciplines related to water management.

Compilation of historical documentation.

a) Information from internal sources within the campus University City was requested to document the situation of the treated wastewater management.
b) The location of the WasteWater Treatment Plant (WWTP) and type of treatment process.
c) Applicable regulation.
d) Historical analysis of water quality was revised: data in influent and effluent, during the period 2001-2008; Faecal Coliforms, Helmint eggs, fats and oils, Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS).

Description and evaluation of the distribution system of treated wastewater.

a) A review of the distribution system of treated wastewater for green areas irrigation was fulfilled and a flow diagram was elaborated.
b) The research team evaluated the physical and operative conditions of the WWTP.
c) Analyzes of the effluent water quality were carried out: Faecal Coliforms, Helmint eggs, fats and oils, BOD_5, COD and TSS, according to APHA, 1998.
d) Physical conditions of treated wastewater storage tanks were evaluated in order to take actions to prevent re-contamination during storage.
e) Faecal Coliform concentration was determined as an indicator of microbiological contamination in storage tanks.
f) Bacteriological quality analyzes were performed in aerosols from sprinkler irrigation. In order to identify the microorganisms during the sprinkler irrigation, a monitoring of the aerosols (five samples) was done using an Andersen equipment. (figure 2).

Figure 2 Air monitoring during sprinkler irrigation.

Analysis of hazards and critical control points.

a) A hazardous event is an incident or situation that can lead to the presence of a hazard. In this context, the possible situations that may arise in each system stage were analyzed.
b) To identify threats and weak links in the system, critical control points (physical and operative conditions; and water quality), were established. A hazard is any biological, chemical, physical or radiological agent that has the potential to cause harm. In this case study, biological agents represent the main hazard to human health.

Corrective actions.

a) After having identified the critical points, actions were prioritized to implement the control measures.
b) Failures in the treated wastewater distribution system were attended, through the development and implementation of an improvement and maintenance plan.

Surveillance by implementing a monitoring plan.

a) From the obtained results, the team is developing a proposal to establish a continuous program of monitoring and control for the treated wastewater management in University City.

Document and record.

a) Changes in the wastewater treatment must be were documented.
b) It is essential to demonstrate compliance with environmental regulation, therefore a continuous program was carried out to monitor, control and record water quality data in the WWTP effluent, storage tanks and sprinklers.
c) The IOA “(DGOyC)” must document hazardous events, so as to develop control measures.

With the development of this plan, the four-barrier implementation strategy of control was defined.

Results and Discussion.

Identify roles and responsibilities.

The IOA involved in day-to-day operators (treatment plant operator, water quality analysis experts, plumbers, etc). They are the responsible people for the treatment, management and distribution of treated wastewater in University City. The IOA is in charge of the negotiations with local authorities in order to implement any necessary changes and new projects to execute. Local authorities authorize the budget for corrective and preventive maintenance of the treated wastewater infrastructure.

Assemble the working team.

The team met to implement the WWSP for purposes of reuse, mainly consists of the following actors: local university authorities, IOA involved in day-to-day operations and scientific experts in various disciplines with extensive experience in the field of wastewater treatment and reuse. Experts evaluating the physical and operative conditions of WWTP, and senior researchers such as hydraulic engineers, chemical engineers, biologists, communication experts and other disciplines, integrated a sub-team which is leading the proposal to implement the WWSP. Figure 3 shows the flow chart which shows the interrelations among the actors involved.

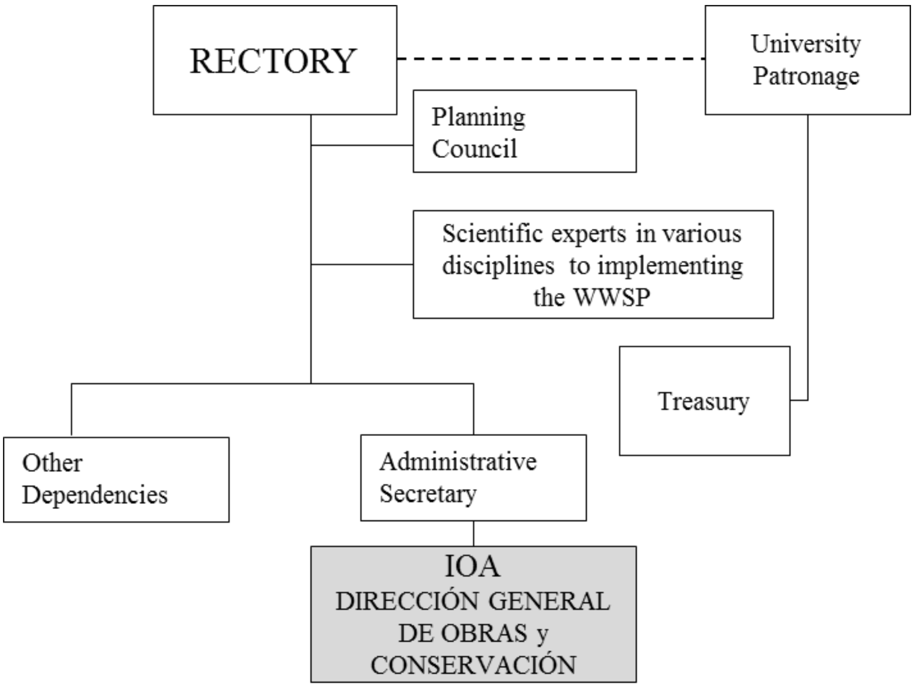

Figure 3 Actors involved in the work team met to implement the WWSP.

Compilation of historical documentation.

The compilation of historical documentation about the location of the WWTP and type of treatment was collected. To document the situation of the treated wastewater management, information from internal sources was requested. The collection of historical data gathered 19 bachelor and master degree thesis from 1989 to date. Three theses published in the last four years, developed subjects closely related to this document (García, 2009; Silva, 2009; Vargas, 2010). The theses provided information regarding either the characterization or the treatment of University City wastewater.

The conclusive results obtained from a rigorous analysis of the information from last ten years concerning WWTP water quality brought out significant changes from 2001 to 2008: BOD_5 duplicated its value and COD increased 1.5 times from 2006 to 2008 compared to the period from 2001 to 2005, and the TSS concentration increased gradually from 50 to 200 mg/L (2001-2008). The data analysis showed that treated wastewater used in public services with direct human contact did not accomplish the regulations until 2008. It is worth mentioning that in its beginning, the WWTP had an educational purpose, meant to help students with their career practical aspects. Nevertheless, bearing the water scarcity crisis, UNAM has been reusing its own treated wastewater. This entails the implementation of a project for the safe management of treated wastewater, as the proposed in this document.

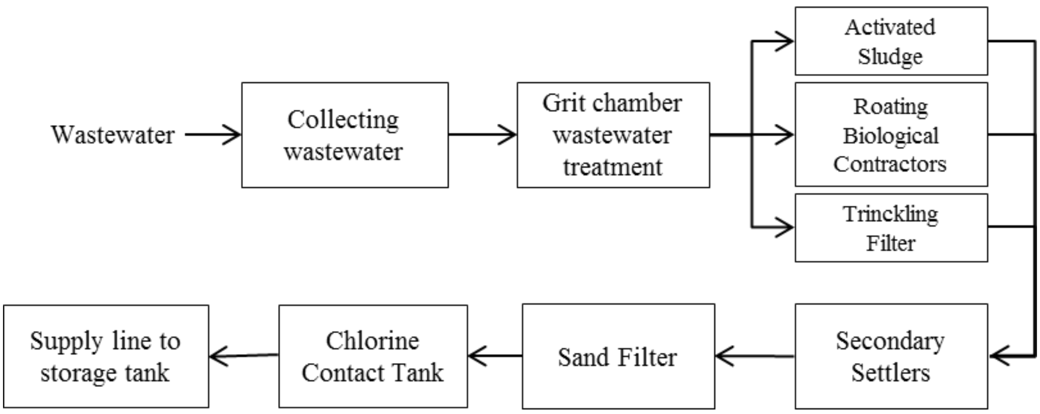

Figure 4 Description of the wastewater treatment system until 2011.

The applicable regulation is the "Norma Oficial Mexicana, NOM-003-SEMARNAT-1997" which establishes the maximum contaminant limits for treated wastewater for reuse in public services (Table 1).

Table 1 Maximum contaminant limits for treated wastewater for reuse in public services.

	MONTHLY AVERAGE				
Type of reuse	**Faecal Coliforms MPN/100 mL**	**Helmint eggs (h/L)**	**Fat and Oil mg/L**	**BOD_5 mg/L**	**TSS mg/L**
[a] Public services with direct contact	240	< 1	15	20	20
[b] Public services with casual or indirect contact	1,000	< 5	15	30	30

[a] Public services with direct contact, it involves activities where the public user is exposed to direct or physical contact, filling lakes and canals with recreational boating, rowing, canoeing and skiing, ornamental fountains, washing vehicles, watering parks and gardens.
[b] Public services with casual or indirect contact, it involves activities where the public user is exposed indirectly or incidentally to physical contact and access to water is restricted, either by physical barriers or security personnel: irrigation of gardens and highway medians, medians in streets, ornamental fountains, golf courses, fire systems, artificial lakes (not leisure), hydraulic barriers and security vaults.

Description and evaluation of the distribution system of treated wastewater.

After reviewing historical documents, later in 2010, a review of the distribution system of treated wastewater was carried out and a representative flow diagram was developed (Figure 5). The treated wastewater from the WWTP is pumped to thirteen storage tanks where it is reused in green areas irrigation.

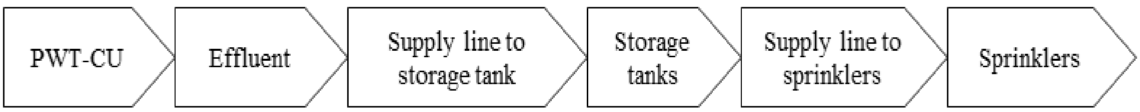

Figure 5 Distribution system of treated wastewater.

A research team composed of scientists from the Institute of Engineering of the UNAM, with extensive experience in the field of wastewater treatment, evaluated the physical and operative conditions of the WWTP and determined that: the plant was not operating at its design capacity, unitary operations were not in good physical conditions and therefore they were not properly operating.

In 2010 analyses of the effluent water quality were carried out: Faecal Coliforms, Helmint eggs, BOD_5, COD and TSS. The results allowed the comparison between historical data and analyses performed in 2010, therefore, it was corroborated that the wastewater treated in the WWTP did not accomplish local regulations regarding reusage.

Table 2 WWTP effluent water quality (campus University city, 2010).

	Faecal Coliforms MPN/100 mL	**Helmint eggs (h/L)**	**Fat and Oil mg/L**	**BOD_5 mg/L**	**TSS mg/L**
WWTP-University City-UNAM	$3X10^6$	4	ND	11	25
NOM-003-SEMARNAT-1997					
Public services with direct contact	240	< 1	15	20	20

Results are a 12 determinations average performed during the first semester of 2010.
ND: not determined.

According to the physical and operative evaluation of the WWTP, the expert researchers team prepared a proposal to improve the treatment system. The project was developed in 2011 and its description as well as the corrective actions are described in this document.

The physical conditions of storage tanks for treated wastewater were evaluated. In 2010, a diagnosis of the physical conditions of the storage tanks, as well as the quality of the water stored inside. Thirteen tanks were selected seven of them are always filled with potable water, while the other eight tanks are filled with treated wastewater from the WWTP. The inspections showed that most of the storage tanks were in bad conditions and had leaks in the walls. Maintenance is given once a year and only sediments are removed and walls and floors are washed.

The quality of the water stored in the tanks was evaluated for seven months, from May to November 2010. Figure 6 shows the results of the parameters considered in mexican regulation. Nevertheless, table 3 shows all the measured parameters. It is worth to remember that the water stored in these tanks is reused in green areas irrigation which are used as recreational areas by alumni and visitors.

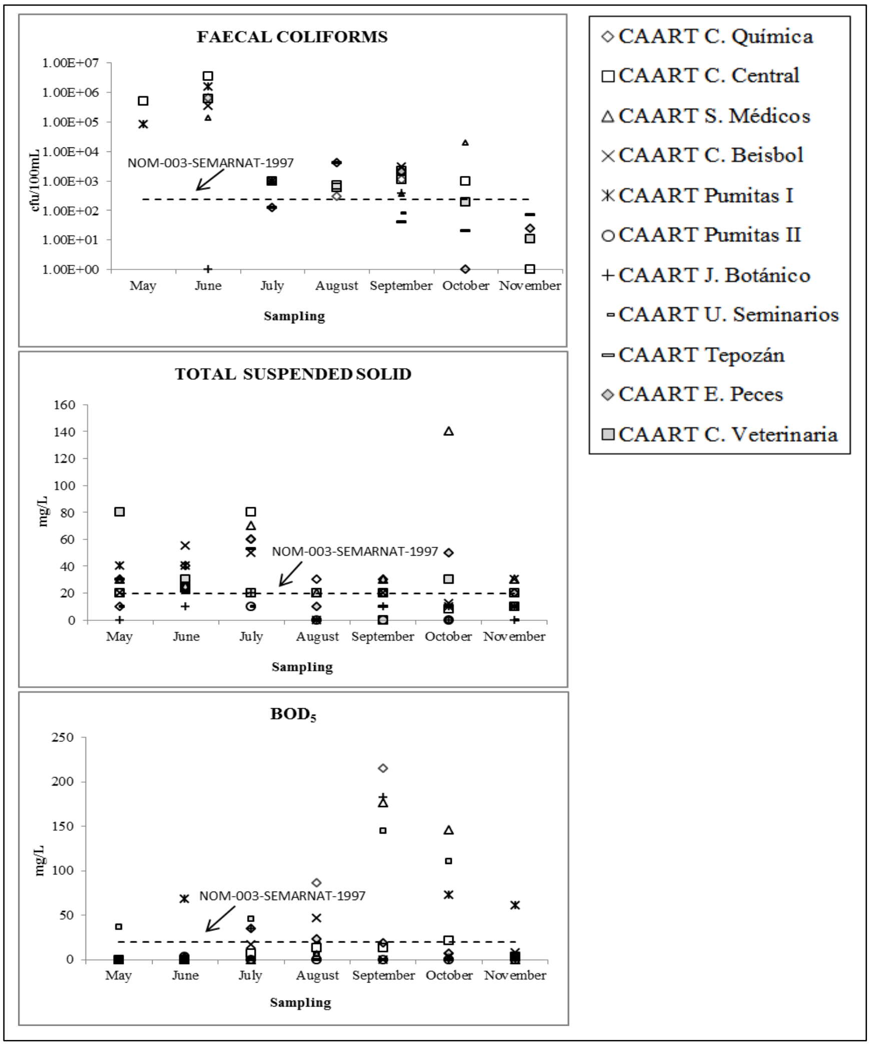

Figure 6 Water quality in storage tanks of treated wastewater (may-november, 2010) according to NOM-003-SEMARNAT-1997.

Table 3 Water quality in storage tanks of treated wastewater may-november, 2010.

STORAGE TANKS	Temperature (°C)	pH	Conductivity (mS/cm)	TSD mg/L	TSS mg/L	COD mg/L	BOD mg/L	Total Coliforms CFU/100 mL	Faecal Coliforms CFU/100 mL
Química	18.59	7.64	0.8561	429.67	25.56	66.89	12.68	1.72E+06	3.26E+05
Central	19.77	7.55	0.8987	451.22	25.33	81.34	32.70	1.75E+06	4.09E+05
Servicios Médicos	21.36	7.70	0.9002	451.78	31.25	65.89	30.36	3.10E+05	1.75E+05
Beisbol	18.56	7.60	0.7947	399.22	28.00	55.96	30.47	5.46E+05	4.01E+05
Pumitas I	19.53	6.22	0.6745	339.17	26.67	50.18	39.57	9.05E+05	8.50E+04
Pumitas II	18.76	6.31	0.4283	215.13	12.50	.19	5.50	5.01E+04	<1
Botánico	17.60	6.45	0.4103	205.56	6.67	.10	7.44	1.57E+03	6.85E+02
Unidad de Seminarios	17.08	6.43	0.4030	202.33	10.00	.15	8.53	<1	8.00E+01
Tepozán	18.36	6.83	0.3917	197.67	18.22	1.53	7.23	2.14E+04	4.82E+01
Peces	17.49	8.17	0.3714	186.67	28.89	25.37	12.09	1.01E+05	2.43E+03
Veterinaria	20.08	7.54	0.9282	480.89	33.11	69.39	52.34	1.33E+05	2.46E+04
Promedio	18.81	7.17	0.6428	324.22	25.34	45.12	21.23	6.76E+05	1.75E+05

Results are a seven determinations average.

On the other hand, a rigorous analysis of the irrigation system was performed and it was observed that: in University City, green areas are an important extension of the campus, it is nearly 200 hectares, which are irrigated approximately for nine months (September-June). Besides of the current irrigation policies, there are certain deficiencies in the irrigation system design, caused by the misallocation of the sprinklers, resulting in a wrong water management due to the overlapping of the action radius.

Considering that airborne microorganisms and other biological particles must concern authorities, as they can cause public health hazards (Pascual, 2003). The bacteriological quality in aerosols from sprinkler irrigation was determined. In this study, we found 8 species reported as potentially pathogenic bacteria: *Staphylococcus sp, Bacillus sp, Pseudomonas sp, Pseudomonas aeruginosa, Enterobacter agglomerans, Vibrio damsela, Vibrio fluvialis and Aeromonas hydrophila*.

Additionally, a bacteriological analysis was performed to the green areas irrigated with treated wastewater. The presence of Total Coliform and Fecal Coliform in the order of 1000,000 CFU/g (Colony Forming Units in one gram of sample analyzed) were detected and in presumptive tests for bacteria, potentially pathogenic in the order of 100,000 CFU/g, such as *Salmonella, Shigella* and *Staphylococcus w*ere detected.

Analysis of dangers and critical control points.

According to WSP-WHO 2005, to determine the critical control point, the following factors of influence were considered: wastewater treatment processes, reception and storing practices, accidental or deliberated contamination, distribution system maintenance and protection practices, and variations due to weather.

Through the evaluation of the distribution system, it was possible to identify the wastewater treatment process as a critical control point. This factor considers: the plant localization, the need of roofed installations in order to prevent any risk to the nearby population, the correct performance and the accomplishment of mexican regulation regarding to water quality for direct contact public service. Therefore, if an emergency appears at this point, the irrigation could be stopped immediately and if possible, irrigate the green areas with tanker water, in order to prevent polluted water filtration to the aquifers. The treated wastewater reception and storing practices is another critical control point, which considers the monitoring of the physical condition of the storage tanks, preventing the accidental or deliberated contamination; as well as watching water quality and avoiding bacterial re-growing. The last critical point is the monitoring of the bacteriological quality of water in the sprinklers. An estimation could be done by a correlation of the absorbance value. The absorbance measure or optical density indirectly shows the number of bacteria.

Corrective actions.

Actions were prioritized in order to respond to failures in the treated wastewater distribution system. The first corrective action was to implement new technology to improve the wastewater treatment system. As a result of the evaluation of the WWTP, the diagnosis leaded university authorities to implement a renovation project for wastewater treatment using state of the art technology including an ultrafiltration process. The new technology is shown in Figure 7.

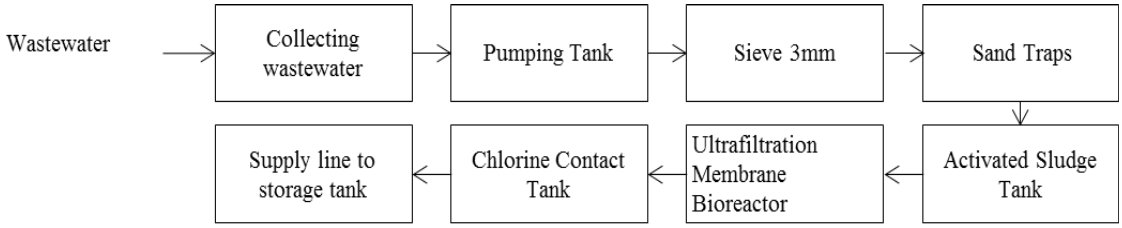

Figure 7 New technology implemented in 2011 to improve the wastewater treatment system in University City-UNAM.

In December 2011, the renovation work on the wastewater treatment plant was concluded. From February to June 2012, monthly monitoring of the WWTP effluent was performed (Table 4). After the installation of the new technology, the results of the water quality accomplish mexican regulation regarding direct contact public service (NOM-003-SEMARNAT-1997). Further monitoring is suggested.

Table 4 WWTP effluent water quality (campus University city, 2012), after execution of the renovation project.

	Faecal Coliforms MPN/100 mL	**Helmint eggs (h/L)**	**Fat and Oil mg/L**	**BOD_5 mg/L**	**TSS mg/L**
WWTP-University City-UNAM	0	ND	ND	13	7
NOM-003-SEMARNAT-1997 Public services with direct contact	240	< 1	15	20	20

Results correspond to the last performed analysis (May, 2012)
ND: not determined

Another failure in the treated wastewater distribution system that is currently being attended is the repairs on the storage tanks so that the quality of the water stored in the tanks preserves the same quality as the one analyzed from the effluent, avoiding microorganisms' growth. As the completion of the executive project for the wastewater treatment improvement is very recent, two samplings of the water quality on the storage tanks have been performed. In these samples, bacterial colonies have been detected, yet, the species have not been identified. More samplings including parameters from NOM-003-SEMARNAT-1997 are needed, so, if needed, good practices on protection are suggested to competent authorities and the OIA in order to prevent accidental or deliberated contamination. This will promote the correct management of the tanks and the optimization of the investment on the treatment plants, which product is the water stored and distributed by the tanks.

The third proposed action for the correct management of the treated wastewater was the optimization of the irrigation by installing an automatic system with fast coupling valves and changing the vegetation for low water consuming species. This will allow a higher irrigation efficiency and substantial improvements on water and energy savings.

Surveillance by implementing a monitoring plan.

Although there are already established maintenance programs, they need to be improved to attend the deficiencies detected in the wastewater distribution system. Nowadays, a proposal to establish a continuous program of monitoring and control to the management of treated wastewater in the University City-UNAM is being developed. This proposal includes monitoring water quality in different spots: the effluent from the treatment plant, the storage tanks of treated wastewater and aerosols from sprinkler irrigation. Besides, a more rigorous maintenance and control program is proposed to the involved actors, it includes the corrective maintenance in the established critical points.

According to WSP-WHO 2005, monitoring plans should include the following information: parameters to be monitored, sampling location and frequency, sampling needs and equipment, schedules for sampling, methods for quality assurance and validation of the sampling results, requirements for checking and interpreting the results, requirements for documentation and management of records, including how monitoring results will be recorded and stored as well as requirements for reporting and communication of results.

Document and record.

Documentation and records systems should be kept as simple and focused as possible. The level of detail in the documentation of procedures should be sufficient to provide assurance of operational control when coupled with a suitably qualified and competent operator. In this process it's necesary to document situations such as: Changes in the wastewater treatment process. It is essential to demonstrate compliance with environmental regulations, therefore a continuous program of monitoring, control must be carried out and water quality data in the WWTP effluent, storage tanks and sprinklers must be recorded. As well as IOA must document hazardous events, with the aim of carrying out control measures.

We developed a flow chart that includes the development of the eight components as guidance for implementing the WWSP (Figure 9).

With the development of these components, the implementation strategy of essential barriers of control was defined. The proposal includes four essential barriers of control: the first barrier refers to the evaluation wastewater treatment process; the second barrier included a continuous monitoring program of treated wastewater (effluent) quality; barrier three, continuous checking of the conditions of storage and distribution of treated wastewater, as well as the quality of stored water; finally barrier four included, constant monitoring of bacteriological quality in aerosols from sprinkler irrigation.

Conclusion

The World Health Organization (WHO) guidelines for Water Safety Plans (WSPs) are based on the human health risk assessment of the drinking water supply system (Davison et al., 2005). However, due to the requirements of wastewater reuse management, it is important to develop projects similar to WSPs, but focused on the reuse of treated wastewater, which can be applied in the future in other places with similar elements. The existence of guidelines and WWSP contributes to a sustainable development of landscape irrigation which may promote a decrease in health risk, taking into account important specific local conditions, such as the quality required for reclaimed wastewater according to its use. The WWSP provides the potential for significant environmental, social and economic benefits that should lead to savings in the development of water reuse projects by means of scientific bases for standards and guidelines.

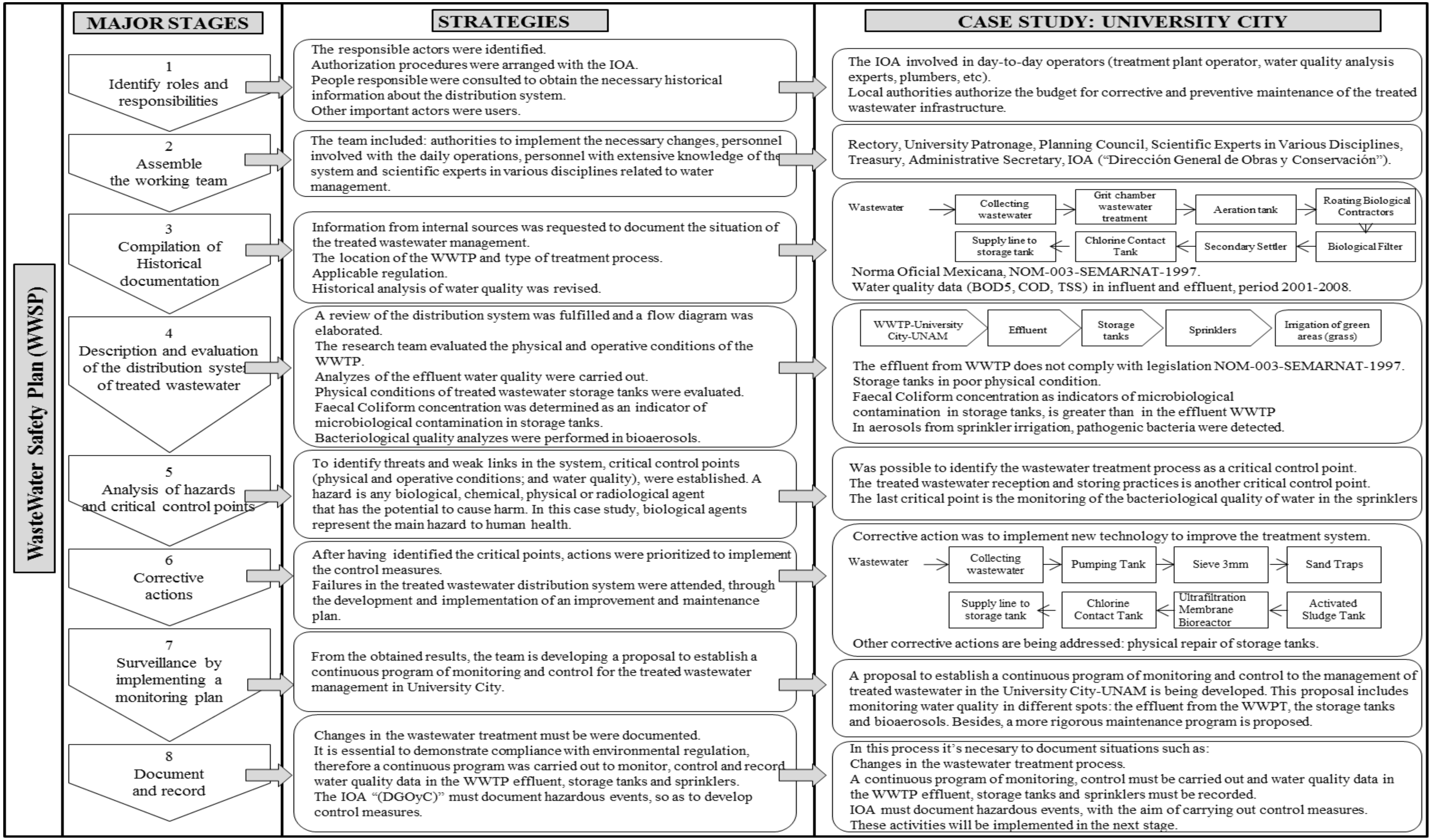

Figure 9 Flow chart that includes the development of the eight components for implementing the WWSP, case study: University City.

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