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Article

Golf Course Irrigation with Reclaimed Water in the Mediterranean: A Risk Management Matter

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Abstract: Controversy regarding the amount of water consumed or saved as a result of human activity is currently paramount in water-scarce areas. In recent decades, golf—a land and water consuming activity—has been implanted in several areas of the Mediterranean basin, where the scarcity of water resources is well-known. As a result, the use of conventional water resources for golf course irrigation is increasingly contested and its replacement by reclaimed water has become essential. This paper examines the wide range of issues involved in its use on golf courses, including hazards—due to the presence of microorganisms and pollutants—and the corresponding risks that can appear. The resulting biological, chemical and physical water quality concerns are analyzed. Legal aspects related to the use of reclaimed water are also discussed and good reuse practices are suggested, including a detailed examination of risk assessment procedures and tools through observation or chemical, physical and microbiological analysis. The HACCP system—which focuses on quality determination in water samples from relevant control points—is described in detail, as it is generally accepted as one of the most scientific ways to detect health problems on a golf course. The paper concludes that, given the increasing availability of treated and reclaimed water and the water needs of golf courses, the future development of the sport in areas without surplus water resources—such as the Mediterranean basin—will predictably depend upon the use of reclaimed water. In recent years, risk assessment or analysis has emerged as an essential tool to guarantee the application of reclaimed water at an acceptable risk level. There certainly have been considerable advances and improvements in the tools that guarantee the safe use of reclaimed water, although current methods available require simplification for their practical application. Nevertheless, protocols applied at present seem to be adequate in order to address the key issue of enhancing the development of reclaimed water use on golf courses.

Keywords: golf; golf courses; reclaimed water; reclamation; reuse; wastewater

1. Introduction

Controversy in terms of the amount of water consumed or saved as a result of human activity is currently paramount in water-scarce areas. In recent years, the concept of water footprint fueled this controversy; in fact, the Water Footprint Manual [1] indicates that human activities consume or pollute a lot of water. The manual adds that at a global scale, agricultural production generates most water use, but that a substantial volume of water is also consumed and polluted in the industrial and domestic sectors [2]. Water consumption and pollution are associated with specific activities, such as irrigation, bathing, washing, cleaning, cooling and processing. Total water consumption and pollution are generally regarded as the sum of a multitude of independent water demanding and polluting activities [1]. Nevertheless, a distinction should be made on the issue of the actual extraction of water from the natural cycle, because several activities just use the passage of water through facilities (e.g., hydroelectric production) while others divert water from its natural source (rivers, aquifers…) and use it mainly without return to surface waters (e.g., agriculture).

Apart from agriculture, there are other irrigation activities or water-related services to human society in developed and underdeveloped countries that supply leisure and tourism activities and are creating or increasing water demand. These include: hotels with green areas; swimming pools; spas; golf resorts; and theme parks based on the exploitation of ideas related to the cinema, comic characters, *etc.*, that often partly rely on extensive water surfaces. Certainly, there is an increasing need for water for leisure demands in general and tourism activities in particular for both national and international users.

Golf courses and theme parks are dependent upon the availability and use of a certain amount of water [3]. Theoretically this water has a cost that must be accounted for at a defined price and included in the economic viability calculations of the facility. Given that the water footprint (WF) concept, introduced by Hoekstra in 2002 [4], is an indicator of freshwater use that includes not only direct, but also indirect, water use by a consumer or producer, WF can be regarded as a comprehensive indicator of freshwater resources appropriation, preferable to the traditional and restricted measure of water extraction. Thus, the WF of a product is the volume of freshwater used to produce the product, measured over the entire supply chain.

Golf courses and theme parks constructed in arid and semiarid areas are man-made ecosystems that extract a certain amount of water from existing sources; at a first glance, their sustainability is generally considered highly doubtful. This argument has been sustained by several environmental groups that launched campaigns against such facilities, based on their negative environmental impacts, especially with regard to water resources. However, when the actual water use and consumption of such facilities is compared with several agricultural crops, bearing in mind revenues and the real impact of its water use, there is not such a difference. Nevertheless, as one of the most rapidly expanding types of extensive land-use, golf course development has often generated controversy. Golf courses require a considerable amount of open surface and potential wildlife habitat because the average 18-hole golf course covers about 54 ha of land. Moreover, potential problems associated with golf course construction and maintenance include soil erosion and pollution; surface and groundwater depletion; *etc.* As a result, in recent years there has been a considerable demand for golf courses to adopt environmentally sustainable strategies in design, construction, and management. Golf courses are therefore infrastructures that, from an environmental or agronomic perspective, must be managed as if they were crop surfaces where plants suffer permanent stress. Universities, research institutes, golf organizations, and environmental associations such as the National Audubon Society are joining forces in research for ways to make golf courses more environmentally compatible. Naturally landscaped courses are growing in popularity and the golfing community is sensitive to aesthetic and environmental concerns. Many of these more natural courses retain native vegetation, land forms, soils and typical habitat units [5].

In any case, nowadays golf cannot be considered simply a sport, because it involves very important economic interests. For example, as long ago as 1993 the Tourism Authority of Catalonia (Spain) proposed golf development as a policy to promote special-interest tourism [5] and golf now produces an economic impact of almost 20 million euro per year in Catalonia. From this point of view, Spain is the second attraction pole for golf in Europe, with the Balearic Islands, Costa del Sol and Catalonia as the main destinations. Portugal is also an important attraction pole in the Mediterranean area [6]; while Italy and Greece are entering this market and some countries on the southern shores of the Mediterranean are also starting to invest heavily in the business.

1.1. The Sport of Golf

From a social viewpoint, golf courses in the Mediterranean have been considered facilities for an elite group who practice a minority sport and use resources—especially water and land—in a sumptuary way. This has pressed golf course managers to reduce water consumption as an ecological and social strategy, but also to mitigate the increasing cost of water [7]. Water consumption on a golf course depends on its dimension, local climate, water retention properties of substrata and water requirements of turf and can therefore vary from zero (in rainy seasons) to 2,500 m^3/per day in a dry, hot season. Average water consumption on a standard 18 hole golf course (with an irrigated surface of 54 ha) can be estimated at around 0.3 Hm^3 per year. At the same time, water authorities in several countries are enforcing by law the irrigation of golf courses with alternative water resources, mainly reclaimed water.

On the contrary, in many northern European countries golf is a traditional and popular activity with somewhat reduced costs and water needs in comparison with the Mediterranean countries, and golfers belong to a wide range of socio-economic groups. Nevertheless, this sport created the necessary conditions for the economic development of several areas on the Mediterranean shores, especially southern Spain and Portugal. Such places have been defined as golf destinations, which imply several advantages from the point of view of sport-related tourism. However, the transfer of traditions from temperate, humid northern countries to the hot, dry Mediterranean coasts has caused certain imbalances. On a number of golf courses environmental aspects have not been managed in a professional manner, with excessive reliance on chemicals to maintain the turf, instead of the implementing of tools derived from a sound knowledge of the grass/soil-substrata/water ecosystem that is just like an agronomic field. In fact, a golf course can produce a low negative environmental impact if well managed. The techniques of good practices include a correct control of salts accumulated in the soil, suitable application of fertilizers and pesticides, effective irrigation avoiding run-off, and effective management of turfgrass. The peculiar agronomical/ecological characteristics of a golf course, its need for water and the lack of water resources in southern Europe and northern Africa have led to the use of reclaimed wastewater for course irrigation. However, with the exception of Spain, there are no rules and regulations for water reuse on golf courses, although agricultural reuse regulations are sometimes applied, which leads to management problems.

In fact, golf courses are seldom evaluated for their positive ecological values, as in the present case in which they constitute a safe place to incorporate reclaimed water into the environment. It is therefore necessary to develop more comprehensive studies on the impacts of golf courses. In fact, the impacts of a golf course can be many and varied, but the most significant are those affecting vegetation, soils, landscape, and the socio-economic environment. These impacts can be either positive or negative, mainly depending in each case on the state of conservation or degradation of the zone, as well as on the social system. The fundamentals of effective environmental management for golf courses focus on the concept of environmental management systems. There are well-developed tools that allow companies and organizations to develop suitable policies, procedures and measures for the integration of environmental practices in their daily routine. Two environmental management systems have been developed [8] as standards for the industry: ISO-14001 [9] and EMAS [10].

1.2. Golf Courses

The basic idea subjacent to the game of golf is that the golfer is playing (or struggling) against the course. Consequently, the course should be built considering the potential player. As a result, the design of each course will be more or less exacting, which in turn is reflected in the presence or absence of open water, the type of grass used on fairways and greens and the operation and maintenance of the entire course and its surrounding areas. The "minimal" requirements are those pertaining to courses located in tourist areas, where the interest of the owners is usually to obtain maximum benefits from the infrastructure. In this case, fairways are generally wide and rough is reduced, to avoid players wasting time searching for balls. The "top" requirements are on courses that aspire to host important championships, and hence are more difficult, in order to create additional problems for professional players. The fairways are narrow, the rough is high and thick and there are numerous hazards (including water). On most golf courses additional playing surfaces and areas for different purposes surround the actual course to support players (practice grounds, clubhouse, car-park ...). There are also unused areas, where wildlife can be preserved. Water consumption for the correct maintenance of the course differs greatly, depending on the type of features included. Nevertheless, all courses share common structures, some for playing and others as support elements of the whole infrastructure. A definition of the "soft" parts of the system (*i.e.*, the playable surfaces) is provided in Table 1 and the features of the non-playable components are summarized in Table 2 and Figure 1.

Golf course design is an important factor for water management. Design has changed a lot from the early days of this sport, when it was practiced by shepherds in Scotland or in what is now known as the Netherlands. Nowadays, there are large golf infrastructures that can manage more than 1000 players per day. In the early days, designers adapted each course to the existing landscape characteristics. Nowadays, however, it is common to wholly level the area and then reshape it, as the powerful machinery now available makes it feasible to build courses this way. Hence, courses are losing individual personality and adaptation to the existing features and, as a consequence, the management of runoff—natural or due to irrigation—becomes difficult and problems are created. It can be asserted that these features change the usual water patterns of the area in question, creating an artificial small catchment area where water has to be managed differently.

Table 1. Sport related components of a golf course (modified from [11]).

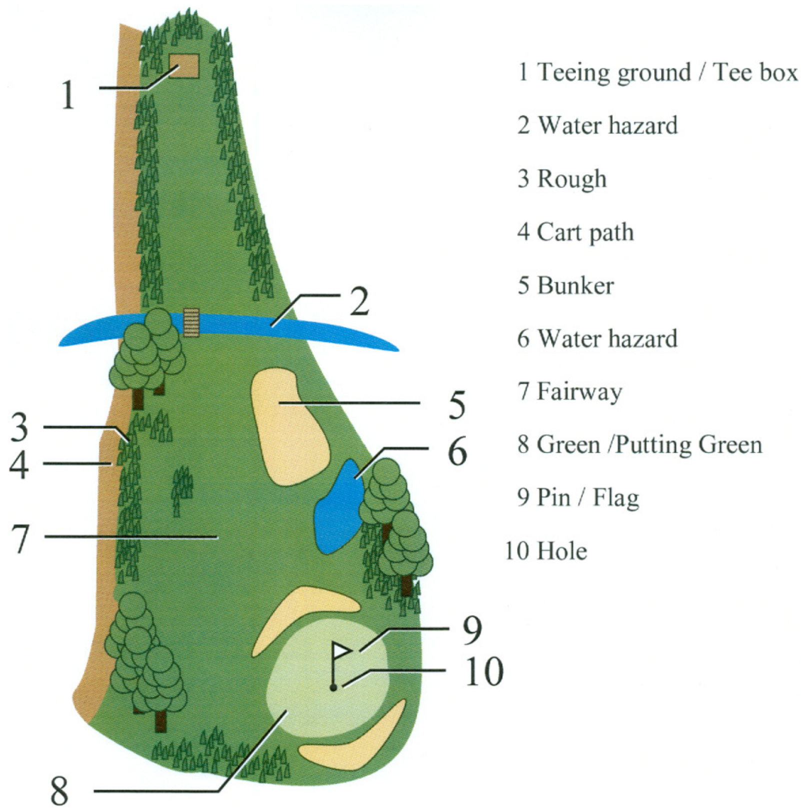
Component	Definition/Characteristics	Observations
Teeing ground or tee box	Starting place for each hole	The grass suffers from continuous uprooting. The tee off position (starting line) has to be moved frequently
Fairway	Closely mown area between the tee box and putting green of each hole	The fairway height depends on the type of grass in use, soil conditions, local climate, player expectations and course budgets (maintaining lower fairway heights is more costly)
Collar	Ring of grass around the putting green that is cut slightly higher than the turf on the putting green itself	Not always present
Putting green	The (putting) green is the culmination of a hole, where the hole and flagstick are located	The green has the shortest turfgrass on a course - and the smoothest surface
Rough	Areas on a golf course beyond the fairways that generally feature taller, thicker grass or natural (un-kept and un-mown) vegetation	Designed to be punitive to players who miss the fairways and often also found around bunkers and greens. It can vary in height and thickness
Water hazard	A pond, lake, river, sea, drainage ditch or any other open water on the course	Require specific maintenance to avoid eutrophication. Sometimes used to store water or provide additional treatment for reclaimed water
Bunker	A golf course hazard that is a hole or depression in the ground partly filled with sand (or a similar material). Bunkers vary greatly in size, shape and depth	Usually drained and must be protected from clay or silt entering through runoff or wind
Driving range and practice putting green	Area where golfers can practice their swing and putting skills	Maintained like a fairway or a putting green respectively

Table 2. Components of a golf course not directly related to the sport.

Component	Characteristics	Observations
Cart paths	The designated route around a golf course, that golf carts are expected to follow	Usually tar or concrete-paved, although some are more rudimentary soft- surface paths
Clubhouse	The main building at a golf course containing a reception area the pro shop, and usually a food and drink service	Additional services may include a meeting room, bar, lounge, or locker rooms. Not every golf course has a clubhouse, although most do and these vary in size, service range and luxury.
Gardens	Usually maintained by the club around the clubhouse, car-parks and other facilities	If reclaimed water is used for watering, it requires special management
Swimming pool	Additional optional service	Depending on the pool's location, it may be necessary to control that irrigation water does not enter the pool
Additional areas and services	In resorts and some private clubs: tennis, paddle tennis, swimming pools, *etc.*	Can be managed by the golf course maintenance system. If there is grass or gardens, water can be provided from course resources
Maintenance facilities	The maintenance department is responsible for irrigation, mowing, fertilization, pesticide application and general upkeep of the golf course grounds	The maintenance area is where pesticides are loaded into application equipment, mowers and other pieces of equipment are serviced, and pesticides, fuel, fertilizers and cleaning solvents are stored. This is where pollution of soil, surface water, or ground water is most likely to occur
Irrigation system	System devoted to facilitate the water needed by the soil-plant-atmosphere continuum of a golf course	Ranges from simple water sprinklers to sophisticated, computer-programmed management systems that comprehend fertilization (fertigation)
Hotels, resorts and residential areas	Lodging and residential facilities owned by same proprietor	Gardens can be managed by the club maintenance system. Problems associated with the use of reclaimed water must be taken into consideration
Car-parks	For club members and other players	Run-off management is required. Recovered water can be used for irrigation
Areas beyond the course	Natural areas, boundaries, perimeter areas, buffer zones, *etc.*	The golf course can exert an impact on them and vice-versa
On-course facilities	Bar, toilets, ball washing devices, *etc.*	Waste, tap water, wastewater have to be managed

The entire management of the course is performed by superintendents who must be capable of managing everything within the area, from water to waste, including chemicals, fertilizers, grass, wildlife, *etc.* From a legal point of view, it should be noted that in several countries (e.g., Portugal, Catalonia) the corresponding public administration bodies have attempted to limit the number of golf courses, and determine their type and management systems with respect to the amount of water and land resources employed, but have not met with much success. On the basis of the evidence, however, it is important to establish exactly how the change of water supply from conventional to reclaimed will make changes in the operation and management of courses necessary. Certainly, this should be done with all due consideration to social, economic, environmental and playability points of view.

Figure 1. Golf course components.



1.3. The Golf Course as an Ecosystem

All ecosystems consist of two differentiated, interacting parts: the biocoenosis (a "living" component) and the biotope or physical substrata where life is based. There are two main biotopes in landscapes: aquatic elements (streams and lakes) and solid elements (soil and subsoil), between which several relationships are established. On a golf course, the biocoenosis consists of different species of grass (turfgrass), selected according to situation and adjacent vegetation, together with grass-related flora and fauna that can constitute beneficial organisms or, alternatively, plagues. Natural plant species and wildlife also thrive in gardens, rough and wilderness surrounding the facility, while external vegetation and animals—in search of food—can easily colonize the course. This dependency exerts an influence on course operation and maintenance, due to the fact that some animals (birds, rabbits, boars...) forage or excrete on the premises (the most annoying are digging animals), while others actually live there as "parasites" (worms, insects...).

Golf courses are in many ways like agricultural fields, as they both constitute a soil/plant/atmosphere continuum linked by the water needed for the plants to grow. One important difference, however, is that the second generates a marketable agricultural product to be consumed after retrieval, while, in the case of golf courses, the product is "consumed" where it is produced. It is hence important for the grass (turfgrass) to show good resilience to use and spoiled surfaces require immediate replacement. On the other hand, fast growing grass has the inconvenience of constantly needing mowing, so a certain balance should be struck. As a result, the periodicity of mowing and the degree of resilience vary in accordance with seasonal and general climatic conditions, the intensity of use of the turf and cultural practices.

Since a golf course's grass system operates in the classical way of every plant, *i.e.*, evaporating water, the intensive use of a golf ecosystem should theoretically provoke more evapotranspiration than an equal extension devoted to a different type of crop. In practice this is not true for several reasons: other crops with a greater foliar surface evaporate more water; the complete covering with turfgrass protects the soil; and the frequent formation of hydrophobic layers between the grass and the soil reduces or even impedes water percolation. The need to force the grass crop on sometimes generates water excess in part of the system, especially in hollows on fairways, in bunkers and in the lower layers of greens. This generates the need to incorporate a good drainage system, capable of evacuating excess rain or irrigation water, as well as the water needed to reduce salinity in the bottom layers of grass, in the root zone.

The substrata employed on greens and fairways differ. Greens are built according to instructions clearly defined by the United States Golf Association (USGA) [12], and include drainage, since the soil texture is sandy. Fairway grass can be grown in the existing soil with minor adjustments unless the shape of the terrain has been heavily modified. Due to intense fertilization and chemical application on both greens and fairways, drainage water can be contaminated with nutrients and chemicals, which then requires management of course runoff. "Secondary" vegetation, *i.e.*, trees, shrubs and plants in the gardens around the course, has to be grown in an adequate substrate or soil and also requires irrigation. Natural vegetation requires no soil change, but exotic species may have different soil requirements. Concern about this kind of additional vegetation has increased, leading to the introduction of the xeriscape concept on golf courses in arid and semiarid areas and a resultant reduction of water consumption [13].

2. Water on Golf Courses

As already indicated, due to the scarcity of water in Mediterranean regions and other areas with similar or even more arid climates, the use of conventional water resources for what are considered luxury purposes—such as golf courses—is increasingly contested. Therefore, non-conventional water sources, such as reclaimed water, are playing an increasing role in the planning and development of water supplies for several types of activity.

The relationships between golf course ecosystems and the environment are extremely complex and need to be clearly and carefully identified because of the social pressures on and implications of this type of facility. The efficient management of water resources is a key element in accomplishing a proper environmental integration of golf courses. Water resource management on golf courses must be planned and implemented considering at least water resource conservation, reclaimed water use, irrigation efficiency, adapted non-invasive grasses, lake management and wise use of fertilizers and pesticides. The key points for good golf course management start with careful planning which, in relation with water, must include

- The identification of the water source(s) that will be used for watering all course facilities;

- The building of the playing areas according to water availability and the resource to be used (*i.e.*, reclaimed water);
- The establishment of cultural practices (management) specifically designed to use reclaimed water (*i.e.*, fertilization, pest management, soil maintenance, grass cutting ...).

Several new developments emphasize the theoretical water savings on golf courses, by relying on runoff recovery, reuse and irrigation reduction. Although the subjacent idea is correct, reality creates additional problems. A clearly negative example is the use of water bodies (usually lakes) within the course to recover any runoff coming from rain or irrigation in excess of needs. The practice consists in managing the resource in a way that no water in liquid form is lost to the facility. The build-up of pesticides, fertilizers and other chemicals, as well as pathogenic microorganisms can create problems for grass, ranging from eutrophication to toxicity affecting plants and wildlife. Again, good management practices are basic, consisting of implementing only sensible operations capable of maintaining the course and its hazards in satisfactory playing conditions. Lakes with an ugly appearance and generating unpleasant odors generally annoy players, although passers-by or occasional visitors will be less disturbed.

Water footprint is an expression that has gained great popularity since its appearance, due to its media impact. For this case, it can be defined as the total volume of water used to manage a golf course; and water use can be measured in terms of water evaporated/evapotranspirated and polluted per unit of time. However, it is important to indicate that the water footprint does not provide information on the positive and negative effects of the embedded water on local water resources, ecosystems and livelihoods. In this respect, golf courses are frequently accused of leaving an excessive water footprint and, hence, one of the main social concerns regarding golf courses is water consumption for the operation and maintenance of what is seen as a sumptuary activity that competes with other uses and has a negative impact on the environment.

As already indicated, the management of the water resources on a golf course is often conditioned by design and construction of the facility. The errors performed in these stages (e.g., construction of a bad drainage system) can cause severe long-term management problems. High water consumption does not necessarily imply healthy turf; in fact, in many cases it is just the opposite. Excess water can cause many diseases in turf, due directly to grass illnesses or lack of oxygen in the root area, in addition to favouring compaction and making play difficult. At the other extreme, a reduction of the amount of water used in an attempt to save resources, can lead to problems in the soil-salt management of the course. The need to perform regular water balances to evaluate the irrigation requirements of golf courses is justified by the fact that in semi-arid climates the grass on golf courses must be irrigated daily, at least during summer, and usually also in spring and autumn. Water demand in winter can be reduced to near zero, depending on the climate pattern of each specific site. Different methods are available to evaluate irrigation requirements; some use empirical formulae and other physical based equations, but the classical empirical method of applying water based on the criteria of the course manager is adequate in only a few cases. Nevertheless, it is important to bear in mind that all parts of a course do not need the same amount of water. Given the surface of the facility (usually more than 20 ha irrigated) and the different landscaping characteristics present, sector-specific management of the water applied is a basic requirement.

2.1. Available Water Resources

There are several strategies to obtain water for the irrigation of golf courses. As in conventional agricultural practices in arid climates, water can be obtained from nearby water courses or from underground aquifers. When water resources are not available near the application site, irrigation associations of farmers usually build canals or extraction systems for posterior water distribution. Depending on its location, a golf course can inherit—or even buy—rights from the previous agricultural property where the course is located. As already remarked another solution is the use of non-conventional resources, mainly runoff or reclaimed water in the case of golf courses. No matter what the origin of the water, the technology used in irrigation practices is almost always based on the use of sprinklers. There are, however, a few cases in which underground drip irrigation systems have been used on golf courses [14,15], with reportedly satisfactory results, for this method can be paramount in saving water [16]. Nevertheless, this practice has received criticism and irrigation system manufacturers stated several years ago that correct golf course management should employ only sprinklers. This leads to the question of irrigation efficiency, expressed mainly in terms of the concept of "more crop per drop". Apart from the turfgrass irrigation water, there are other uses of water on golf courses, as indicated on Table 3.

Table 3. Water employed on golf courses.

Specific use	Possible origins	Quality	Comments
Irrigation of the course Irrigation of gardens without public access Irrigation of areas with public access	Any: surface water, groundwater, drinking water, runoff, reclaimed water, desalinated water (brackish or sea)	If reclaimed, conforming to rules and regulations	Apart from health considerations, agricultural related factors should be considered
Resort and services: swimming pool & other facilities with direct human contact	Drinking water, surface water, groundwater	Conforming to tap water and bathing regulations. Disinfected if not drinking water	Should be kept separate from possible contact with reclaimed water
Turfgrass around swimming pools	Disinfected water (not containing chlorine)	Usually not indicated. Reclaimed water should not be used	Clear separation from the rest of the course
Cleaning (carts, clubs, balls...)	Natural water, tap water	Disinfected	Not recommended to use reclaimed water
Drinking & catering	Drinking water	As established by law	Care should be taken to avoid cross-connections
Dust control	Any, except if aerosols are applied		

2.2. Irrigation Efficiency

As stated before, the amount of water required for irrigating a golf course and the periodicity of irrigation depend logically on seasonal and consequently climatic variables (temperature, rain, relative air moisture and wind), but also to a great extent on the characteristics of the soil that serves as substrata. Sandy soils do not retain water to the same extent as muddy or clay soils. Infiltration is generally faster in coarse grain texture soils, so more water is lost through drainage and water must be applied more frequently. On the other hand, soil thickness is also important, for the thicker the soil, the higher its capacity to hold water. Additionally, a shallow impervious layer impedes turf roots from developing correctly and so these are much more susceptible to changes in weather. In such circumstances, anaerobic processes in the root zone are quite common. Consequently, it is especially important to know the soil's exact physical characteristics in each zone of the course with a view to the correct management of the water administered to the implanted turf. In order to calculate the volume and duration of water provision, it is necessary to determine soil depth and the rate at which water will infiltrate into the soil. Infiltration varies according to soil texture, structure, and existing moisture. In addition, the water infiltration rate is not constant but diminishes as the soil profile becomes moister. However, water retention by golf course substrata depends as much on texture as on the peat or organic matter contents [8].

On most golf courses, water distribution is based on watering according to defined patterns and fixed amounts, nowadays mainly using computer programs. This type of operation, with programming the time and amounts is dependent upon seasonal and climatic variations, considering in addition variations in water necessities due to the evolution of the cultures and weather fluctuations. The establishment of optimal soil moisture conditions for turf development is the basic condition for water consumption reduction. Since the main objective of golf course irrigation is the obtainment of a grass surface where the player feels comfortable, irrigation should be focused on obtaining a regular, smooth grass surface, especially on the greens. In addition, the yield of turfgrass should be measured not in terms of productivity but in terms of ornamental value. This function includes homogeneity, density, color, texture, smoothness, resilience, *etc.* All these characteristics depend on the capacity of the grass to grow and regenerate, on its state of health and on the intensity of use (the number of players and maintenance operations). Obviously, different parts of the course generate different demands on the grass. In these circumstances, efficiency can be defined as the capacity to maintain a perfect green surface over time, and this is certainly not obtained with uniform irrigation of the entire course. It is necessary to adjust sprinklers or drippers to offer the plant the quantity of water needed for regular growth, considering all the influences mentioned (*i.e.*, soil depth, frequency of irrigation...) but also others, like shade, vicinity to trees, slope, *etc.*

The current trend in agriculture is to develop new irrigation methodologies, adapted to water use reduction in traditional crops. In fact, deficit irrigation is being applied to obtain maximum efficiency and sometimes even better crop quality. The application of this concept to golf courses encounters certain difficulties. For example, on tees, putting greens and areas with heavy duties, deficit irrigation is not recommended. Nevertheless, in other areas this technique can represent 70–90% of the optimum theoretical demand. Another important concept is that of survival irrigation, which is applied when there is an extreme shortage of water for irrigation. It consists in applying the minimum possible amount of water to avoid the death of the grass (between 20 and 40% of the ideal quantity), usually sufficient for grass recovery when the normal pattern can be resumed. An additional issue related to efficiency is the need to cover the entire grass surface with a minimum amount of water. Due to the fact that sprinklers and other irrigation devices generally deliver water in circular form, it is difficult to guarantee that all the plants will receive an identical amount of water, due especially to overlapping.

There are several ways to calculate irrigation uniformity, a calculation that is further modified by wind and other features. For example, localized irrigation improves uniformity and contributes to water saving at the same time, due to better distribution of the necessary amount of water to the root zone and the reduction of evaporation from the soil. Non-uniform irrigation provokes several problems, namely, a lack of or bad turf growth; a need for manual watering; soggy surfaces; water wasting; and the excessive application of pesticides and nutrients.

2.3. Economic Aspects of Reuse

Since the turn of the century, the economics of water reuse has provoked considerable discussion and even FAO has shown its interest [17]. Several papers on the topic, such as [18,19], discuss the best way to make calculations based on different approaches, although most focus on cost-benefit tools. In the case of golf courses, the price of water is a key issue, as part of the population is reticent to attributing water resources to golf courses, especially in drought situations, although there is not the same opposition to the use of water for lawn irrigation in the same communities. As a result, authorities tend to increase the price of water for what is considered a luxury use. If non-conventional resources are available, reclaimed water is usually the preferred one. Runoff recycling, rainwater collection and treated greywater are also employed, but their use is less frequent, e.g., [20]. In extreme cases, due to the lack of other resources, some golf courses can rely only on desalination using expensive technologies, such as reverse osmosis. Several golf courses have their own reclamation trains but usually municipalities or water authorities supply the course with reclaimed water [21]. Prices differ considerably, in accordance with the size of the reclamation system and the seasonality of its use. As a result it is difficult to quote a price, but it oscillates between several cents of euro and just over one euro, including analytical costs and mortgage of the treatment facilities [22].

3. Reclaimed Water

When using reclaimed water, hazards can appear and the corresponding risks can be quantified. Such hazards are, in all cases, due to the presence of several pollutants, including pathogens and chemicals, in the released reclaimed water. Resulting water quality concerns can hence be described as biological, chemical and physical.

3.1. Water Quality

Apart from the pollutants considered as unique, salinity is a potential hazard which can affect both soils and plants. Since it results from the combined action of more than a single pollutant and given its importance, the topic is dealt with separately.

3.1.1. Microbiological Issues

From a biological point of view, it should be noted that the number of water-related pathogens in reclaimed water is still significant and that their identification is not usually directly sought (Table 4). Instead, bacterial indicators are generally employed to determine the degree of risk associated with reclaimed water. Among them, *E. coli* and coliforms (total and faecal) are nearly always used for establishing the microbiological quality of reclaimed water and the efficiency of the reclamation treatment. Nevertheless, the mentioned indicators are not at all reliable in identifying the presence or absence of viruses and parasites. For this reason other indicators are now employed (e.g., nematode eggs) or suggested (bacteriophages); and several pathogens are determined directly (e.g., cysts and oocysts of *Giardia* and *Cryptosporidium*) and have been designated as index organisms.

Table 4. Main pathogens potentially present in wastewater and associated diseases.

Organisms	Pathogen	Associated disease
Bacteria	*Salmonella typhi*	Typhoid fever
	Shigella spp	Shigellosis (bacillary dysentery)
	Vibrio cholera	Cholera
	Campilobacter jejuni	Gastroenteritis
	Pathogenic *Escherichia coli*	Gastroenteritis
	Enterobacter aerogenes	Gastroenteritis
Viruses	Polioviruses	Poliomyelitis
	Picornaviruses (animal viruses)	Paralysis, common cold, myocarditis
	Hepatitis A virus	Infectious hepatitis
	Hepatitis E virus	Hepatitis
	Rotaviruses	Gastroenteritis
	Noroviruses	Gastroenteritis
Protozoa	*Entamoeba histolytica*	Amoebiasis (Amoebic dysentery)
	Giardia intestinalis	Giardiasis (diarrhea)
	Cryptosporidium parvum	Cryptosporidiasis (diarrhea)
Helminths	*Ascaris lumbricoides* (N)	Ascariasis (roundworm infection)
	Taenia spp. (C)	Taeniasis
	Trichuris trichiura (N)	Trichuriasis
	Schistosoma spp. (T)	Schistosomiasis (bilharziasis)

N: Nematodes; C: Cestodes; T: Trematodes.

In relation to further hazard and risk calculations, not all pathogens generate the same level of risk. This depends, for example, on aspects related to latency, persistence in the environment, infective dose and natural decay. On the other hand, there are characteristics that cannot be considered, such as the variable susceptibility of human individuals. Nevertheless, risk calculations are usually performed with data on a few pathogens although the presence of indicators is not directly related to the risks. For example, Mara *et al* [23] give some indications on how to perform the mentioned risk calculation.

3.1.2. Issues Related to Physics and Chemistry

From the physical and chemical points of view, the number of wastewater components is huge, and it seems impossible to deal with such numerous parameters (details are included in Tables 2 and 3). The number of physical parameters is relatively reduced and several of them can be determined on a continuous basis (e.g., temperature, pH and conductivity) (Table 5). From the physical viewpoint, the main problems are those which will affect the player (e.g., odor) or the "playground" aspect (e.g., black solids on surfaces).

Table 5. Physical pollution potentially present in urban wastewater (modified from [24,25]).

Physical parameter	Agent	Effect/Observations
Radioactive compounds	Radon, radioactive isotopes	Bioaccumulation, toxic effects
Residual heat (thermal pollution)	Water temperature above normal level	Effects on aquatic life. Reduction of dissolved oxygen concentration
Odor	Gases (hydrogen sulphide, mercaptanes, cyanide, ammonia…)	Nuisance effects on human health
Color	Natural metallic ions (iron oxides, manganese oxides), humic acids, lignin derivatives	Aesthetic and nuisance effects
Taste	Phenols, dissolved salts, disinfection by-products…	Effects on human health
Total solids: suspended solids (settleable, non-settleable), filterable solids (colloidal, dissolved)	Suspended solids (organic matter, clay, silt,…); Filterable solids (organic matter, dissolved salts…)	Diverse effects

However it is impossible to pre-determine indicators in the case of chemicals, for the origin of the wastewater must be known and, moreover, the types of chemicals that are most important must be decided on a case-by-case basis. Only a reduced number of pollutants—those indicated on Table 6—would actually be harmful to a golf course, including especially salinity (or ecotoxicity) related components.

Table 6. Chemical agents of concern potentially present in municipal wastewater (modified from [24–26]).

Chemical parameters	Chemical agent	Effect/Observations
Easily biodegradable organic compounds	Proteins, carbohydrates	Reduction of dissolved oxygen from aquatic ecosystems (anoxic conditions). Generation of hydrogen sulphide and methane gases
Scarcely biodegradable organic compounds	Greases, phenols, cellulose, lignin and similar	Residual COD, reduction of dissolved oxygen
Xenobiotic compounds	Several formulations of synthetic compounds	Bioaccumulation, toxicity, interferences with the life cycle
Nutrients (macro)	Nitrogen, phosphorus, potassium	Eutrophication, reduction of dissolved oxygen, toxic effects
Nutrients (micro)	S, Fe, Mn, Cu, Zn, Co, B…	Plant toxicity
Metals	Hg, Pb, Cd, Cr, Cu, Ni, Al, Fe, Mn, Zn…	Bioaccumulation, toxic effects
Dissolved salts	Chlorides, sulphides, nitrates…	Effects on agricultural uses, risk for human health (nitrates)
Other chemical compounds (organic and inorganic)	Pesticides, pesticides, organic halogens, residual chlorine/disinfection by-products	Carcinogenic, teratogenic and/or mutagenic effects

3.1.3. Salinity

From an agronomic point of view, salinity is a control parameter of great interest. The polluting effect of salinity in soil and groundwater is a key issue when reclaimed water is used for golf course irrigation. The application of subsurface drip irrigation systems save water and, therefore, less salt is added to the soil. There are also several ways to combat salinization problems using environmentally safe and clean techniques, as has been demonstrated by experience in the Algarve region, Portugal, the most southwestern part of Europe [27].

- Use of salt-removing turfgrass species;
- Use of drought tolerant turfgrass species;
- Reuse of minimal levels of reclaimed water, just enough to obtain a good visual appearance.

3.1.4. Nutrients

The nutrient balance is a very important parameter in determining the quality that reclaimed water has to accomplish, for imbalances cause bad grass development and poor resilience that can even be detected through color differences. The nutrient balance takes into account.

- The species of vegetation planted (grass, trees);
- The nutrient needs of these species;
- The theoretical reclaimed water supply volume in the field (average);
- The hydraulic retention time of the storage facilities (as a long retention time will diminish the nutrient content in reclaimed water).

4. Legal Aspects

When dealing with reclaimed water irrigation of turfgrass and other plant species in a golf facility, apart from specific rules and regulations relating to the sport of golf, there is a need to follow each country's legal specifications. The entire reuse procedure requires strict control. There are two types of control, one related to the quality of the reclaimed water and the second related to risk management of the reuse procedures. For this purpose it is necessary to establish:

- Rules and regulations;
- Risk assessment tools / processes.

Before reusing reclaimed water, it is necessary to determine whether or not it is safe for reuse. Currently, this can be done in two ways:

- Applying the traditional method of comparing it with standards;
- Using Hazard/Risk Assessment tools.

4.1. Rules and Regulations (Standards) for Golf Course Irrigation with Reclaimed Water

Until a few years ago, reclaimed water quality was measured, independent of other considerations, on the basis of empirically calculated standards, based on civil servants' criteria rather than scientific evidence. Standard figures depend on several concepts, including the following [28]:

- Economic and social circumstances;
- Legal capacitation by implicated entities and administrative bodies;
- Human health/hygiene level (endemic illnesses, parasitism);
- Technological capacity;
- Previously existing rules and/or criteria;
- Crop type;
- Analytical capacity;
- Risk groups possibly affected;
- Technical and scientific opinions;
- Other miscellaneous reasons.

Three types of factors can be distinguished in the above list: technical and technological (analytical, treatment methods; and capacity, knowledge, *etc.*); legislative and economic (criteria, socio-economic, legal competence, *etc.*); and health-related (sanitary state, diseases, risk groups, *etc.*). For decades, standards and quality regulations have been a matter of discussion among scientists, health and legislation officers and engineers, because of the variety of parameters to be controlled. Much controversy has arisen among research teams and regulating bodies on the quality that reclaimed water must meet for reuse with an acceptable degree of risk. Existing wastewater reuse regulations have been based traditionally on microbiological quality considerations, and it is only in recent years that chemical and toxicological concerns have appeared on the scene. The need to improve the determination of qualitative aspects has arisen, not necessarily by increasing the number of analysis but rather by implementing complementary tools, like risk assessment or good reuse practices.

Although almost all the laws governing wastewater reuse refer to agricultural use, there are several countries that support golf course irrigation and establish limitations for such purposes. For example, the use of reclaimed water to irrigate golf courses is popular in the United States of America (US), especially in the states of Florida, California, Arizona, Hawaii, Texas, Nevada and Washington, where considerable experience has been acquired. In fact, estimates suggest that the number of golf courses in the US using reclaimed water might easily exceed 300. The last edition of the US Environmental Protection Agency (USEPA) guidelines [29] for water reuse includes the different state regulations for urban wastewater reuse in landscape irrigation, including golf courses (Table 7). The USEPA also suggests guidelines and recommendations for this use (Tables 8 and 9).

Table 7. State regulations for golf courses irrigation (USEPA, 2004) [29].

Specification/State	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized, filtered, and disinfected	Secondary treatment, and disinfection	NS	Oxidized, coagulated, filtered, and disinfected
BOD_5	NS	NS	20 mg/L $CBOD_5$	NS	30 mg/L	5 mg/L	30 mg/L
TSS	NS	NS	5 mg/L	NS	NS	NS	30 mg/L
Turbidity	2 NTU (Avg) 5 NTU (Max)	2 NTU (Avg) 5 NTU (Max)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg) 5 NTU (Max)
Coliform (CFU)	Fecal Non detectable (Avg) 23/100 mL (Max)	Total 2.2/100 mL (Avg) 23/100 mL (Max in 30 days)	Fecal 75% of samples below detection 25/100 mL (Max)	Fecal 2.2/100 mL (Avg) 23/100 mL (Max in 30 days)	Fecal 2.2/100 mL (Avg) 23/100 mL (Max)	Fecal 20/100 mL (Avg) 75/100 mL (Max)	Total 2.2/100 mL (Avg) 23/100 mL (Max)

NS: Not specified by state regulations; NTU: Nephelometric Turbidity Units; Avg: Average.

Table 8. Guidelines for irrigation of golf courses (modified from [29]).

Type of reuse	Treatment	Reclaimed water quality	Reclaimed water monitoring	Setback distances
Urban water reuse Landscape irrigation (including irrigation of golf courses)	Secondary Filtration Disinfection	pH = 6–9 ≤10 mg/L BOD_5 ≤2 NTU No detectable fecal coliform/100 mL 1 mg/L Cl_2 residual (minimum)	pH— weekly BOD—weekly Turbidity—continuous Coliform—daily Cl_2 residual—continuous	15 m to potable water supply wells

Additional comments: 1. At controlled-access irrigation sites where design and operational measures significantly reduce potential public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve <14 fecal coliform/100 mL, may be appropriate; 2. Chemical (coagulant and/or polymer) additions prior to filtration may be necessary to meet water quality recommendations; 3. The reclaimed water should not contain measurable levels of viable pathogens; 4. Reclaimed water should be clear and odorless; 5. Higher chlorine residual and/or longer contact time may be necessary to assure the inactivation or destruction of viruses and parasites; 6. Chlorine residual of 0.5 mg/L or greater in the distribution system is recommended to reduce odors, slime, and bacterial regrowth; 7. A high standard of reliability, similar to water treatment plants, is required at wastewater reclamation facilities.

Table 9. Recommended limits for constituents in reclaimed water for irrigation (modified from [29]).

Constituent	Recommended limit for long-term-use (mg/L)	Constituent	Recommended limit for long-term-use (mg/L)
Aluminium	5.0	Lithium	2.5
Arsenic	0.10	Manganese	0.2
Beryllium	0.10	Molybdenum	0.01
Boron	0.75	Nickel	0.2
Cadmium	0.01	Selenium	0.02
Chromium	0.1	Tin, Tungsten, & Titanium	-
Cobalt	0.05	Vanadium	0.1
Copper	0.2	Zinc	2.0
Fluoride	1.0	pH	6.0
Iron	5.0	TDS	500– 2,000
Lead	5.0	Free Chlorine Residual	<1

With respect to Europe, in the Algarve region of Portugal, there is a lot of experience in wastewater reuse for golf course irrigation, conforming to national regulation (NP 4434/2005 [30]). Spain has also a national regulation on the quality of reclaimed water used on golf courses (RD 1620/2007 [31]). In Spain, golf courses are mainly located in the Mediterranean coastal tourist areas and around Barcelona and Madrid for local demand. The principal water quality limits outlined in the regulations in the Iberian Peninsula are summarized in Table 10.

The new WHO approach has somewhat changed the rules of reclaimed water use, not only on golf courses but in general. These recommendations seem to constitute a new way to consider reuse from the legal and practical application point of view that will facilitate the practice. Nevertheless, several years later it has become evident that this new way to analyze risks is not as easy as was expected initially. The need for a huge amount of microbiological data that was not usually collected previously, the calculations inherent to the approach, the difficulty of interpreting data and translating the calculations into a lay language are all obstacles in the implementation of this new approach. It is therefore clear that no definitive practical solution exists yet and that the calculations constitute an exercise for specialized scientists.

It is also mandatory to make a hydrogeological study of the area taking into account the soil and groundwater characterization, in order to gauge the vulnerability of the area. Moreover, the grass type to be planted must be selected in accordance with the quality and availability of water and soil. Nevertheless, the discussion on how strict standards must be is on-going and no agreement among the different points of view seems forthcoming. Meanwhile, the World Health Organization (WHO) [32] is promoting a new perspective, using a system based on Disability Adjusted Life Years (DALYs) instead of numeric standards [33]. This new approach appears promising, but needs further understanding, profound research and a good communication policy. Other possibilities could be developed, such as a good reuse practices code or the risk analysis approach, which to a certain extent is connected with the DALY system.

Table 10. Reclaimed water quality regulations for golf course irrigation in Portugal and Spain [30,31].

Constituent	Portuguese regulation NP 4434/2005		Spanish regulation RD 1620/2007
	Recommended Limit (mg/L)	Maximum limit (mg/L)	Maximum limit (mg/L)
pH	6.5–8.4	-	-
Conductivity	1 dS/m	-	3.0 dS/m
Suspended solids	60 mg/L	-	20 mg/L
Turbidity	-	-	10 NTU
SAR	8	-	6
Intestinal nematode eggs	1 egg/ 1 L	-	1 egg/ 10 L
Coliform	Fecal coliforms 200 CFU/100 mL	-	*E. coli* 200 CFU/100 mL
Aluminum	5.0	20	-
Arsenic	0.10	10	0.1
Barium	1.0	*	-
Berylium	0.5	1.0	0.1
Boron	0.3	3.75	0.5
Cadmium	0.01	0.05	0.01
Ion Chlorine	70	-	-
Chromium	0.10	20	0.1
Cobalt	0.05	10	0.05
Copper	0.20	5.0	0.2
Fluoride	1.0	15	-
Iron	5.0	*	-
Lead	5.0	20	-
Lithium	2.5	5.8	-
Manganese	0.20	10	0.2
Molybdenum	0.005	0.05	0.01
Nickel	0.5	2.0	0.2
Nitrate	50	*	-
Selenium	0.02	0.05	0.02
Sulphate	575	*	-
Tin, Tungsten, & Titanium	-	-	-
Vanadium	0.10	1.0	0.1
Zinc	2.0	10	-

Additional comments in Portuguese regulation: 1. Treatment: secondary (or tertiary), filtration and disinfection; 2. Disinfection by UV or ozone rather than chlorine; 3. Irrigation method should avoid reclaimed water contact with public; *: value that can be fixed by the administrative body involved.

4.2. Good Reuse Practices

There are additional approaches to the irrigation of golf courses with reclaimed water, apart from the methods mentioned above. One such approach is the establishment of codes of good reuse practices that are usually applied to the entire range of reuse options. Several of them are enforced by the authorities, while others are issued by professional associations, as is the case in Spain [34]. The state of Florida (USA), where reuse in golf courses is very common, developed a Code of Good Practices for Water Reuse [35]. This code, designed to aid reuse utilities as they implement quality water reuse programs, includes 16 principles that are summarized in Table 11.

Table 11. Principles of the Florida Code of Good Practices for Water Reuse (modified from [35]).

Protection of Public Health and Environmental Quality	Public Health Significance	Potential for public contact that can generate risk
	Compliance	Compliance with all applicable requirements for water reclamation, storage, transmission, distribution, and reuse
	Product	Reclaimed water that meets treatment and disinfection requirements and that is safe and acceptable for the intended uses when delivered to the end users
	Quality Monitoring and Process Control	Monitoring of the reclaimed water produced and rigorous enforcement of the approved operating protocol. Only high-quality reclaimed water is delivered to the end users
	Effective filtration	Optimizing performance of the filtration process in order to maximize the effectiveness of the disinfection process in the inactivation of bacteria and viruses and to effectively remove protozoan pathogens
	Cross-connection control	Effective cross-connection control programs rigorously enforced in areas served with reclaimed water
	Inspections	Routine inspections of reclaimed water facilities, including the located on the property of end users, to ensure that reclaimed water is used in accordance with requirements and that cross-connections do not occur
Reuse System Management	Water supply philosophy	Adoption of a "water supply" philosophy oriented towards reliable delivery of a high-quality reclaimed water product to the end users
	Conservation	Reclaimed water is a valuable water resource, which should be used efficiently to promote water conservation
	Partnerships	Enter into partnerships with administrations, end users, public, drinking water utility, other local and regional agencies, water management department and health department to follow and promote these practices
	Communication	Provide effective and open communication with the public, end users and other partnerships
	Contingency plans	Develop response plans for unanticipated events, such as inclement weather, droughts, supply short-falls, equipment failure and power disruptions
	Preventative maintenance	Prepare and implement a plan for preventative maintenance for equipment and facilities to treat wastewater and to store, convey, and distribute reclaimed water
	Continual improvement	Continually improve all aspects of water reclamation and reuse.
Public awareness	Public notification	Provide effective signage advising the public about the use of reclaimed water and to provide effective written notification to end users of reclaimed water about the origin of, the nature of, and the proper use of reclaimed water
	Education	Educate the public, children, and others about the need for water conservation and reuse, reuse activities in the area, and environmentally sound wastewater management and water reuse practices

In all cases, it is important to establish ways of public participation (communication procedures), which form part of good reuse practices. Hence, knowing the perceptions and experiences using reclaimed water of golf course managers, workers and users is essential. The USGA Green Section [12] conducted a survey focused on technical aspects of water quality, irrigation system, management and provider issues, and on the perception of golfers, staff and the public. Negative comments about reclaimed water appeared very limited. The most repeated comments referred to odor problems, together with algae and pond weeds. Total dissolved solids also seemed to be a significant concern. However, those satisfied outnumbered the dissatisfied by a ratio of 2 to 1 [36].

5. Risk Assessment Procedures

At the outset, the differences in meaning between the expressions "hazard" and "risk", frequently used in this section, should be clarified. "Hazard" is defined as any biological, chemical or physical agent that is reasonably likely to cause illness or injury in the absence of its control. Thus, the word hazard, as used in this document, is limited to safety issues. Similarly, a hazardous event is an incident or situation that can lead to the presence of a hazard (what can happen and how it can occur). "Risk" is the likelihood of identified hazards causing harm in exposed populations within a specified time frame.

Reclaimed water obtained in compliance with reuse standards should be of a high enough quality to reduce risks to an acceptable level. Nevertheless, due to the differences between regulations in different countries, it is not feasible to apply uniform methodology and analytical control worldwide or even at regional level. The latest developments for the regulation of wastewater reclamation and reuse are based on risk-related tools. Analytical work, initially implemented for establishing the quality of reclaimed water, must be the basis for risk-related examination, and then should be evaluated for usefulness and further analytical developments. Although the majority of rules, regulations and calculations are prepared for agricultural irrigation, reuse in golf courses can apply mainly the same procedures, albeit considering that the end-users (golfers) should not enter into contact with reclaimed water. At present, management systems based on the hazards/risks associated with wastewater treatment practices, recycling and application are being developed but so far they have rarely actually been implemented on courses. The risk approach on real full-scale sites must follow a specified pattern, which includes elements from the simplest observations to much more sophisticated tools, including computational work. The following instruments are necessary to determine the risks associated with playing golf:

- Real site observation tools;
- Analysis: chemical, physical and microbiological;
- Health risk assessment, including the Hazard Analysis and Critical Control Point (HACCP) system and the DALY approach for further calculations on acceptable risk and technology evaluation.

5.1. Observation Tools

The main steps in the recycling and reuse processes include the possibility of interpreting features or signs that might indicate a malfunctioning of the entire system or part of it by trained personnel.

With regard to reuse on golf courses, there are several external characteristics that could be interpreted as the result of quality or management problems related to reclaimed water. Several examples are shown on Table 12. Turfgrass, soil, substrata, lakes and streams can be used as indicators, especially if the course staff is familiar with "normal" characteristics. Nevertheless, the problems mentioned could also be attributed to management problems. Lists or forms can help staff to control the variable features which might indicate problems. Afterwards, further research can be performed to detect the origin of the malfunctioning. Apart from the features indicated in the Table 12, the presence or absence of animal and plant species, their variety, quantity and health conditions can also be a good indicator for detecting problems.

Table 12. Examples of observation tools on a golf course.

Matrix or part of the course	Features	Comments
Turfgrass	Color	Light color or color patches, uneven or reduced growth can indicate salinity, over- or under-irrigation, bad soil conditions…
	Growth	
	Pathogens	e.g., fungal infections are usually indicative of bad turfgrass conditions
Plants (not turfgrass)	Bad conditions	Several pollution problems can be detected by studying tree or bush characteristics (e.g., patches on leaves)
Soil/Substrata	Impervious, thatch or black layers	Excess of organic matter, salinity and other water components can contribute to limit water infiltration and percolation
Free water surfaces	Algal growth, odor	Excess of microscopic algae is a symptom of eutrophication
Groundwater	Odor	Unpleasant odor or black particles can indicate anaerobic conditions or the pollution of irrigation water
Runoff	Colored, suspended solids	E.g., reddish runoff can indicate that there are anaerobic conditions in soils or hollows

5.2. Analysis: Chemical, Physical or Microbiological

It is generally accepted that the most scientific way to detect problems on a golf course is to perform analysis on the different components of the facility. Reclaimed and other water on the course (see Table 3), grass and other plants, soils and substrata can and sometimes must be analyzed. Three types of analysis can be performed: preventive, regular and legal. Preventive analytical work is carried out in order to discover problems before they appear. On a well-managed course, grass, soils and water are periodically sampled and analyzed either *in situ* or in a laboratory. Tendencies towards growth or decrease can indicate the first stages of problems and help to prevent them. At most golf courses regular analysis to detect the needs of the system (e.g., nutrient contents in soil, water and plants) are undertaken. This can help to manage the facility adequately, with the additional benefit of obtaining savings on fertilizers, pesticides, *etc.* Finally, there are compulsory analyses, especially if the course is irrigated with reclaimed water. For this purpose, the existing rules and regulations must be applied. The main types of analysis are physical, chemical and biological (see Tables 4, 5 and 6), but those performed to comply with legal requirements when using reclaimed water refer mainly to the microbiological characteristics.

5.3. The HACCP System

The evolution of the classical tools for the evaluation of reclaimed water quality—as well as for drinking water—focuses on safety (*i.e.*, safety from the perspective of health) in terms of hazard and risk. In fact, several tools for hazard and risk assessment are being developed and are beginning to be available. The best known is the HACCP system, which was developed initially for the foodstuff and aeronautics industries, focuses on quality determination in samples from relevant control points. The establishment of these points, together with further analysis of samples, increases safety while reducing costs through more efficient use of analytical work. The HACCP system addresses in a logical, ordered and preventive way the identification and evaluation of hazards associated with all the steps in the reuse of reclaimed water, its control and the identification of the points where control will be critical from different points of view. It is a tool which evaluates the hazards and establishes control systems more closely focused on prevention than on enhancing the quality of the final product. The tool can be applied to the entire water use cycle in developed societies. It is also a tool that helps authorities to undertake water-related inspections, while promoting self-control activities. HACCP is a broad approach, requiring a compromise and involvement from all stakeholders in relation with reclamation and reuse, and specially managers, staff and users of a golf course.

There are seven basic principles in all HACCP systems as indicated in Table 13. After the theoretical development of these principles, the actual application should be undertaken considering the specificities of each course (*i.e.*, the presence or absence of lakes, the type of irrigation…). These seven principles were established by the National Advisory Committee for the Microbiological Criteria for Foods (NACMCF) and now feature as a supporting tool for the preparation of Water Safety Plans in the revised WHO 2004 guidelines [32], as well as for guidelines for safe water reuse [37]. Before establishing a HACCP plan, adequate preparation and planning is necessary. It is paramount for the pertinent administrative body (water agencies, health departments, *etc.*), company management, and the collaborators/workers/staff at every level to understand and assume the responsibility of implementing the HACCP system.

After ensuring that the seven principles are complied with, further work is necessary. In this case, the implementation of a HACCP system is based on two separate steps:

- Prerequisite requirements;
- HACCP plan implementation.

The prerequisite requirements, also called Good Hygienic Practices (GHP) in other fields and contexts, provide the foundation for effective HACCP implementation and should be in place before a HACCP procedure is established (Table 14). Prerequisites are practices and conditions needed prior to and during the implementation of a HACCP system. Confirmation of effective prerequisites means that the HACCP team can focus on the genuine design of a HACCP plan for the golf course, without having to repeatedly address hygiene requirements common to all processes, and applicable at most process steps in each HACCP flow diagram. However, where it is obvious that the prerequisite requirements ensure that the objective of preventing, eliminating or reducing hazards to acceptable levels is achieved, it should be considered, based on the principle of proportionality, that there is no need to proceed with the obligation to establish, implement and maintain a permanent procedure based on HACCP principles.

Table 13. The seven principles to be developed in Hazard Analysis and Critical Control Point (HACCP) systems.

Item	Observations
1. Conduct a hazard analysis	Needs to be developed for wastewater treatment and recycling facilities, including golf courses
2. Identify the CCP (Critical Control Points)	Not clearly defined whether or not they should be in the entire wastewater management (*i.e.*, from the point of wastewater generation to the point of use and beyond: e.g., fate of generated products like vegetables). On golf courses the procedure should be developed from the point of delivery to the golf-related environment
3. Establish target and tolerance levels	It is extremely important not only to determine the percentage of non-complying samples, but also the tolerance level (maximum deviation allowed)
4. Establish a monitoring system	Needs to be issued taking into consideration the analytical capacity (e.g., complex chemicals) and the cost of the whole control procedure as specified by existing laws and regulations and beyond if necessary
5. Establish corrective actions	When problems are detected and all the information is available, according to the potential risk identified, corrective actions should be implemented. Meanwhile, consideration should be given to the possible closure of the facility and suspension of the use of reclaimed water
6. Establish verification procedures	The whole procedure must be analyzed continuously and periodically
7. Accumulate documentation	It is necessary to identify all problems during the life span of the project

Table 14. Main prerequisites for the development of HACCP systems: Application to golf courses.

Prerequisites	Observations
Personal hygiene and training	Safety/hygiene-based design of facilities and equipment. Staff training is basic for hazard reduction and it must also include information for golfers
Sanitation procedures	Cleaning and disinfection of water-related facilities to avoid recontamination of reclaimed water, especially in lakes
Pest control procedures	Control especially of all types of rodents and insects in the course facilities. Redefinition of the pest concept on the course
Maintenance	A specific Maintenance Plan for the reclamation and reuse facilities must exist
Traceability	Follow-up procedures for reclaimed water
Standard operating procedures	Standardization of the operating procedures when using reclaimed water
Other requirements	Depend on each course

Once the prerequisites are established, it is necessary to implement a HACCP plan, a logical sequence of twelve action steps. Five preliminary tasks need to be accomplished before the application of the HACCP principles to a specific product and process. After these five preliminary tasks have been completed, the seven principles of HACCP should be applied (Table 15). In fact, HACCP procedures must theoretically be performed for the reuse of reclaimed water in all circumstances.

Table 15. Logical sequence for implementation of a HACCP plan [38].

Item	Observations
1. Building of a team for HACCP design and implementation in a golf course	Ensure that staff members involved in the development of a HACCP system on the golf course have a basic understanding on how the system works and are suitably trained to ensure effective implementation
2.Description of the product (reclaimed water and golf course)	Describe the two products: reclaimed water and the golf course, and the relationships with staff and users (players), based on quality criteria
3. Definition of where to apply the HACCP system	Determine in which point/s of the water cycle on the golf course is the HACCP system to be applied
4. Flow diagram of the reuse system	Draw up a flow diagram to show each step of the water-related systems on the golf course. If the recycling system is located on the course, it should be included in the entire analysis
5. "*In situ*" verification of the flow diagram	Confirm that the flow diagram is correct on the actual course and where excess water is diverted
6. Identification and enumeration of all possible hazards and risks. Risk analysis. Determination of control measures for risk	This is one of the main points of the HACCP system. There are several models for implementation. On golf courses this must be related to the end-product (the course), the initial users (staff) and the end users (players)
7. Identification of Critical Control Points (CCPs)	The correct definition of CCPs is basic for the implementation of a HACCP system. A CCP is a step in the process where a control procedure must be applied to prevent a hazard from arising or reduce it to a safe level. On the golf course these must be identified from the delivery point of reclaimed water to its insertion in the environment (the course and its surroundings)
8. Establishment of critical limits for each CCP	Set limits to identify when a CCP is out of control. It is extremely important not only to set the percentage of samples that can not comply, but also the tolerances (maximum deviation allowed)
9. Establishment of a system to monitor the CCP	When CCPs and critical limits are identified it is important to monitor and record what is happening at each CCP. It needs to be designed taking into consideration the analytical capacity and the cost of the whole control procedure
10. Establishment of the corrective actions to be taken for the possible deviations	When monitoring indicates that a CCP is not under control and problems are detected, due to the risk that will be generated, corrective actions should be implemented. Meanwhile suspension of the facility should be considered and reclaimed water not used
11. Establishment of verification procedures for the HACCP system	The whole system must be reviewed and corrected periodically and whenever there are changes in the process or the course
12. Establishment of documentation and a recording system for HACCP procedures	For the successful implementation of the HACCP, appropriate documentation and records must be kept and be readily available.

Hazards and risks are the basis for modern reuse control, and the concepts should be fully implemented in coming years. For hazard analysis, only significant hazards implied in the different steps of the recycling and reuse process must be identified and evaluated. The risk and its severity must be considered, together with all the related chemical, physical or biological hazards. Preventive measures are established for each hazard in all the steps and should be implemented to avoid every hazard detected or to reduce it to acceptable levels. Such measures are:

- Reduction of possible contacts between the pathogen and the target organism;
- High quality reclaimed water.

The reduction of contact could be achieved through what are known as good reuse practices, intended partly to reduce possible contacts that, in a broad sense, could imply either direct or indirect contact: skin or mucous membrane contact, aerosols entering the respiratory tract, *etc*. Hence, any contact reduction will imply risk reduction. The following points describe each step of the sequence in the implementation of a HACCP plan.

5.3.1. Building of a Team for HACCP Design and Implementation

The first task in developing a HACCP plan is to assemble a HACCP team consisting of individuals who have specific knowledge and expertise appropriate to the golf product and the processes implied. It is the team's responsibility to develop the HACCP plan. The team should be multidisciplinary and include individuals from areas such as engineering, sanitation, quality assurance, and water microbiology, apart from golf experts. The team should also include local personnel who are involved in the operation as they are more familiar with the operational variability and limitations. In addition, this fosters a sense of involvement among those who must implement the plan. The HACCP team may need assistance from outside experts who are knowledgeable about the potential biological, chemical and/or physical hazards associated with the product and the process. Due to the technical nature of the information required for hazard analysis, it is recommendable for experts who are knowledgeable in the process either to participate in or verify the completeness of the hazard analysis and HACCP plan. Such individuals should have the knowledge and experience to correctly:

- conduct a hazard analysis;
- identify potential hazards;
- identify hazards which must be controlled;
- recommend controls, critical limits, and procedures for monitoring and verification;
- recommend appropriate corrective actions when a deviation occurs ;
- recommend research related to the HACCP plan if important information is not known ;
- validate the HACCP plan;
- be capable of applying the whole procedure to the specific context of a golf course.

5.3.2. Description of the Product (Reclaimed Water)

It is mandatory to describe the final product "reclaimed water" according to the use for which it has been authorized. The quality requirements will be based on existing regulations or guidelines.

5.3.3. Definition of Where to Apply the HACCP System

The precise point of the water cycle at which the system will be applied must be decided. It is also necessary to include the reclamation process and the reuse site, in this case the golf course and its surrounding facilities, if irrigated with reclaimed water.

5.3.4. Flow Diagram of the WWTP, Reclamation and/or Reuse Systems

The purpose of a flow diagram is to provide a clear, simple outline of the steps involved in the process. Hazard identification is facilitated through the construction of a flow diagram. The scope of the flow diagram must cover all the steps in the process which are directly under the control of the establishment. In addition, the flow diagram can include steps that take place before and after the processing that occurs within the facility. The flow diagram need not be as complex as engineering drawings. In fact, a block type flow diagram is sufficiently descriptive, while a simple sketch of the facility is often useful in understanding and evaluating product and process flow. When more than one reclaimed water quality exists with significant differences and different treatment lines, it is necessary to draw up a flow diagram for each line. In the case of golf courses, the authentic scheme of the irrigation system—*i.e.*, the one finally implemented—is absolutely necessary.

5.3.5. "*In situ*" Verification of the Flow Diagram

When the treatment and recycling system becomes operative, the HACCP team should perform an on-site review of the operation to verify the accuracy and completeness of the flow diagram. Modifications should be made to the flow diagram as necessary and document this.

5.3.6. Identification and Enumeration of all Possible Hazards and Risks. Risk Analysis. Determination of Control Measures for Risk

After addressing the preliminary tasks discussed above, the HACCP team conducts a hazard analysis and identifies appropriate control measures on the course and the nearby areas affected.

Effective risk management requires the identification of all potential hazards, their sources, possible hazardous events and an assessment of the risk involved in each of them. The purpose of this hazard analysis is to develop a list of hazards which are of sufficient significance to be reasonably likely to cause injury or illness if not effectively controlled. Hazards that are less likely to occur would not require further consideration within a HACCP plan. In hazard analysis, it is important to consider the ingredients and raw materials, each step in the process, product storage and distribution, and final preparation and use by the consumer. In the case of golf courses, the ingredients and raw materials would include inputs (reclaimed water, fertilizers, players...) and outputs (vegetal material removed from the course, aerosols...). When conducting a hazard analysis, safety concerns must be differentiated from quality concerns.

A thorough hazard analysis is the key to preparing an effective HACCP plan. If the hazard analysis is not done correctly and the hazards warranting control within the HACCP system are not identified, the plan will not be effective regardless of how well it is followed. Hazard analysis and the identification of associated control measures accomplish three objectives: identification of existing hazards and associated control measures; identification of modifications needed in a process or product through analysis in order to further assure or improve product safety (*i.e.*, the course); and, also through analysis, provide a basis for determining Critical Control Points (CCPs). At first the matrixes pinpointed for comprehensive analysis should be: grass, soils, water and atmosphere are. At a later stage, the number of analysis may be reduced, depending on the results obtained.

The process of conducting a hazard analysis involves two stages. The first is hazard identification that can be regarded as a brain-storming session. During this stage, the HACCP team reviews the following elements in the reclamation system and on golf course:

- the effluent (reclaimed water) and its variability;
- accidental or deliberate contamination;
- the activities conducted at each step in the process;
- pollution source control practices;
- the process and technologies;
- storage and distribution practices;
- distribution, maintenance and protection practices;
- external matrices (air, water, soil, vegetation, *etc.*,);
- the intended use and consumers.

Based on this review, the team develops a list of potential biological, chemical and physical hazards which may be introduced, increased, or controlled at each step in the process. Hazard identification focuses on drawing up a list of potential hazards associated with each step of the process that is under direct control. The control measures needed and the frequency of monitoring should reflect the likelihood and consequences of loss of control. In any system, there may be very many hazards and potentially a large number of control measures. It is therefore important to rank the hazards in order to establish priorities, by using a prioritization matrix. The objective of this matrix is to rank hazardous events to provide a focus on the most significant hazards. A simple numerical rating (*i.e.*, score 1–5) is assigned to the different levels of likelihood and the severity of the consequences. The qualitative level of relative risk determined, based on the likelihood and potential impacts of an event, are evaluated using a matrix (Table 16).

Table 16. Prioritization matrix for qualitative risk analysis [38].

Likelihood	Consequence/impact				
	Insignificant = 1	**Minor = 2**	**Moderate = 3**	**Major = 4**	**Catastrophic = 5**
Almost certain = A	H	H	E	E	E
Likely = B	M	H	H	E	E
Moderate = C	L	M	H	E	E
Unlikely = D	L	L	M	H	E
Rare = E	L	L	M	H	H

E-extreme risk, immediate action required; H-high risk, management attention needed; M-moderate risk, management responsibility must be specified; L-low risk, managed by routine procedures.

The significant hazards will correspond to the activities with highest scores. It must then be decided above which score the following steps are to be performed. The main reason for applying such a system is to eliminate the hazards that are not significant for the purposes of the entire procedure (*i.e.*, the non-relevant items). The HACCP team's technical knowledge and expertise, historical data and relevant guidelines can be used to establish the likelihood and severity of potential hazards. In order to evaluate the hazards and hazardous events on golf courses, it is necessary to determine the ways a person might come into contact with pathogens and/or chemicals at a particular site, for example, a putting green. Three routes to exposure for golfers can be considered, assuming that this theoretical golfer would (1) kneeling down on the green to align putts; (2) handling golf club grips that have been laid on the green; and (3) touching the soles of golf shoes while cleaning them after the round. These are dermal exposure pathways, *i.e.*, those that involve absorption of chemicals through the skin.

5.3.7. Identification of Critical Control Points (CCPs)

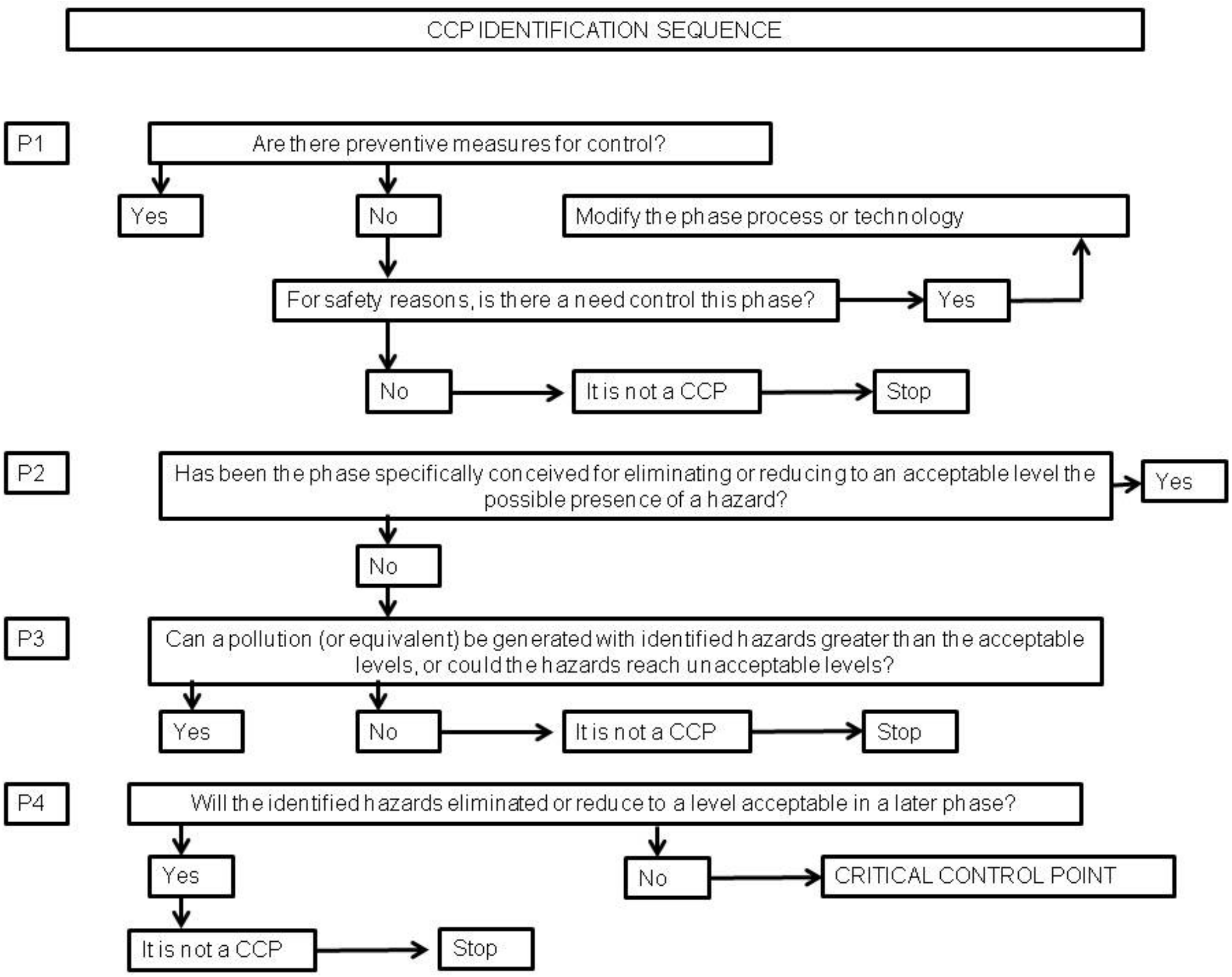
A paramount point within a HACCP is the definition of CCPs, which must be identified and defined. CCPs are defined as points, steps or procedures where control can be applied, and where a hazard for reclaimed water safety can be anticipated, eliminated or reduced to acceptable levels. When identifying all the CCPs, a systematic procedure must be established. Complete and accurate identification of CCPs is fundamental to controlling the safety hazards in the process, which, on golf courses, refers to the reuse of reclaimed water. CCPs are located at any step where hazards can be prevented, eliminated, or reduced to acceptable levels. CCPs must be carefully developed and documented. In addition, they must be used only for purposes of product safety. Initially, CCPs were defined as "weak points" from the health point of view, since the agrofood industry is focused mainly inside built facilities. Nonetheless, considering reuse in a broader sense (the whole treatment chain plus reclaimed water application), other problems tended to appear—a situation that led to an attempt to expand the initial concept and define other types of critical points (Table 17). As in every facility involving health and environmental issues, the establishment of CCPs on a golf course presents difficulties and must be course-specific. However, the development of Points of Attention (POA) at a first stage greatly facilities the correct definition of the PCCs at a later stage.

Table 17. Definition and types of Control Points (CPs).

CPs	**Types**	**Observations**
"Criticality"	Critical	To be fully analyzed, observed and defined
	Not critical	Could be initially discarded, although changes in the processes can alter the initial classification
Classification	Health-related	The typical CCPs, exclusively related to human health
	Technological	Must include the type of technology and Decision Support Systems (DSS) for its selection
	Ecological	Related to environmental impact (positive or negative)
	Economic	Feasibility of the entire process in monetary terms, although intangibles must also be included
	Social	Public acceptation. Specific tools are being developed
	Administrative	From the point of view of administrative bodies. Different levels are to be considered
	Management	Integrated management of water resources is necessary. Reclaimed water must be included in the entire amount of resources (at water basin or administrative levels)

Once scores and CCPs are defined, it is then necessary to identify the control parameters. Classical standards have been the basis for obtaining a lot of data on faecal contamination indicators and some data on nematode eggs. There are not usually additional data on microbiology available, unless the golf system has been the subject of a research project. With respect to chemicals, the data available are even scarcer, because their obtainment usually involves expensive analysis, which require quite complicated analytical methods. It is only on sites where reclaimed water reaches the tap (*i.e.*, water supply systems) that such analytical work is performed continuously. The information accumulated during the hazard analysis is essential to the HACCP team in identifying which steps in the process are CCPs. It is not simple to determine if a Point in a defined reuse system is really a CCP. Standard procedure for the establishment of CCPs is presented in Figure 1. Although application of the CCP decision tree can be useful in determining if a particular step is a CCP for a previously identified hazard, it is merely a tool and not a mandatory element of HACCP. A CCP decision tree is not a substitute for expert knowledge.

Figure 2. Guideline for the identification of CCPs.



Water reuse on golf courses presents somewhat unique characteristics due to the specific conditions present in these facilities. In order to identify all the steps and activities of the process and proceed to determine the CCPs, some key features have been identified, for each specific use of the reclaimed water, as shown on Table 18. However, not all the possible uses of reclaimed water in golf courses are irrigation, as can be seen on Table 19.

Table 18. Key features to define CCPs in golf course irrigation with reclaimed water.

Parts of the system	Content	Observations
1. Transport from the reclamation plant	Indicate the mechanism (gravity, pumping), time of operation, *etc.*	The transport system is a reactor the kinetic of which can be modified through management (e.g., short night pumping)
2. Private storage system	Type of water stored, storage time, outflow management, *etc.*	Reclaimed water quality can be modified as a result of storage time and mixing with other types of water
3. Distribution system	Description of the equipment (pumping, gravity, pressure, outflows, *etc.*) and its management and maintenance	Water quality can be modified by management procedures, material types, *etc.*
4. Application system/s	Irrigation technologies (localized, sprinklers, exudation...)	Influences the risk associated to reuse (contact with the irrigated vegetation)
5. Description of the irrigation area	Physical definition of the irrigation area/s	Permits are awarded for a clearly delimited extension. Irrigation is not permitted when players are on the course. Control must be exerted so that reclaimed water cannot reach adjacent associated private gardens or nearby residencies
6. Description of irrigated vegetation	Type of vegetation that can be irrigated with the water, apart from the grass on the course	Permits are associated with a clearly defined type of vegetation. In this case, use seems to be general: course irrigation
7. System inspections	Autocontrol and external controls	Regulated by legislation
8. Operational control methods	There should be control of the problems related to the technology used (irrigation, distribution, *etc.*)	For example, sprinklers or drippers can be clogged or moved from the correct place. It is important to control the irrigation process to improve grass growth and limit water loss
9. Reclaimed water quality control in the point of use	Control the possible changes in water quality before its application	Especially important for microbiological quality and some specific toxicity
10. Control and management of related environmental matrixes	Study of related matrixes (where the water is applied and where it can go)	Control of aerosol dispersion, runoff, etc. It is especially important to control permeability and puddle formation
11.Potential health problems among the population	The contact/ingestion of reclaimed water by players or the public must be evaluated	Players' training is necessary. Existence of warning signs about the type of water that is used on the course

Table 19. Reclaimed water uses on golf courses and restrictions to use

Reclaimed water uses on golf courses	**Restrictions**	**Observations**
Irrigation of fairway grass	Irrigation while players are on the course is FORBIDDEN	Water content of organic matter and fertilizers must be controlled
Irrigation of greens	Irrigation while players are on the course is FORBIDDEN	Water content in organic matter and fertilizers must be controlled. Irrigation program can favor the growth of *Poa annua*: adequate management practices are required
Fertirrigation (fertigation)	The total content of nitrogen and phosphorus is limited: an important issue if runoff to lakes on the course exists	It is important to correct the usual imbalances (especially potassium)
Irrigation of gardens associated with the course	Private gardens, incidental gardens and playing surface	Areas that are not used for play: control of runoff to swimming pools, clear warnings about the irrigation system used
Other irrigation (gardens, trees…)	Attention must be paid to the water impact in certain plants (especially salinity)	Localized irrigation systems are recommended where feasible
General irrigation on the course	Specific protection of drinking water sources and eating facilities	Ingestion of reclaimed water in food and drink must be avoided
Internal uses (club house)	Follow urban and domestic water use restrictions	Direct or indirect ingestion of and contact with reclaimed water must be avoided
Dust control on pathways and other areas without grass	Apply when players are not circulating on the course	Runoff control
Compost	Attention to aerosol formation, lixiviates and runoff	Grass and other waste products can be composted
Water bodies	Clear warnings about the use of reclaimed water and prohibition of bathing. Attention to the state of related fauna and flora	Permission or prohibition of ball recovery from water bodies used as obstacles should be indicated
Streams	Clear warnings about the use of reclaimed water	

5.3.8. Establishment of Critical Limits for Each CRITICAL Control Point

A critical limit is a maximum and/or minimum value at which a biological, chemical or physical parameter must be controlled to prevent, eliminate or reduce to an acceptable level the occurrence of a hazard. A critical limit is used to distinguish between safe and unsafe operating conditions at a CCP. Critical limits should not be confused with operational limits that are established for reasons that have nothing to do with the safety of the process. Each CCP will have one or more control measures to guarantee that the identified hazards are prevented, eliminated or reduced to acceptable levels. Each control measure has one or more associated critical limits. Critical limits may be based upon factors such as: temperature, time, physical dimensions and chlorine concentration.

5.3.9. Establishment of a System to Monitor Critical Control Points

Monitoring is a planned sequence of observations or measurements to assess whether or not a CCP is under control and to produce an accurate record for future use in verification. Monitoring serves three main purposes:

- It is essential to safety management in that it facilitates tracking of the operation. If monitoring indicates that there is a trend towards loss of control, then action can be taken to bring the process back under control before a deviation beyond a critical limit occurs;
- It is used to determine when a deviation occurs at a CCP and there is loss of control, *i.e.*, exceeding or not meeting a critical limit. When a deviation occurs, an appropriate corrective action must be taken;
- It provides written documentation for use in verification.

An unsafe final product may result if a process is not properly controlled and a deviation occurs. Because of the potentially serious consequences of a critical limit deviation, monitoring procedures must be effective. Ideally, monitoring should be continuous, viable when using many types of physical and chemical methods and always preferable when feasible. There are several ways to monitor critical limits on a continuous or batch basis and record the data on charts. Monitoring equipment must be carefully calibrated for accuracy. The assignment of responsibility for monitoring is an important consideration for each CCP. Specific assignments will depend on the number of CCPs and control measures and the complexity of monitoring. Personnel who monitor CCPs must be trained in the monitoring technique for which they are responsible, fully understand the purpose and importance of monitoring, be unbiased in monitoring and reporting, and accurately report the results of monitoring. In addition, employees should be trained in procedures to follow when there is a trend towards loss of control so that adjustments can be made in a timely manner to assure that the process remains under control. The person responsible for monitoring must also immediately report a process or product that does not conform to critical limits. All records and documents associated with CCP monitoring should be dated and signed or initialed by the person carrying out the task. When it is not possible to monitor a CCP on a continuous basis, it is necessary to establish a monitoring frequency and procedure that will be reliable enough to indicate that the CCP is under control. Statistically designed data collection or sampling systems lend themselves to this purpose. Most monitoring procedures need to be rapid because they relate to on-line, “real-time” processes and there will not be time for lengthy analytical testing. Monitoring and control points for golf course irrigation are shown on Table 20.

A piezometric control net must be established throughout the course in order to monitor groundwater quality. The control net can include newly constructed piezometers and open and tube wells that are well characterized: geological column, depth, construction materials. The characteristics of the piezometric net (placement, type of piezometer) will depend on the vulnerability of the soil and groundwater derived from the results of the hydrogeological studies. As a minimum requirement, this control net must reveal the groundwater quality in the area of reuse upstream and downstream of the underground flow.

Table 20. Monitoring and control points for golf course irrigation.

Point	Type*	Frequency of control	Observations
Outlet of the recycling system	C, T	Specified in legislation	May coincide with routine control treatment
Storage	NC, T	Can be established in accordance with concession conditions	Adequate management is required
Mixing with other water	NC, T	Control of mixing when this occurs	Possibility of precipitation
Distribution	NC, T	Continuous	Monitoring through pressure control
Treatment prior to application	T, En	Specified by legislation and by the facilities	Possible additional filtration and disinfection
Environmental matrix: Atmosphere	NC, H	Specific study	Aerosols
Environmental matrix: Groundwater	NC, E	Biannual, studies of HRT and percolation	HRT: Hydraulic Residence Time
Environmental matrix: Surface water	NC, E	Daily	Runoff control
Environmental matrix: Soil	NC, E	Annual	Hydrophobicity and black layer problems
Residents and general public	NC, H	Epidemiology	If there are residents or public pathways nearby
Users	NC, H	Epidemiology	Information is required. Reclaimed water related diseases must be declared
Employees	NC, H	Epidemiology	Information is required. Reclaimed water related diseases must be declared

*: Critical, Not Critical, Health-related, Ecological, Technological, Economic.

5.3.10. Establishment of Corrective Actions for Possible Deviations

HACCP system management is designed to identify health hazards and to establish strategies to prevent, eliminate, or reduce their occurrence. However, ideal circumstances do not always prevail and deviations from established processes may occur. When this occurs, corrective actions are necessary, with the important purpose of preventing a hazardous final product. Therefore, corrective actions should include the following elements:

- Determine the cause of non-compliance and correct it;
- Determine the disposition of the non-compliant product;
- Record the corrective actions that have been taken.

Specific corrective actions should be developed in advance for each CCP and included in the HACCP plan. As a minimum, the HACCP plan should specify what to do when a deviation occurs, who is responsible for implementing the corrective actions, and that a record of the actions taken will be kept. Individuals who have a thorough understanding of the process, product and HACCP plan should be assigned the responsibility of overseeing corrective actions. When necessary, experts may also be consulted to review the information available and to assist in determining the non-compliant product.

5.3.11. Establishment of Verification Procedures for the HACCP System

Verification is defined as those activities—other than monitoring—that determine whether or not the HACCP system is operating according to stated objectives outlined in the water quality targets. Proper verification should take place during the development and implementation of the HACCP plans and maintenance of the HACCP system. An effective HACCP system requires little end-product testing, since sufficient validated safeguards are built early into the process. Therefore, rather than relying on end-product testing, it should rely on frequent reviews of their HACCP plan, verification that the HACCP plan is being correctly followed, and review of CCP monitoring and corrective action records.

Another important aspect of verification is the initial validation of the HACCP plan to ensure that the plan is scientifically and technically sound, that all hazards have been identified and that if the HACCP plan is properly implemented these hazards will be effectively controlled. Information needed to validate the HACCP plan often include: (1) expert advice and scientific studies; and (2) in-plant observations, measurements, and evaluations. Subsequent validations are performed and documented by a HACCP team or an independent expert as needed. In addition, a periodic comprehensive verification of the HACCP system should be conducted by an unbiased, independent authority. This should include a technical evaluation of the hazard analysis and of each element of the HACCP plan, as well as an on-site review of all flow diagrams and the corresponding operation records of the plan.

A comprehensive verification is independent of other verification procedures and must be performed to ensure that the HACCP plan is resulting in the control of the hazards. If this process identifies deficiencies, the HACCP team must modify the HACCP plan in accordance. Verification activities are carried out by individuals within the process staff, third party experts, and regulatory agencies. It is important for those involved in the verification activities to possess appropriate technical expertise in order to perform this function.

5.3.12. Establishment of Documentation and Records for HACCP Procedures

Efficient and accurate record keeping is an essential component in the application of a HACCP system. HACCP procedures should be documented. Documentation and record keeping should be appropriate to the nature and size of the operation. Documentation refers to:

- Hazard analysis;
- CCP determination;
- Critical limit determination.

Record keeping refers to:

- CCP monitoring activities;
- Deviations and associated corrective actions;
- Modifications to the HACCP system.

Generally, the records maintained for the HACCP system should include the following:

- A summary of the hazard analysis, including the rationale for determining hazards and control measures;
- The HACCP plan:

- A list of the HACCP team and their assigned responsibilities
- Description of the product, its distribution, intended use, and end users
- Verified flow diagram
- A HACCP Summary Table that includes:

  a. The hazard(s) of greatest concern
  b. Critical limits
  c. Monitoring
  d. Corrective actions
  e. Verification procedures and schedule
  f. Record-keeping procedures;

- Support documentation such as validation records;
- Records that are generated during the operation of the plan.

6. Discussion

In recent decades, golf—a long-standing traditional sport in the humid British Isles—has been implanted in several areas of the Mediterranean basin. In many cases, golf courses development in this new scenario has been associated with tourist resorts or private property developments. There is ample evidence that this newly implanted activity has made a significant contribution to the corresponding national, regional and local economies, while, at the same time it has provoked negative evaluations by others. The key underlying issue is related to the water resources used for the irrigation of golf facilities. Detractors argue, on the one hand, that golf irrigation is a luxury that cannot be accepted in the Mediterranean. On the other hand, they consider that golf courses are only bait—or an excuse—for urban development. Several media have collaborated in the creation of this negative analysis based on a biased approach to golf, disregarding its huge contribution to tourism, not only in the form of short breaks but of long-term residential tourism, in which urban development plays an essential role. In these circumstances, the key issue is obviously the allocation of water resources and, to be more precise, the cost-benefit relationship of water resource use on golf courses in comparison with its use for other purposes in the same area, e.g., agriculture. A complementary consideration is the use of reclaimed water, especially with respect to its viability on golf courses and its contribution to saving groundwater.

First of all, the true dimension of the problem should be identified. Legislation throughout most of the Mediterranean regions has, for some time now, made the use of reclaimed water compulsory on all new golf courses and long-established ones have been or are being adapted for its use. Hence, from a practical point of view, the number of golf courses using reclaimed water is significant. The South of Spain and Portugal are perhaps the areas the most widespread use of reclaimed water for course irrigation, together with other Mediterranean areas of Spain, especially Catalonia and Majorca Island. In fact, these four areas together make up the main traditional golf destinations for Northern European players. There has been considerable development of golf in the South of France, where some courses apply reclaimed water for irrigation (although exact data is not available). Nevertheless, it must be borne in mind that there is no scarcity of water resources in this region and efficient distribution systems exist, so water does not constitute a key issue.

Elsewhere in the Mediterranean, golf has developed to a much lesser extent. A few courses are located in Southern Italy—notably six on the island of Sicily—although demand for golf tourism is still lagging behind supply [39]. Obviously, potential for further golf development on the island exists. Greece has still not developed the sport to an extent that is comparable to other Mediterranean countries, for only seven golf courses are listed [40]. Cyprus is also a golf tourism destination, where the few courses are mainly attached to resorts and located on the west coast of the island [40]. However, no information is readily available on the water resources used. Given the scarcity of water on the island, use of reclaimed water for watering the courses would appear to be the only valid option. In Malta there is a single golf course [40]. and, given the scarcity of water resources on the island, its irrigation with reclaimed water would be a good opportunity to save water. Golf courses are also being constructed in the countries of former Yugoslavia, especially in Croatia, and these are mainly also associated with the development of tourism.

With respect to Northern Africa, it must be stated that reclaimed water is sometimes the only resource available for irrigation. Hence, several of Morocco's 20 courses (e.g., those in Marrakech) and Tunisia's 10 courses (e.g., Tunis) are being irrigated with reclaimed water [40]. Although in Egypt there are several courses mainly associated to resorts and destined for tourist demand, the scarcity of wastewater treatment plants does not make it feasible to irrigate the courses with reclaimed water [39]. There are currently two golf courses in Israel [40]., but no indications of the resource used for irrigation is available. There is a similar absence of information about water resources on Turkey's dozen or so golf courses [40].

Hence, in consonance with the expansion of golf tourism in Mediterranean areas, it is certainly evident that reclaimed water will be necessary for irrigating those facilities, which in turn makes it clear that the development of reuse practices for irrigation of golf courses is becoming increasingly necessary. From a scientific point of view, however, the discussion must follow other paths, given that a golf course is always a SPAC (Soil-Plant-Atmosphere Continuum) and not an artificial, greenhouse-like infrastructure. Apart from its use as a playing field, other roles are apparent, e.g., a haven for menaced flora and fauna species, a place to incorporate waste (compost, reclaimed water, biosolids...) safely into the environment and a green area.

The use of reclaimed water can alter the management circumstances of a course, both from a legal point of view and because of possible negative impacts on the environment and health. There is growing discussion on the need to adapt existing water reuse rules and regulations to reality, not only for golf course irrigation but also for agriculture and other uses. Several of the existing rules seem to be excessively restrictive, especially those referring to reuse for industrial and water bodies' recovery purposes. The problems arising in the management of golf courses irrigated with wastewater are not, in fact, significantly different from those on other courses. They include:

- Construction problems that can sometimes appear after several years of operation. In this case, the difficulties are the same as on other courses, except that, if water escapes from the facility, health problems can arise;
- On courses that form part of a resort, consideration of the interaction (contact) of water with residents, especially with respect to aerosols and runoff of reclaimed water;

- The need to exert strict control of the nutrients applied, because of the nitrogen and phosphorus content in reclaimed water;
- The increased risk of water eutrophication, due to the nutrient contents of reclaimed water and runoff;
- Additional responsibility with regard to the problems derived from management, when the reclamation facility is managed by the course.

In the reuse of reclaimed water, the authorities place increasing demands on the final user, by requiring the application of an auto-control procedure for the irrigation network, reclamation (if it exists), reclaimed water, runoff, environmental impact, *etc.* The cost of this auto-control must be paid by the course. There is a trend to implement procedures for risk assessment on golf courses, especially those irrigated with reclaimed water. The main tool to implement risk assessment is the HACCP system (Hazard Analysis and Critical Control Points). In this case, it is also necessary to implement staff training programmes. In the golf course irrigation process, golfers can be considered the end-users of the water. Hence, players should be made aware of the type of water used for irrigation, so this should be indicated on the score-card and signposted around the course. In this respect, and bearing in mind that tourism should be associated with safety in relation to water and health, the development of hazard and risk analysis is important to guarantee safety in the use of reclaimed water on golf courses.

7. Conclusions

Golf courses have mushroomed in many areas around the Mediterranean shores in response to two sources of demand. On the one hand, economic development in many countries has encouraged an increase in demand from the local population, with the discovery of the benefits of this open-air sport, partly thanks to the impact of media attention to local professional players that have become international idols. On the other hand, the rapid expansion of golf tourism over the last three decades has led to an exceptional rate of growth, which has frequently been concentrated in specific destinations. The present economic circumstances suggest that this rate of growth cannot be sustained.

However, in several countries—notably those in the Mediterranean—golf development has been pinpointed as a target of the environmental activists on the grounds of a supposed excess of water and land consumption, as golf courses are often associated with luxury resorts, real estate developments and other land-consuming infrastructures. This association has created a negative image of golf, perhaps further stimulated by a bad communication policy on the part of the stakeholders in golf development. In fact, scientific study of golf systems reveal the true level of water consumption and a more balanced assessment of the positive and negative economic and social impacts. Golf courses can serve as places to recycle waste (compost, sludge) and reclaimed water in a controlled environment, thus minimizing the negative impacts of both waste and the actual courses. Hence, the validity of some of the arguments put forward by detractors is not clear. What is, however, clear is that golf courses irrigated with reclaimed water require:

- Differentiated management of the golf course ecosystem;
- The carrying out of a risk assessment of the use of the resource;

- Managers and staff with specific formation on the use of reclaimed water and good knowledge of rules and regulations on reuse;
- Professional superintendents with specific knowledge on wastewater reclamation and reuse;
- A good communication policy.

Likewise, the use of chemicals must be dissociated from the use of reclaimed water on the golf courses, especially in facilities managed according to American protocols, which are slightly different from European management systems that are based on more natural premises and criteria. Certainly in the reuse of reclaimed water on golf courses, management should be adapted to minimize the specific problems associated with reuse, but this can, in fact, generate certain benefits, including the improvement of integrated management of water resources in the region or basin in question.

Information on the type of water resource used to irrigate golf courses in the Mediterranean is not readily available in some countries, as it is not facilitated on the relevant webs (specific courses or those devoted to the sport in general). On the contrary, information on courses using reclaimed water in the USA is plentiful, since it is considered an added value in the image of the facility. Certainly, given the increasing availability of treated and reclaimed water and the water needs of golf courses, the future development of the sport in areas without surplus water resources will predictably depend upon the use of reclaimed water. Its use for irrigation is essential, not only because of the lack of water resources, but also due to the increasing criticism of the use of conventional water resources and the improvement of the tools that guarantee the safe use of reclaimed water. This source must then become one of the basic resources of the Mediterranean golf courses.

In the light of future trends, the need for further improvements in knowledge of reuse practices and their associated controls—always based on safety for golfers and other stakeholders—has arisen. Among the tools to implement reuse available, cheaper and more sustainable reclamation treatments and risk analysis systems are being developed. In recent years, risk assessment or analysis has emerged as an essential tool to guarantee the application of reclaimed water at an acceptable risk level. However, current methods available require simplification for their practical application. Present protocols seem to be adequate in order to address the key issue of enhancing the development of reclaimed water use on golf courses.

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