STRATEGIES FOR WATER MANAGEMENT. A GLOBAL IRRIGATION MODEL

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This study focuses on the physical component of irrigation water management in regions where its scarcity is intensified by recent urban centre development, seeking not only the definition of strategies for major savings in consumption, but rather their inclusion in landscape principles for more sustainable urban design solutions.
The (re)establishment of a close relation between water management and planting techniques (perpetuated in vernacular irrigation techniques) is quintessential. Therefore, a global model of irrigation water management is being developed, with a mathematical reasoning of evaluation and validation, based on local climatic data and on the confrontation between principles and practices of irrigation and their follow-up to the stage of getting the results.
Strategic plant selection; extensive, low-density, hydro-zone grouped planting; microclimatic and topographic modelling; further infiltration and water harvesting areas; induction of hydric stress; localized irrigation and soil improvement are some of the landscape principles and practices applied.
Early conclusions from field experiences developed in Lisbon, Portugal, point to the possibility of higher achievements in water irrigation efficiency in the Mediterranean and, possibly, in arid regions worldwide. Those performances include water supplies below evapotranspiration and even below annual local precipitation rates.
When integrating these and other sustainable practices in water irrigation systems, one expects higher landscape's performances in dry regions, followed by the necessary changes in dry landscape's paradigms.

Key words: water management, irrigation model, landscape design, landscape management, hydric stress, resilience.

1. Current state of landscape planting irrigation in arid and semi-arid climates

Recent large scale urban developments in several arid and semi-arid regions has lead to an increasing demand for vast landscaped areas, facing adverse environmental conditions and implying, therefore, large inputs of energy and resources. Water is the scarcest one.

Contemporary landscape design in these regions has underestimated, usually, local constraints. As rainfall is much lower than common ornamental plantings' considerable evapotranspiration, intensive irrigation based on groundwater has been supplied. Despite its heavy utilization over the last years, groundwater still provides the majority of the irrigation water. However, water levels have been declining and water quality deteriorating. Natural recharging rates have been hugely exceeded, threatening short term sustainability of these recent urban communities.

The Abu Dhabi Emirate has one of the highest water consumption rates per capita in the world and is, therefore, taking an effort to manage water use for landscape and minimize the use of non-renewable resources[1]. The irrigation for parks, gardens and recreational areas, accounts for 7.9% of total water use. Recharge to the aquifers in the Emirate is estimated at only 4% of the total current water use (Abu Dhabi Water Resources , p. 6). Despite this evidence, landscape planting design still relies on large-scale supply of water and its management practices still waste huge amounts of this scarce resource: preference for exotic species; unbalanced ratios of intensive water demanding landscaping typologies and

[1] Data has been obtained through different projects' research in Abu Dhabi Emirate.

extensive, less demanding ones; overuse of sprinkler irrigation when localized irrigation would be more efficient; daily instead of nightly irrigation.

Besides the indispensable increase on the use of recycled water, it is essential for landscape design to update both the concept and the irrigation practices, rejecting the conventional approach introduced from wetter regions, in order to drastically decrease water budgets.

2. Irrigation water as a scarce resource – examples of valued, respected and sustainable use

2.1. Vernacular techniques

Man has been developing water harvesting techniques for millennia. The more scarce water is, the more inventive those techniques.

Although they were originated with an empirical basis and, therefore, not very systematic, time has cleared them and, today, they continue to be essential support for the study of irrigation water.

2.1.1. Moisture capture

After the conquest of Palermo, Italy, in 831, Sicilian agriculture took advantage of the relevant scientific knowledge brought by the Islamic civilization. Remaining from this heritage, the “giardini panteschi” are self-sufficient agronomic systems typical of Pantellaria, a Mediterranean island located between Sicily and Tunisia. They consist of circular dry stone walls (8-12 m diameter; 3-4 m high and 1.3 m width) which protect the inner cultivated area, creating an ideal microclimate (Agricoltura Sostenibile a Pantelleria). The volcanic stone not only prevents everlasting strong winds from damaging the crop (usually orange trees, which otherwise would not be able to reach its maturity height) but it also captures the night dew. During the night, when warm and humid winds coming from the sea face these colder walls, water condenses and is absorbed by the porous stone. Throughout the day, the stone walls collect and take this precious water to the root zone, where it is slowly released (Ecco il segreto dell' acqua nel giardino di Pantelleria, 2008) (Figure 1).

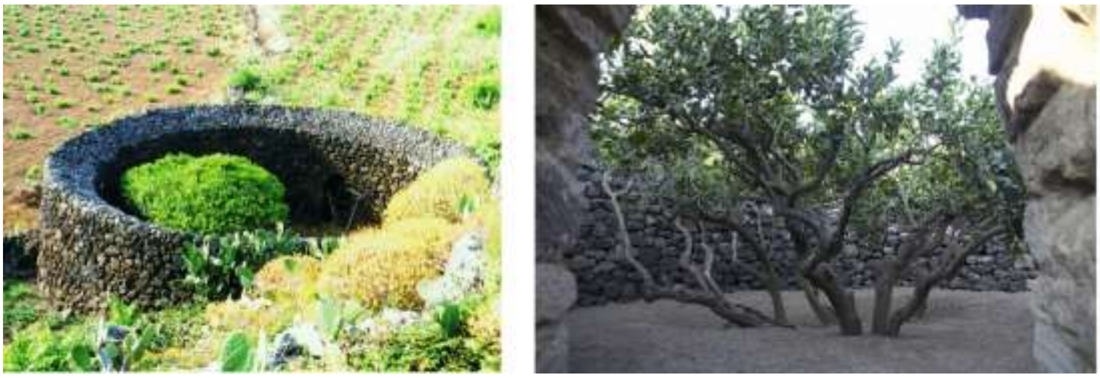

Figure 1: Circular dry stone walls in Sicily, Italy.

In the vineyards of La Gería, in Lanzarote Island (Canarias, Spain), single vines are planted in pits 4-5 m wide and 2-3 m deep, with low, curved volcanic stone walls around each pit. This technique is designed to harvest rainfall during summer storms, to capture overnight dew and to protect the plants from the winds (Figure 2).

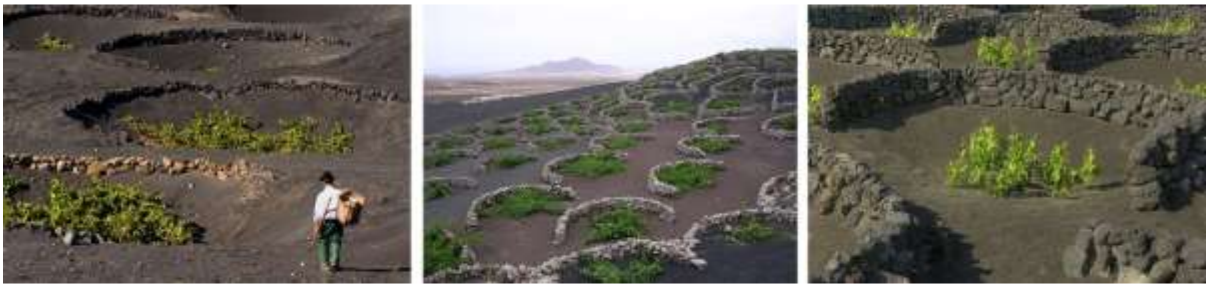

Figure 2: Examples of La Gería’s vineyards, Lanzarote, Spain.

Dew and fog capture has proved to be an effective way to collect water for irrigation. Contemporary techniques, such as fog fences constructed in Yemen or South Africa, retained 4.5 liters of water per square meter. In the Abu Dhabi Emirate, for instance, summer conditions are ideal for fog capture (containing about 0.05 grams of water per cubic meter), as prevailing winds from the Persian Gulf bring hot and humid air to the coastal regions – 22 grams of water per kilogram of air (Columbia University, School of International and Public Affairs. Master of Public Administration in Environmental Science and Policy. Workshop in Applied Earth Systems , 2010, p. 99).

2.1.2. Water harvesting

Water harvesting is a technique based on the combination of a large runoff contributing area and a small water collecting basin, in a ratio depending on precipitations, on the amount of water needed in the collecting basin and on the accepted degree of drought risk (Sardo & Hamdy, p. 4).

Archaeological surveys in the Negev Desert, Israel, showed that ancient Nabateans’ techniques could harvest, annually, one cubic metre of rainwater from 16 m^2 of surface area. Rainwater was captured from nearby steep and rocky unproductive areas, collected in water channels and distributed to the lower cultivated lands by gravity. The average proportion of the catchment area to field area was about 20:1, which meant an annual moisture increment that was double or triple what the average annual precipitation would have been, making the cultivation of cereals, orchards and vineyards feasible (Aronson, 2008, pp. 111-112).

2.2. Innovative methods of landscape irrigation

2.2.1. Irrigation water needs of landscape plantings in California - The Landscape Coefficient Method (LCM)

In agricultural systems, water is applied to produce a crop. Whether being tomatoes, beans, or apples, growers apply water to optimize yield and quality. In landscape systems, health, appearance, and growth are of greatest interest. Irrigation is managed to sustain plant defense systems; to achieve desired canopy densities and colour; to generate desired growth; and to produce flowers and fruits (in some species). Irrigation is not used to produce a harvestable crop in landscapes. Because of this difference between landscape and agricultural systems, it is believed that landscapes can, and should, be managed at a lower irrigation level than that needed for crop production (California Department of Water Resources, 2000, p. 12).

LCM is an innovative method of estimating irrigation needs of landscape plantings in California’s Mediterranean climate. Unlike conventional methods derived from agronomic practices, which intend to maximise growth rates and outputs by replacing (or even overcoming) the maximum amount that can be lost via evapotranspiration, LCM comes up with the challenge of supplying a minimum amount of water (inducing a controlled extent of hydric stress), just enough to keep landscaping plantings growing healthy and with a reasonable appearance (California Department of Water Resources, 2000). Water needs are estimated through the evaluation of specific landscape factors, such as multiple-species planting, planting density and microclimate. Based on research, observation and field experience, a species evaluation list has been developed, allowing this sustainable method to be applied and updated all over the region.

Results of investigations at the University of California revealed that irrigation substantially below referential evapotranspiration (20 to 60 % accordingly to the species and the climate zone) can be applied to establish Mediterranean shrubs and plant covers with no apparent drought-related injury (California Department of Water Resources, 2000) (Sachs, 1991).

3. A global model for efficient irrigation

The following model of water management consists of a mathematical reasoning of evaluation and validation, based on the confrontation between principles and practices of irrigation and their follow-up to the stage of getting the results:

design principles + management practices ↔ results (< ETP and < annual precipitation)

Table 1 Design principles, Management practices and results

Design principles	Management practices	Results
Strategic plant selection	Induction of hydric stress	Water supply below evapotranspiration
Plant grouping according to similar water requirements	Localized irrigation	Water supply below local precipitation
Extensive, low-density planting	Water storage improvement	
Microclimatic regulation		
Run-off control		
External compensating areas		

It is important to stress at this phase that this model is still in early stages of development. For this reason, it is considered that more specific measures of action may be presented briefly, as well as results of the integrated combination of those measures.

Throughout this study, the term ‘efficient irrigation’ will be used to refer not merely to a high yield of the applied amount of water (as broadly referred due to the productive, agronomic tradition), but rather to a sustainable, landscape planting oriented approach, resulting from an integrated appliance of environmentally certified landscape design and hydraulic engineering procedures.

3.1. Efficient irrigation oriented landscape design principles

3.1.1. Strategic plant selection: native, drought adapted, species

In dry regions, landscape design should consider, by default, the use of native species (or species from other arid and semi-arid zones) for the majority of the planting areas. Regularly used ornamental species from exotic origins (with sub-tropical and temperate climates) should indeed become an exception.

Besides helping to promote both the local distinctive landscape character and biodiversity, this design principle takes advantage of innate adaptive growth and lifecycle strategies against shortage of water (Aronson, 2008, pp. 39-42):

i) Drought avoidance: annuals (survival of the plant community instead of individual specimens) and bulbs(fast growing and early maturity of the aerial part of the plant, soon after the wet season until the following temperature and dryness increase, while the subterranean part, protected by the soil layer, lives on collecting nutrients).

ii) Drought tolerance: resistance to transpiration (reduced leaf surface area, grey coloured reflective leaves, reflective hairs, resinous leaf coatings, self-shading geometrical arrangement of leaves or dormancy during periods of extreme water stress) and shallow and wide root systems in order to collect surface moisture or rainwater instantly and efficiently.

iii) Succulence: round shape (smallest surface to volume), internal water storage (under a waxy water-proof skin), Crassulacean acid metabolism photosynthesis (which allows plants to separate the stages of light absorption and biosynthesis -at night - and lessen water losses to one-tenth).

Many Mediterranean plant species can also be considered to sustainably introduce variety into arid landscape plantings, as they present many of the pointed strategies: dying in summer (annual plants), hiding below ground (geophytes), double root system (sub superficial/deep), reducing transpiration (sclerophyllous plants), summer dormancy (leaves' loss in summer), reducing exposed surfaces (modified branches and leaves, like thorns and spines), sheltering from heat (hairy plants and grey foliage), capturing moisture from the air, conserving water (succulent plants), salt, wind, cold and drought: balls and cushions (Filippi, 2007, p. 24).

3.1.2. Plant grouping according to similar water requirements: hydro-zones

Planting design in dry climates should aim for efficient water use by strategic plantation to plant communities of similar water requirements, which can help to inform how, where and when irrigation is needed (PROAP, 2011). Therefore, planting design should follow the setting of a sequence of hydro-zones – landscaped areas having plants with similar water needs that are served by one irrigation valve or set of valves with the same schedule (California Department of Water Resources, 2000, p. 145). Hydro-zones should take in account the available water budget (and also its predicted evolution in the medium and long-term); the intended landscape bearing capacity; the relative importance of the plantings' appearance; and the expected average distance to the user.

Table 2. Water efficient landscape worksheet: example of a sustainable approach to planting design for an arid region. (Adapted from (p. 29)).

Hydrozone type	Valve no.	Irrigation method	Water budget	% of total water budget	% of irrigated area	% of landscape area	Carrying capacity	Planting´s appearance	Distance to user
High water use plants	-	-	+ + + +	5	3	5	+ + + + +	+ + + + +	+
Moderate water use plants	-	-	+ + +	10	7	10	+ + + +	+ + + +	+ +
Low water use plants	-	-	+ +	35	30	15	+ + +	+ + +	+ + +
Very low water use plants	-	-	+	50	60	30	+ +	+ +	+ + + +
No water use plants (after establishment)	-	-	-	-	-	40	+	+	+ + + + +

3.1.3. Extensive, low-density planting

The simulation of new public spaces, adapted to different types of uses, has raised the need to clearly distinguish intensive green areas from extensive ones. Intensive areas, with high density planting, plentiful irrigation and greater bearing capacity, usually breed leisure zones. On the other hand, extensive areas occupy greatest surface of the green areas, and have almost no irrigation. These sorts of areas operate mainly as big urban scenarios.

Using the same treatment, i.e., the same energy investment, in both scenic and intensive use spaces is clearly unsustainable, financially and ecologically. When considering a near-zero bearing capacity of scenic areas, the need to change design principles and strategies, to prioritize efficiency, becomes clear.

The establishment of a close relation between water management and planting techniques, such as the maximization of the plantation distances between hedges (always keeping the sensation of a continuous green cover surface), the minimization of the planting tiers (reducing transpiring leaf surface area), or the use of inert groundcovers is quintessential.

3.1.4. Microclimatic regulation

Protection from sun and wind provides an important decrease in water losses through evaporation and transpiration.

Both natural and built shade elements reduce air temperature by limiting on the one hand, direct solar radiation and, on the other hand, indirect radiation from ground surfaces exposed directly to sunlight.

“[...] variations in climate significantly affect plant water loss. Experiments in Seattle and Washington, USA, found that a planting in a paved area can have 50% greater water losses than a planting of the same species in a park setting. Other studies in California found that plants in shaded areas lost 50% less water than plants of the same species in an open field condition. This variation in water loss caused by microclimate conditions needs to be accounted for in a coefficient used for landscape plantings”. (California Department of Water Resources, 2000, p. 11)

Strong winds, often carrying sand and salt, can be reduced locally, through a careful design approach, by taking advantage of the shielding effect of buildings, walls, screens and hedges, which allow non-tolerant plants to be grown nearby.

3.1.5. Run-off control

In urban landscapes, stormwater runoff from sealed and asphalted pavements should be channeled to planted swales and retention basins. In order to avoid water run-off and to provide its infiltration in extensive areas, some agronomic practices can be adapted to landscape plantings.

Different solutions can be proposed, depending on the solution's ratio cost/endurance. Among the semi-permanent solutions, the one suggested by Vallerani, in which several deep furrows are interrupted by crescent-shaped pits, where rain water is collected, seems to be fast to implement, efficient in terms of water harvesting and cheap (costs range from 20 to 60 US $/ha), when compared to other solutions. In terms of its endurance, this systems is expected to last five years, approximately (Sardo & Hamdy, p. 5).

This solution can also be applied to flatlands, through the creation of an artificial slope between the furrows, thus conveying water into them.

Other, perhaps cheaper and less durable, solutions can be mentioned, such as the microbasins, otherwise called diked furrows or tied ridges. In this case, furrows are dammed in the fall after the harvest time, that is, when there are no cultural practices. Microbasins capture the rainfall during the winter season, thus conveying all the precipitation water into the soil. It is important to refer that evapotranspiration losses are not considered, as they are usually in winter. In springtime microbasins can be easily removed with the first soil cultivation, proving that this solution lasts one single season. However, and despite their short lifetime, microbasins can be highly effective especially in salt leaching, since experiments have demonstrated that runoff can be reduced to zero, provided that they are correctly sized.

According to Hamdy (p. 4), microbasins technique seems to very important when it comes to aquifer enrichment,overland flow elimination and consequently erosion control.

3.1.6. External compensating areas

Landscape projects often focus on confined areas where water and other resources' consumption cannot be balanced by the areas' recharge capacity. Therefore, the "attaching" of external, extensive vast areas to the more intensive ones, has been proved to be an ecologically efficient method of compensation: run-off control, infiltration promotion, water and rainwater harvesting, can take place in an effective, large-scale way.

3.2. Efficient landscape irrigation practices

3.2.1. Induction of hydric stress

Sustainable planting in arid regions (strictly considered) should not depend on irrigation. However, current landscape expectations and functions in public space require initial inputs of water during establishment, and later, a minimum supply to avoid serious levels of water stress resulting in irreversible damage. Therefore, not only should most efficient irrigation techniques and equipment be applied, but also water budgets should be decreased to minimum levels.

The induction of hydric stress to landscape plantings – one of the most significant current discussions in this field – aims to reduce water uses, besides avoiding injury symptoms related to excess water, reducing soil erosion, and cutting down the cost of weed removing. It consists of providing deliberately and successively water supply indexes below the evapotranspiration indexes inherent to each species, soon after establishing, throughout an adaptation period preceding full reduction, always aiming for acceptable landscape performances. Low and irregular irrigation (i.e. uneven frequency, duration and quantity) promotes root developing, which in turn, increases plant autonomy and resiliency (the ability to recover from a shock or disturbance, for instance, water stress and related pests). Nevertheless, some studies point that susceptibility to insect attack and injury may increase with water stress (California Department of Water Resources, 2000, p. 59).

“Cerastium required irrigation at rates of 50%-75% ET during the establishment season (1991) for optimum appearance. During the second year, appearance was similar at rates of 25% to 100% ET, while visual appearance was poorer at 0% ET” (Staats & Klett, 1995, p. 182).

Careful study, selection and use of drought tolerant plants are essential. Native species from arid and semi-arid regions can maintain health and appearance without irrigation after they become established. They are already adapted to natural hydric stress. Many of them are suitable for landscape planting in public spaces, and should be used instead of exotic, more demanding species, provided that: they get a minimum water supply whenever maximum allowed stress levels occur; they are correctly grouped in hydro-zones; they are planted more densely, in hedges or massy clusters, and also mixed with other species, for more interesting visual appearance and effects.

This technique has been studied within the scientific community as a possible solution to reduce water consumption in vegetation with purely ornamental functions.

3.2.2. Localized irrigation

Localized irrigation methods, such as drip irrigation, apply water at low rates, keeping the soil around the roots near field capacity, saving water (due to reduced evaporation compared to wind affected sprinkler irrigation), preserving soil structure, and making control of pests and weeds easier. Furthermore, grey water use is possible and safe, as well as the addition of fertilizers and pesticides.

However, in dry climates, zones of salt accumulation may occur near the root zone, and if the wetted zone is not extended throughout the growing period, root development may be inadequate and disproportionate, when compared to plant’s aerial development (Verbeten, 1998, p. 10). Therefore, it is believed that efficient drip irrigation should imply irregular water allocations (uneven frequency, duration and quantity) and continuous relocation since establishing until early maturity stages, in order to follow and even promote root growing.

3.2.3. Water storage improvement

Adding organic material to the soil facilitates water storage for direct use by plant roots. Therefore, planting compost should be carefully adapted and, at least, all landscape green waste should be incorporated on site, improving nutrient recycling and inhibiting soil heating. Special chemicals sprayed on sandy soil, for instance, can improve its water retention (Aronson, 2008, p. 46). However, in hot and dry climates organic materials and polymers break down quickly. On the other hand, addition of minerals, such as clay or similar, provides a permanent soil restructuring and increases ability to hold moisture. In UAE, where this procedure has already been tested and evaluated, it is proved that it enables sustaining landscape plantings with long lasting gaps between irrigation events: every three days in summer and every seven days in winter (Abu Dhabi Urban Planning Council, p. 213).

Replacing plant cover by mulching in extensive landscape areas decreases water needs and losses. Organic mulching is believed to be the most efficient: "[…] desert soils covered with organic mulches were found to have lower water evaporation rates and less amplitude in the pattern of diel temperature fluctuations than those covered with inorganic mulch" (Singer & Martin, 2009, p. 166). Nevertheless, inorganic mulching from nearby origin (stone chippings, gravel, pebble, quarry waste), may be effective as well, besides adding different colours and textures to groundcovers.

The use of layers with different levels of permeability in selected soil depths (to decrease the water infiltration towards the deeper soil horizon) has also been tested as a real strategy to incorporate into innovative landscape principles, by reducing water consumption, increasing water use and enabling more suited mechanisms of drip irrigation (Aronson, 2008).

3.3. Environmental certification assessment tools

The sustainable effectiveness of design principles and practices within this paper may be certified by environmental certification assessment tools, such as the World Sustainability Society (WSS) [2] or the ESTIDAMA Program[3].

These certification processes rate the different systems' sustainability performance and measure human activities' impacts in the environment. Sustainable practices included in the design process, regarding natural resources preservation and natural systems' enhancement, among others, are rewarded with better sustainability results.

Various parameters are taken into account in these rating systems and water is, undoubtedly, one of the most relevant. In this study several strategies that contribute for valuable sustainability results are referred, in particular regarding water. Better results in this sort of certification can be obtained by reducing water supply, avoiding unnecessary losses and increasing infiltrated water.

This study focuses some design principles which deeply decrease water consumption and increase water retention: strategic plantation in terms of plant requirements (by clustering native species with similar water needs in hydro-zones), mixing hard-soft covers in extensive areas (decreasing planting density while maintaining the sensation of a continuum) and modulating topography in order to concentrate rainwater in lower areas. This stormwater management technique not only allows water retaining for irrigation purposes and increases infiltrated water in the soil (decreasing water run-off and consequently soil erosion), but also allows "eco-compensation", providing water storage to irrigate further areas (WSS).

Efficient irrigation practices such as the use of dripping systems and the induction of hydric stress also contribute to better results when assessing sustainability, as they avoid

[2] WSS is a non-profit foundation which the main goal is to create an universal measure of sustainability that allows to quantify the impacts of human activities on the natural resources (WSS).

[3] Program managed by Abu Dhabi Urban Planning Council (UPC) to promote sustainability and enhance liveability in the emirate under the ambit of Abu Dhabi Vision 2030 (ESTIDAMA).

unnecessary losses and reduce water supply, respectively. Mulching and soil improvement through the incorporation of organic and mineral additives help reducing water evaporation and facilitate water storage for direct intake.

It is expected that a complete and integrated use of these procedures will obtain very effective results when rating the sustainable performance of one given system, as they enhance the reduction of water supplies, promote water retention and reduce unnecessary losses.

3.4. Efficient water irrigation synthesis. Example of query tools

Figure 3: Efficient water irrigation synthesis

irrigation rate	⬤	●	⬤	●	•
plant selection	high water use plants(high density plantation)	low water use plants(medium density plantation)	high water use plants (high density plantation)	low water use plants(medium density plantation)	no water use plants (after establishment)
carrying capacity	⬤	●	⬤	●	•
observers distance	•	●	•	●	⬤
user frequency	⬤	●	⬤	●	•

When incorporating in landscape architecture's sustainable practices not only the solutions within this paper's proposed global model, but other possible solutions operating on water irrigation efficiency mechanisms as well, comparative analysis on different integrated solutions, adapted to distinct desired bearing capacities, different uses and different use's intensity become quintessential.

The table shown below demonstrates how these sort of models can be transformed into easy and efficient query tools not only within landscape architecture's context, but for all professional fields that somehow deal with water irrigation systems and water management as well, both in private and public spaces.

4. Conclusions and considerations

This paper focuses on the awareness that landscape planting irrigation in dry regions must break up with typical agronomic methods of fully evapotranspiration restitution to optimize output.

The model developed along this research is expected to provide a real sustainable and global new approach to landscape planting irrigation, aiming not only to keep water supply below evapotranspiration rate, but rather below local precipitation rate. In the last case, it becomes important to acknowledge that external compensatory areas may be required, in terms of water infiltration and harvesting.

Though still in embryonic development, field experiments taking place in Lisbon, Portugal, suggest that these goals are likely to be achieved in the Mediterranean, and also in more arid regions, provided the development of a deep knowledge of local native species with aesthetical and functional landscape value; the testing of controlled but severe extents of hydric stress; and finally the consideration of external, vast compensating areas, where rainfall infiltration and water harvesting can take place.

Further research is required in order to deepen this proposed model's mathematical expression with comparative systematic data, ecological design principles and sustainable managing practices, thus offering major water savings and rewarding environmental certification ratings.

By incorporating the sustainable practices within this document in wider landscape design solutions, landscape architecture can actually enhance landscapes' performances, especially in terms of efficient irrigation, in dry regions worldwide, therefore changing dry landscape's paradigms.

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