Strategic asset management approach for planning investment in a large-scale irrigation system

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ABSTRACT

Typically, large-scale irrigation systems are built almost entirely in a short time-frame, a significant part of the assets age at the same time and concentrated investment needs for rehabilitation are predictable. This paper focuses on planning these needs in an aggregated way, providing a big picture for the long term investment plan. A methodology for this purpose was developed and applied to a large-scale irrigation utility in Portugal. For such, the following steps were taken: (i) system breakdown by functional areas; (ii) infrastructure components disaggregation; (iii) diagnosis of the reference situation; (iv) evaluation of long-term alternatives for rehabilitation investment planning. The methodology is in line with the IAM approach recommended by IWA and the ISO55000 standards. In this paper, the specificities of this particular application, namely a proposal of irrigation component classes, and the studied alternatives, are presented. As an overall result, it was possible to indicate a path for economic sustainability without committing the infrastructure sustainability: it is based on gradual replacement of the assets reaching their useful life, combined with a constant rehabilitation rate. This paper is a contribution to an AM system for irrigation utilities, so alignment with IAM and the contribution to a broader IAM system is highlighted.

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INTRODUCTION

Urban water services have been applying infrastructure asset management (IAM) principles in the last two decades. Irrigation water services are still grasping this concept, even though the same asset management (AM) fundamentals and many of the learnings from urban systems are applicable, with some adaptations. For both types of water systems, it is essential to have long-term investment programming, particularly when the infrastructure is expected to have an indefinite life without jeopardizing service sustainability.

Irrigation water services have been interested in IAM for some time (IIDS 1995) and have been applying it recently (Kitamura & Nakaya 2010; Kustiani & Scott 2012). Agriculture water accounts for 70% of the freshwater withdrawals in the world (FAO 2012). In an increasingly productive agriculture, there is a global imperative to make efficient and wise use of irrigation water.

Urban water services have been applying IAM for nearly 30 years. Urban water services experience both internal pressures for water losses control and external pressures to assure service quality and sustainability, which are probably greater than in irrigation systems. Not only is water for irrigation usually cheaper than urban water, but also irrigation systems are seldom a regulated service. The recent economic crisis in Europe emphasised the need to rationalize and justify investments; urban water services found in IAM a solution for efficient management while assuring both service quality and sustainability in the long term (Alegre et al. 2013).

European utilities (such as for transport or water services), as utilities in other parts of the world (GWRC 2009; Jones et al. 2014; Kang 2019), are in varying stages of AM, but have in common the need for a better alignment

between AM strategy and long-term investment planning. For AM leaders, making the right investment decisions is crucial (IAM Exchange 2014). Asset managers identified the availability of platforms for long-term financial sustainability as one of the prime market opportunities (Boon 2017).

IAM is structured in three decision levels: strategic, tactical and operational. Strategic planning is associated with a long-term view, spanning the entire organization. Future needs should be anticipated for a horizon between 5 and 20 years (NMEFC 2006). Tactical planning is intended to materialize the strategies established in strategic planning, determining the way to achieve them geographically and temporally. Splitting the system into functional areas supports tactical diagnosis and analysis, both for the existing situation and for the intervention alternatives. The main challenge at the tactical level is the definition of intervention priorities. Operational planning is associated with the execution of such priorities in the short term.

The three levels are interlinked by the organizational objectives, complemented with an assessment system. This system, meant to diagnose and to monitor the accomplishment of the objectives, is structured into criteria (ISO 24512: 2007), metrics (parameters to evaluate performance, cost or risk), reference values (to classify metrics' results) and targets (proposed values for the metrics' result).

Service sustainability is a common organizational objective for water utilities, and assembling the assessment system for it is becoming common practice. To address irrigation service sustainability, there is a need to assess, among other points of view, the economic value of the infrastructure over time, the need for reinvestments, and the long-term impact of reinvestment policies. Assets of various nature, useful life, cost, age and structural condition have to be dealt with. Large-scale irrigation systems are built almost entirely in a given time-frame, meaning that a significant part of the assets age at the same time and concentrated investment needs for rehabilitation are predictable. But still, infrastructure as a whole is expected to have indefinite life without jeopardizing service sustainability.

Asset management comprises a set of principles adequate to address these concerns. For such, a methodology tailored to irrigation services was developed, aligned with the ISO55000 standards (ISO 2014a, 2014b, 2018) and with the International Water Association recommendations.

The focus of this paper is on a particular aspect: planning rehabilitation investment needs in an aggregated way, not aiming to identify the specific assets to be intervened and when, but rather to provide a big picture for the long-term investment plan.
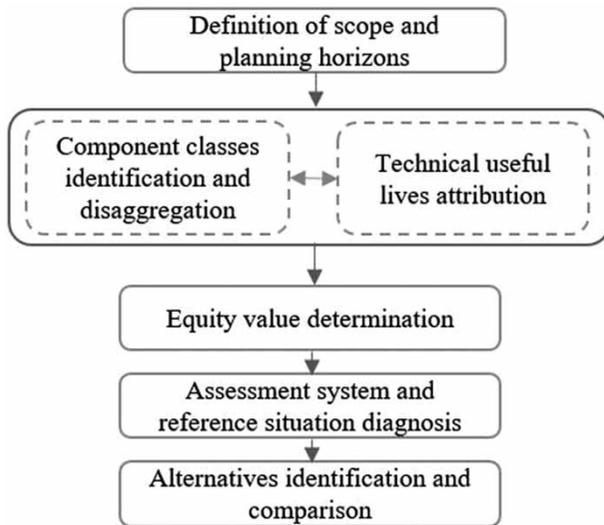
METHODOLOGY

Overall structure

Aiming to plan aggregated rehabilitation needs, in a first stage the assets candidate to rehabilitation investment have to be identified, and the corresponding current value has to be determined. Afterwards, investment alternatives that contribute to long-term service sustainability are recognized and analysed.

Regarding the performance, cost and risk dimensions, within the scope of this project the focus was given to cost, explicitly associated with the rehabilitation activity. In this context, rehabilitation includes major interventions for 'maintenance, repair or replacement of an asset involving changes in its condition or specifications' (EN 752:2008: Drain and sewer systems outside buildings). Thus, it does not cover the smaller maintenance actions, normally considered as operational costs.

Regarding the infrastructure investment value (meaning the monetary value associated with the construction of assets candidate to rehabilitation investments), special attention has to be paid to the accountancy records. When some contracts received external funding, the real investment value is not always fully registered, and the accountancy records might underestimate it. On the other hand, not all parcels in the contract's bills of quantities will be relevant for rehabilitation (e.g. land expropriation).

Of course, rehabilitation planning is intrinsically associated with the assets life cycle. However, water infrastructure as a whole has an indefinite useful life, as it provides a continuous service, and the long-term service sustainability must be ensured. Moreover, when a current value analysis starts, not all the assets are new, nor is the expected useful life the same for all, and so different life cycle stages coincide in time.

The methodology proposed in this paper is based on the steps presented in Figure 1.

Figure 1 | Methodology for planning investment in rehabilitation.

Scope and planning horizons

Regarding planning horizons, although the proposed methodology has a strategic approach, it also unfolds at the tactical level. The following planning horizons are identified: short (5 years), medium (20 years) and long-term (50–70 years). Also, an irrigation system has a system behaviour, and it is not possible to associate service quality with individual assets, as these do not provide a stand-alone service. The minimum unit of analysis and decision is a functional area, including a set of assets that, together, provide a service.

Identification of component classes and technical useful lives

This step is quite specific to irrigation infrastructure, involving different areas of expertise: water network, pumping stations, concrete and earth dams, concrete and metallic devices, roads and pavements. As referred, bills of quantities are firstly purged of interventions considered as operational costs, those that do not refer to physical assets, those assets for which rehabilitation is not expected in the planning horizon and those that are the responsibility of another utility. Secondly, even though functional areas as a whole are the basis of decision, the identification of component classes is required (groups of assets of similar typology and useful life).

Useful life depends on assets' nature and can also be greatly affected by their production, transport and storage conditions, installation procedures, their suitability to local conditions (temperature, humidity) and operation and maintenance practices. For example, reservoirs and dams may theoretically have endless useful lives, as long as they were designed and constructed according to actual best practice standards and provided they are systematically and properly maintained. Given this, the need for complete deactivation of the asset is not anticipated, within the planning horizon of this study, so for dams and earth reservoirs, the need for repair or improvement is estimated at 25% of their whole replacement cost.

It is also important to analyse the component's operating context. The same type of component may have a different useful life if it is inside a building or outside, and in this last case, if it is buried or inside a chamber, or if it is in permanent contact with water or not. The identification of practices for deactivating the component is also of particular importance. For example, a component with a long useful life (for example, a reinforced concrete bank) may have its service life conditioned to the service life of the component to which it is associated (for example, this bank may have to be removed if the pipe to which it is connected is deactivated).

Naturally, the organization's previous experience (which best knows the context in which its assets operate), is also a very relevant source of information for defining useful lives.

In water systems, there is no single criterion for objectively defining expected useful lives of assets. In addition, a risk component may be incorporated. Considering pipes of larger diameters, given their greater production quality, larger thickness and improved maintenance practices, these pipes could have longer useful lives assigned. On the other hand, since risk tolerance in large diameter pipes is lower, these pipes could be replaced earlier; that is, having shorter useful lives assigned.

Asset current value

Due to the unique character of most assets, asset current value was assessed as their updated book value. All asset costs, referring to different construction dates, were updated

to the same year (reference situation) based on Harmonized Index of Consumer Prices (HICP) and the Consumer Price Index (CPI) as in Equation (1).

$$C_a = C_n \times Fa_n \tag{1}$$

being C_a: updated cost for reference situation (€); C_n: construction costs on year n (€); Fa_n: update factor in Equation (2).

$$Fa_n = \prod_{i=n+1} (1 + t_i) \tag{2}$$

being n: construction year; t_i: annual price index (HICP/IPC) between the following year and the reference situation.

Assessment system and reference situation diagnosis

Considering IAM as the umbrella framework, Service Sustainability was identified as the objective to be met, and Economic Sustainability was acknowledged as the criterion. To address this criterion, metrics in Table 1 were proposed to diagnose the reference situation and evaluate alternatives.

IVI, the Infrastructure Value Index (Alegre *et al.* 2014), reflects the youth of the infrastructure, weighted with its residual value. IVI, in Equation (3), is a tool to support planning by combining information on the remaining useful life and cost of the various infrastructure assets. The IVI represents the degree of aging of an infrastructure, as the ratio between its current value and (modern equivalent)

replacement value.

$$IVI = \frac{\sum_{i=1}^{N} V_i}{\sum_{i=1}^{N} C_{Si}} = \frac{\sum_{i=1}^{N} \left(C_{Si} \times \frac{v_{ri}}{v_{ui}} \right)}{\sum_{i=1}^{N} C_{Si}} \tag{3}$$

(i), where V_i: current value of asset i (€); C_{Si}: replacement cost of asset i (€); N: total number of assets (−); v_{ri}: residual useful life of asset i (year); v_{ui}: total technical useful life of asset i (year).

R_r, the annual rehabilitation rate, is the annual financial effort in rehabilitation as a percentage. A_{ul} reflects the assets in service with appropriate age, lower than their technical useful life.

These metrics contribute mostly to the cost dimension, but still incorporate the risk dimension: the IVI equals 1 for infrastructure recently built or put into operation, meaning there will be a need for concentrated investment in a future narrow time window; A_r is an activity metric and has as an output the update of the assets' age; and A_{ul} reflects the fact that assets that have outdated their expected useful life are more prone to service failure. These metrics do not reflect system performance or service value.

Intervention alternatives

The AWARE-P software (www.baseform.org), developed in the AWARE-P project (www.aware-p.org) is a decision-support tool for IAM. One of its tools, the IVI module, was used for calculation of investment needs for different alternatives.

Table 1 │ Metrics in the assessment system

Metric		Reference values[a]
IVI (−)	$IVI = \dfrac{Assets\ current\ value}{Assets\ replacement\ value}$	U: [0;0.2] A: [0.2;0.4] and [0.6;1.0] G: [0.4;0.6]
Annual rehab rate (%)	$R_r = \dfrac{Annual\ rehabilitation\ costs(€)}{Assets\ current\ value\ (€)}$	U: [0;0.8] A: [0.8;1.0] and [4.0;100] G: [1.0;4.0]
Assets within expected useful life (%)	$A_{ul} = \dfrac{Assets\ with\ remaining\ useful\ life\ >\ 0\ years\ (−)}{Total\ number\ of\ assets\ (−)}$	U: [0;95] A: [95;99] G: [100]

[a]G, Good service level; A, Acceptable service level; U, Unsatisfactory service level.

Prior to the development of alternatives, the *status quo* option is analysed as a reference for comparison with the others. The *status quo* option means, in the AWARE-P approach, that 'structural interventions are not carried out and that current infrastructure maintenance and operation practices are maintained' (Alegre & Covas 2010). In a first step, alternatives consist of forcing each of the metrics towards a good service level, to a target defined by the utility. The remaining alternatives are a combined approach of the previous, aiming for a joint effect of financial stability and medium- and long-term service.

EDIA AND THE CASE STUDY

EDIA manages a multi-purpose project that includes a large-scale irrigation system located in Alentejo (southern part of Portugal, western Europe, Figure 2).

The utility was set up in 1995 and began construction of the Alqueva Project in the same year (EDIA 2019). The Alqueva reservoir guarantees a water source for the region, and its associated infrastructure is making the region economically and socially viable. The Alqueva general irrigation system, which serves circa 120,000 ha of agricultural land, consists of 69 dams, reservoirs and weirs, 380 km of primary network, 1,620 km of secondary network, 47 pumping stations, 5 mini-hydroelectric plants and 1 photovoltaic plant. The system is naturally broken down into 3 functional areas, based on the water's origin: Alqueva, Ardila and Pedrógão.

In the Alqueva subsystem, the water is pumped 90 m high to the reservoirs, along a 3.2 m diameter and 850 m long pipe, which distributes water to the whole subsystem. The Alqueva subsystem covers a total of 64,000 ha irrigated area. The Ardila subsystem has 15 dams and reservoirs, covering an irrigated area of 30,000 ha. The Pedrógão subsystem covers 24,500 ha (approximately indicated in the rectangle within Figure 2(b)), with its primary network (42 km), reservoirs and dams (9) and pumping stations (3). It was selected as the case study, as being representative of the other EDIA subsystems in regards to the network extension, construction methods, period of construction and types of existing assets.

The system supplies water for irrigation but also serves as an alternative to urban water supply, as the region suffers from severe lack of water. Alqueva supplies 25 irrigation projects, ensures water supply for 200,000 people and produces hydroelectricity for more than 500,000 inhabitants.

The irrigation system is relatively recent but the utility is already seeking to anticipate and mitigate the concentrated investment needs.
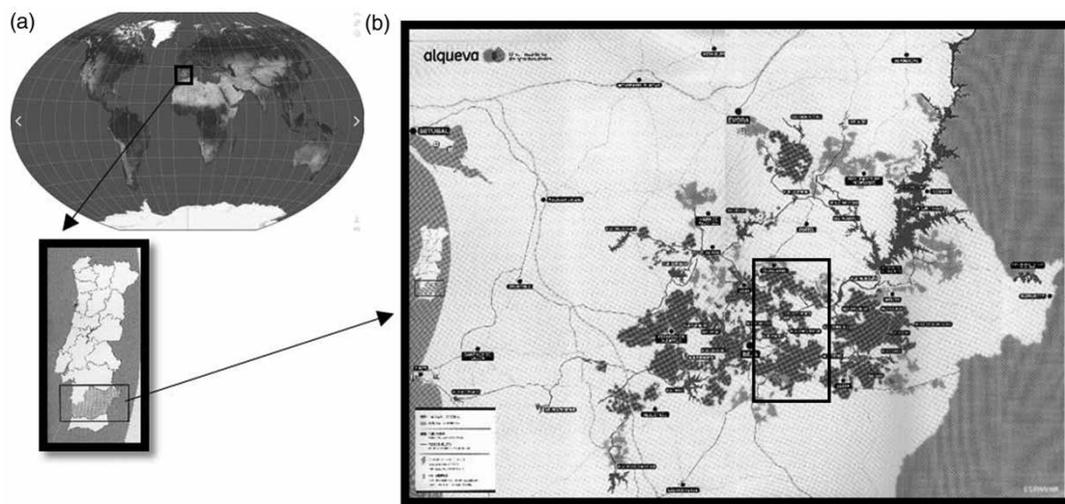
Figure 2 │ Location of the EDIA case study. (a) Alentejo region in Portugal, western Europe. (b) EDIA irrigation system.

RESULTS AND DISCUSSION

Scope and horizons, component classes and useful lives

The reference situation refers to 2017, as this study was carried out in 2018. Regarding the planning horizons, these fit the EDIA's existing planning structure: short (5 years, 2023), medium (20 years, 2038) and long-term (64 years, 2082, the end of the concession contract of the utility). As a scope, the methodology was applied to the Pedrógão case study. In this area, a total of 13 construction contracts took place between 2013 and 2016, involving more than 10,000 assets.

A first structure of component classes was established. This breakdown took into account general recommendations of the methodology, the structure of the bills of quantities awarded by the utility, and their maintenance practices. Whenever future investment is not envisaged (e.g. studies and projects, demolition of existing infrastructure), elements of the bills of quantities were excluded.

In a first-order disaggregation, four groups were organized: dams and reservoirs; buildings; water distribution network; access roads. In more detailed breakdown,

differentiating typology and useful lives were considered. Just as an example, a few of these component classes are presented in Table 2.

Some comments are due to the assignment of the expected useful life. As previously referred, specificities of irrigation systems, mainly given to the experience of the utility in the field, were taken into consideration in the assignment of useful lives, and a risk dimension could also be associated. In this project, pipes of the same material and different diameters were not differentiated, but the operating context was taken into account (e.g. a valve may have a different useful life inside a building or outside, buried unground or within a valve chamber; the geomembrane components' and accessories' useful lives differ depending on whether they have been applied to the bottom or to the slopes of the reservoirs). The deactivation practices were also considered, as a component with a long technical life may have its useful life conditioned to that of its associated component (e.g. a reinforced concrete bank may be removed when the pipe it is coupled with is deactivated). Utility's previous experience is also a very relevant source of information. Current maintenance practices are adequate.

Table 2 │ Groups of assets, examples of component classes and respective useful life (range of years)

Groups		Component classes	Useful life (years)		
Dams and reservoirs	Landfill elements	Dam/reservoir body[a]	90	–	110
		Rip rap protection	80	–	100
		Geomembrane (bottom of reservoir)	20	–	30
		Geomembrane (reservoir slopes)	10	–	15
	Concrete/metallic elements	Overflow elements	30	–	60
		Gates	10	–	40
Buildings	Masonry and reinforced concrete		80	–	100
	Electromechanical equipment	Accessories (e.g. valves)	10	–	20
	Electrical installations		10	–	20
Water distribution network	Pipes	Metallic	50	–	60
		Plastic/concrete	40	–	50
		Trenches			
		Concrete banks	[b]		
	Water channels	Concrete elements	30	–	50
		Gates	10	–	40
	Junctions	Hydrants	15	–	25
		Valve chambers	20	–	30
Access roads	Paved roads	Wear layer in bituminous concrete	10	–	15
		Base layer	20	–	30

[a]Investment is estimated only at 25%.
[b]For each bill of quantities, costs associated will be affected, in proportion to relative length, to the different types of pipes existing in the bill of quantities. The useful life of these components will be the useful life of each type of pipe.

Extending the expected useful lives by enhancing the O&M practices has not been considered.

A total of 60 component classes were identified and all assets within the case study were coded. In all previous IAM applications on urban water systems, a smaller number was adopted. In this case, disaggregation benefited from EDIA's very detailed and reliable information.

Asset valuation

For some component classes, the complete deactivation of the assets, within the planning horizon, is not anticipated (e.g. dams and landfills body, an investment of only 25% of the construction cost is envisaged). For most of the remaining component classes, the total construction cost was taken into account.

A computer application was developed to support codification of all assets (as mentioned, for over 10,000 asset registries), and also for structuring the information, updating it to the reference situation (2017) and determining asset current values. The required parameters for Equations (1) and (2) were identified on a public platform made available by the Portuguese government.

Regarding the relative contribution of component classes to the overall current value, the relevance of aggregating them into a smaller number of classes was analysed. Of the 60 identified component classes, 40 contribute individually to less than 1% of the current value and, from these, 33 to less than 0.5%, but not all have the same useful life. Some component classes of the same group have the same useful life that could be aggregated into a single component class. However, this disaggregation was kept so that the utility could choose to further differentiate useful lives (for example, after implementing the methodology in other functional areas). Also, this coding might support future IAM developments.

Diagnosis of the reference situation and comparison of alternatives

The case study had, in 2017, an IVI of 0.91, which represents the youth of the infrastructure and also results from the fairly narrow time window of the construction investments. For this reason, the result is classified as

Acceptable (against the reference values in Table 2), despite the inherent advantages of a very recently built infrastructure. This classification reflects the concern that, in a few years' time, very likely that there will be again very concentrated investment needs, also in a narrow time window.

Currently, the utility has not made investments in the system, again given its recent construction. This is why $R_r = 0\%$ was assigned an Unsatisfactory level (the reference is set for mature infrastructures). Similarly, all assets are operating within their useful life, resulting in a Good level for $A_{ul} = 100\%$.

The rehabilitation practices of the utility correspond to the *statu quo* alternative ($R_r = 0\%$). In the short term, some assets will reach their useful life, forcing a change in this practice.

The first three alternatives (A, B and C) consist of forcing each metric towards the utility's target, ($A_{ul} = 100\%$, $R_r = 3\%$ and IVI $>= 0.5$, respectively). The remaining alternatives regard the association of alternatives A + C and A + B. Other associations were tested, and these were the most interesting options. This simulation of all the alternatives in the short (2022), medium (2038) and long term (2082) was performed in AWARE-P software.

Figures 3 and 4 show the time variation of the metrics (left axis: IVI, A_{ul} and R_r; right axis: annual investment in rehabilitation).

Figure 3 presents the simulation of the *status quo* alternative. There is no investment and the rehabilitation rate is always zero. Assets in service within their useful
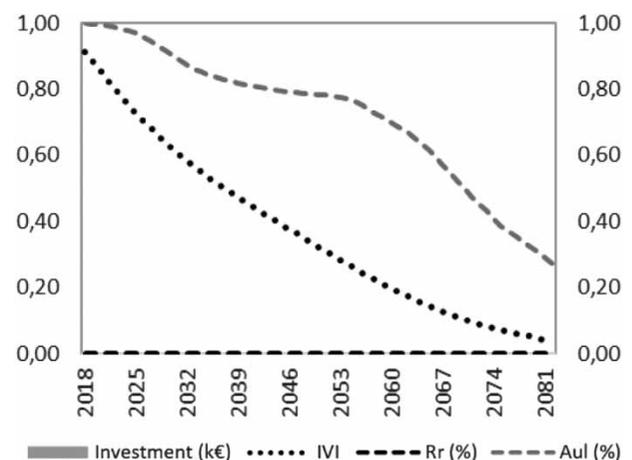
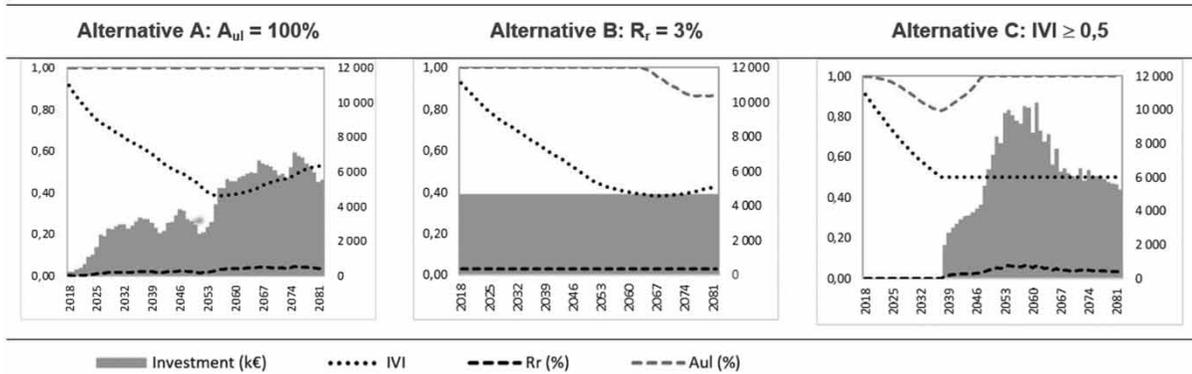**Figure 3** | Simulation for the status quo alternative ($R_r = 0\%$).

Figure 4 │ Simulation for alternatives A, B and C.

life, A_{ul}, reach an Acceptable level in 2020 and, after a soft decrease, reach Unsatisfactory in 2027. The situation deteriorates from 2040 onwards, when the IVI reaches Acceptable level, and worsens after 2056, when IVI reaches Unsatisfactory and A_{ul} decreases, reaching 50% in 2070. Although in the short term the situation does not differ much from the reference situation, worsening is evident in the medium term, and very worrisome in the long term.

Figure 4 presents the simulation for the alternatives A, B and C.

In short, alternative A already requires some investment in the short and medium term, which does not exceed 2% of current value in this horizon, but implies already considerable investments in the long term (up to 7%). The IVI is not significantly compromised and assets are always within useful life.

Alternative B guarantees financial stability, which corresponds to acceptable levels of the metrics in the short and

medium term, but can compromise the service in the long term.

In alternative C, IVI is always greater than 0.5. As the starting point corresponds to a very high IVI, it may decrease for many years. This leads to assets going beyond useful life without replacement, reaching Acceptable A_{ul} in 2020, Unsatisfactory in 2026 and minimum values in 2037 (A_{ul} of 82%), when IVI reaches 0.5 and the model forces the investment in the following years.

Figure 5 presents the long-term overview for $A + C$ and $A + B$ alternatives, combining replacement of assets reaching useful life with Good level IVI ($A + C$) or with a given R_r of 3% ($A + B$).

In the $A + C$ alternative, short and medium-term investments are made, but still a large concentration of long-term investment is required, especially from 2045 on, when IVI reaches 0.5. In this period, annual investment goes up to 6.2%. Although this alternative presents, as alternative C,
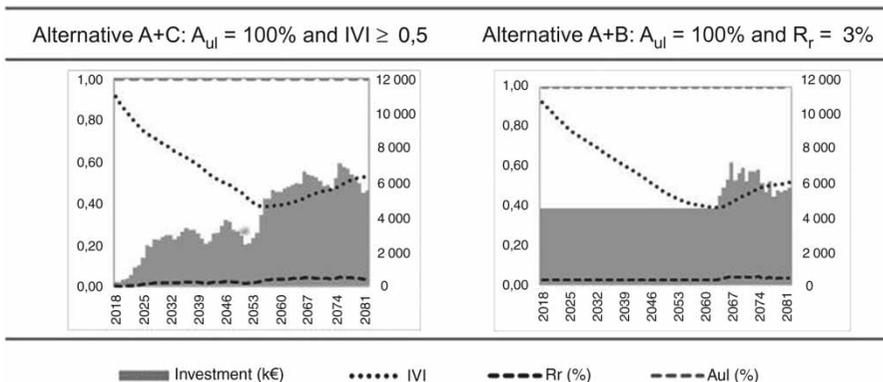

Figure 5 │ Simulation for alternatives $A + C$ and $A + B$.

the advantage of not having assets beyond their useful life (reducing service failure risk), it can still compromise financial stability.

In the A + B alternative, investment is always required, by imposing at least a constant R_r of 3%, provided that all assets operate within their useful life. Both requirements are met until 2064, when, in order to guarantee 100% A_{ul}, annual investment increases to 4.8% in 2067. With this alternative, IVI is practically always above 0.4 (the limit for Acceptable), and the assets are always operating within their useful life.

These results have a global meaning for the system. They use average life expectancies for the various assets, not the actual physical condition of each one. They do not consider functional interdependencies between assets, nor the natural changes in functional requirements. Thus, they do not fit and should not be used as specific forecasts of where, when and how to invest.

These results are appropriate for long-term management and to provide an order of magnitude of investment and of when it is expected, allowing for adequate mitigation measures to be taken.

CONCLUSION

A methodology was developed to plan investment needs in an irrigation system and to support long-term decision, based on IAM fundamentals. It began with establishing a procedure for determining the asset current value, built on a proposal for the breakdown into component classes of similar nature and useful life. This procedure, and the developed computational applications, can be applied to other EDIA areas or replicated to other irrigation systems.

The diagnosis and alternatives' evaluation, based on 3 metrics, was an important step to unfold aspects of economic sustainability, and highlighted gradual replacement of the assets reaching their useful life, combined with a constant rehabilitation rate, as the best solution. Once again, this assessment aims at long-term investment planning and not to identify particular assets to intervene or the type of intervention. Moreover, the interpretations of these metrics' results are enhanced when they integrate a complete IAM evaluation system, incorporating other points of view

related, for example, to service delivery or to the assets' structural condition. An asset that exceeds its expected useful life may still be performing well or, on the contrary, a recently constructed asset may suffer structural damage and compromise the service. These various aspects can be explored with an IAM system in the organization.

The utility may simulate other alternatives and opt for the solution that best responds globally to its objective of Service Sustainability, addressing its criterion of Economic Sustainability, without committing the Infrastructure Sustainability. The utility was provided with the computational applications that will allow it to carry out such simulations, replicate the methodology to other systems and update the data in future revisions of the investment plans.

Finally, the interest of the utility in the implementation of an IAM process has to be highlighted. IAM is a management approach appropriate to irrigation utilities, given the emphasis on provided service and asset value, by balancing performance, risk and cost in the short, medium and longterm. This concern is in line with the National Irrigation Program (Portuguese Decree-Law 77/2108), a government initiative that aims to irrigate more than 90 thousand hectares by 2022, which indicates the need for more sustainable irrigation services. The presented developments have contributed to another project being implemented with the national federation of irrigation services (AGIR project, www.fenareg. pt). Within AGIR, a performance assessment system for asset management and for hydraulic and energy efficiency is proposed to irrigation utilities, and this performance system has already been proposed to the national government's department for agriculture and rural development, for it to be used in a national strategic planning context.

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