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Economics of wastewater treatment: cost-effectiveness, social gains and environmental standards

Abstract

The spread of public services and social infrastructure has been essential to reduce poverty and inequality in developing countries. However, in spite of improving water and sanitation availability, the great majority of people in developing countries have to cope with very low coverage of wastewater treatment plants. This has had serious consequences in terms of spreading diseases and reducing wellbeing, particularly of the poor. The main explanation for this low coverage is the required high investment costs of wastewater treatment plants. On their turn, high investment costs are closely dependent upon an engineer decision interms of technological option to achieve 100% cleanup goal. This paper argues that environmental standards should be based upon the optimum level of pollution subjected to safe health requirements and overall environmental gains. This means that investments on wastewater treatment plants must be based on cost-effectiveness (CE) considerations, allowing a gradually crescent environmental standard implementation process. The authors have modeled two situations in implementing wastewater treatment units (WWTPs) using CE calculations over a twenty years period: (1) the usual optimal engineering option aimed to attend the strict standard of pollution determined by regulations; and (2) an equimarginal option, taking into consideration optimal pollution level. The results show that the equimarginal option has accumulated environmental gains that are higher than the usual optimal engineering option. These findings are particularly relevant to developing countries with strong financial and economic restrictions to invest in projects that have very high initial investment requirements and long payback periods.

Keywords: economics of wastewater, cost effectiveness, environmental standards.
JEL Classification: Q50, Q52, Q58.

Introduction

There has been a world-wide concern with the proportion of people living without access to safe sources of clean water and of basic sanitation. If present trends are maintained about 2.4 billion people in the world will lack adequate sanitation systems by 2015. Children in particular will pay a high price for this situation in terms of lost lives, lack of appropriate school attendance and low education performance due to not only malnutrition and poverty, but also as a result of diseases related to lack of safe water and wastewaters management. In many parts of the developing world, most of the generated sewer returns to natural stream beds without any specific treatment that could have reduced its environmental and social consequences. A low level of income per capita, a high concentration of population in urban areas and scarcity of capital needed for investment in wastewater treatment units make the situation even worse, spreading its negative impacts over a growing number of people.

According to the World Health Organization (WHO), in Latin America and the Caribbean only 14% of all domestic residual waters receive some type of treatment, if one considers all homes connected to available wastewater systems. This reality becomes even more critical if one adds domestic residual waters that proceed from 208 million inhabitants not connected to any system at all and that are unloaded in water courses without any treatment. Due to a process of capitation and devolution of the water for successive cities in a watershed, there usually are indirect reuses of used water. This process, added to population growth, economic development and urbanization, has represented a serious concern in many developing nations (FNS, 2004, pp.16-21).

Conventional models of development of water supply and wastewater treatment sectors in developing countries seem to have serious structural problems. Unsatisfactory indices of service diffusion are generalized. Governments have been unable to demonstrate financial capacity to cover necessary investment and maintenance costs. As a matter of fact, public investments in these sectors have shown inefficiency and contributed to social inequality over the last three decades. It is essential to choose a new management strategy if better achievements are intended for these indices. Briscoe and Garn (1995, pp. 261-267) suggest that market mechanisms must be followed by users, planners, financial agents, and operators involved in the establishment of such public policies. These agents must focus on carefully consideration of costs and benefits involved in the decision-making process. Under this vision, financing decisions are no longer an exogenous factor, exclusive responsibility of a central goverment. They must be decisions by users, who, in practice, will make choices according to how much they are willing to pay for these services.

A general challenge is, therefore, to spread basic wastewater facilities to an expressive number of people that, in general, have low income and reduced numbers of years of formal education. This has to be done in a scenario of increasing limitation of resources that must attend different social demands. Moreover, the diffusion of wastewater treatment facilities must be done without compromising minimum environmental standards that are required for the returned residual water. In spite of all expectations generated over the last three decades or so, there has been a reduction in the expansion capacity of wastewater treatment sector in all developing world. At the same time, there has been increasing conflicts with legal environmental standards established during the 1990s.

The Brazilian situation is illustrative of the dilemma faced by several countries. Almost half (47%) of the Brazilian urban population are contemplated with wastewater collection. However, only 31.7% of the country urban population have their wastewater collected and treated (MCIDADES, 2006). The difference of 15.3% between levels of collection and of treatment represents a serious environmental problem: sanitation companies dump 6.4 thousand tons of BOD_{20}/day, in the form of raw wastewater, into water courses all over Brazil (MMA b, 2006 p. 185). This environmental problem has evident and significant reflections upon quality of life and health safety of millions of Brazilians.

This paper summarizes a contribution in searching for alternatives that can reduce current deficit of wastewater collection and treatment in developing countries. Based upon environmental economics reasoning and concepts, we evaluate two alternatives for resources allocation in investment and operation of wastewater treatment units and indicate the cost-effective one. Aiming to minimize impacts of residual water, our central objective is to economically evaluate a gradual implementation of increasing patterns of wastewater treatment in these units. Our working hypothesis is that this strategy will have great social impact in the short run – in terms of diffusion of wastewater treatment coverage – and higher cumulative environmental gains over time – materialized in recovering of water bodies – for a given level of scarce financial resources.

To achieve our objective we develop a comparative analysis of two alternative procedures to implement and to operate a wastewater treatment unit (WWTP). Taking into consideration actual environmental legislation requirements, these alternatives are: (1) full and once-for-all compliance with existent environmental standards through the complete execution of an usual project of a WWTP (complete residual treatment cycle or engineering option); and (2) full but marginal compliance with existent with environmental standards through the execution of an incremental execution of an usual project of a WWTPS (complete residual treatment cycle or equimarginal option). In doing so we compare, given the present scenario of environmental degradation in the developing countries, the current strategy in which few WWTPs can be completely built with an alternative strategy of implementing incrementally a much larger number of individual WWTPS, initially providing smaller rates of treatment, but targeting higher gains over the years. In this case, the treatment processes would be enhanced throughout the financing period of the project.

It is relevant to point out that if our working hypothesis is verified, our results can be considered as paradoxical. This is so because we propose that a strategy for recovering polluted water resources should start with an immediate reduction of water quality requirements. We propose that this would provide a greater level of environmental protection for the population directly related to the use of water resources. In this respect, our findings are very relevant to any policy strategy aimed at the expansion of sanitation infrastructure in any low income society. This strategy would be based upon a gradual increment of environmental requirements over a planning horizon. In final stages of implementation, required reductions would be very high covering a much larger percentage of the targeting population.

The paper starts with a theoretical framework based upon the environmental economics literature. We also address in the same section 1 some economics of sanitation in order to be able to analyze costs involved in the formulation of public policies for this specific economic sector. In section 2 we present a brief discussion on the dilemma phasing developing countries: overall diffusion of sanitation treatment systems to achieve given water quality environmental standard and limited resources to achieve it. The Brazilian experience is used to illustrate some issues. Section 3 is dedicated to the cost-effectiveness model for the recovery of degraded water courses through the gradual deployment of pollution reduction in WWTPs. Wastewater treatment is a sequential process that is developed through different levels. Therefore, our analysis proposes to compare two alternative models terms of establishing levels of achievement during construction of a WWTPS. Our monetary estimates are also presented. The section "final comments" ends the paper and indicates potential consequences of our findings for policy formulation and implementation.

1. Environmental and sanitation economics: frameworks for pollution flow analyses

The theory of pollution flows assumes that economic agents acting in markets of factors, goods and services, each willing to maximize her or his own satisfaction or profit, will lead the economic system towards a powerful general equilibrium situation. However, as markets are imperfect in real life, the economic system, free of public policy action, does not reach conditions for maximizing the well being of all agents (Mueller, 2003, p. 63). According to the neoclassical environmental economics, if pollution takes place social utility would be maximized when the satisfaction (utility) derived from production and consumption of goods and services is equivalent to the dissatisfaction (negative utility) caused by resulting pollution. In other words, the net social benefit of pollution is maximized when the first derivative is equal to zero, that is:

$$d\,BL(\Psi) / d\,(\Psi) = d\,BT(\Psi) / d\,(\Psi) - d\,DT(\Psi) / d\,(\Psi) = 0 \qquad (1)$$

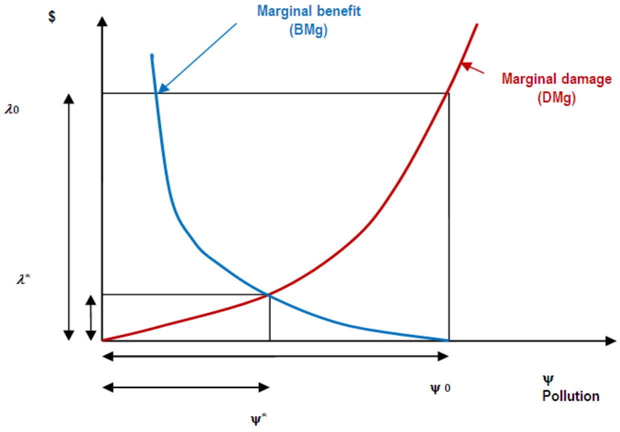
This allows to affirm that:

$$d\,BT(\Psi) / d\,(\Psi) = d\,DT(\Psi) / d\,(\Psi) \qquad (2)$$

In Figure 1 Ψ^* represents the *optimal level of pollution*. Mueller (2003) points out that Ψ^* is obtained at the point where the *marginal benefit curve* of pollution meets the *marginal damage curve* of pollution. The price λ^* is the equilibrium price of pollution. If a polluting firm had to pay this amount (for example, through the payment of a tax) per each unit of pollution emitted, it would have to reduce its level of production from Ψ_0 to Ψ^* to maximize its profit. In doing so, the firm would also reduce the pollution level to λ^* from λ_0 and, therefore, the social utility would be maximized at this *efficient* pollution level.

This elegant theoretical treatment is not easily applied in actual practical situations. The determination of the optimal level of pollution may be quite complex. Many positive and negative impacts of pollution upon economic agents are not straightforwardly measured and expressed in monetary terms. This somehow emasculates the search of an efficient level of pollution for the formulation of public policies. In some cases, one abandons the level of optimal pollution and embraces a criterion of acceptable level of pollution (Mueller, 2003, pp. 108-110). Nevertheless, economics still provides a consistent framework to choose among different and sometimes conflicting alternatives.

Any government action to protect the environment generates also social, political and economic consequences that affect society as a whole. These consequences must be expressed in monetary terms in order to feed economic instruments to help the decision-making process and to evaluate environmental policy. These instruments are essential to any environmental management process. To elaborate, implement and evaluate public policies it is necessary to incorporate instruments and techniques that make findings and recommendations based upon sound scientific reasoning and that are easily understood by the majority of society. Among many techniques to guide decision-making in governmental policies, two are widely used by economists: (environmental) cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) (Pereira, 1999, pp. 13 and 32).



Source: Mueller (2003).

Fig. 1. Optimal pollution level

To use CBA, as it is well known, is to seek efficiency in resource allocation. CEA, on the other hand, is recommended when a policy goal (environmental goal) is fixed by, say, the government and it is desired a minimization of costs to achieve it. Dorfman (1993, p. 306) mentions that the advantage of CEA is allow to seek the minimization of expenses to achieve the stipulated level of protection, if social benefits may not (or cannot) be estimated[1]. CEA is dealt with only marginally in the literature, in spite of the fact that its importance is emphasized by many authors. For example, the EPA (1993, p. 53) stresses the usefulness of CEA, since in practice the search of an optimum pollution level is arbitrarily stipulated.

CBA and ACE are usually applied upon environmental programs in developed countries, where there is great concern with the social results of desired environmental protection levels. This is not so in developing parts of the planet, where evaluation of (environmental) policies, programs and projects should be even more relevant. To achieve a given level of environmental quality it is necessary, firstly, a considerable level of technical knowledge and,

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[1] In fact, working with benefit assessment may represent a significantly complex task. Estimates may be sometimes inaccurate. On the other hand, Dorfman (1993) alerts us about the possibility of government failure in arbitrarily fixing goals.

secondly, the availability of means to achieve the desirable environmental level. In other words, the level of conservation is related to environmental standards and environmental management policy instruments are required to achieve it.

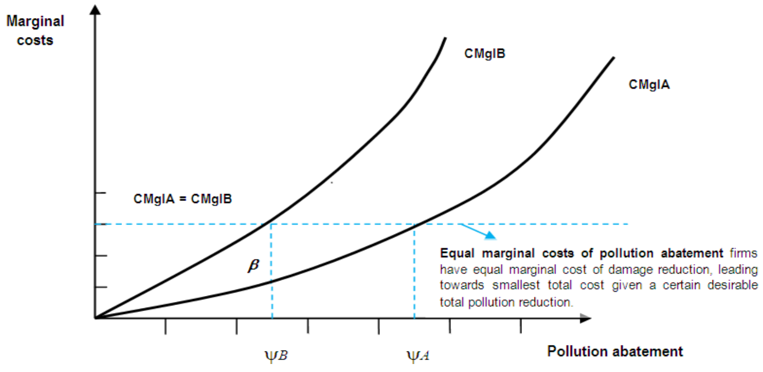
From an economic perspective, the choice of optimum level of an environmental standard is one of the most challenging decisions facing a policy maker. This choice represents, on the one hand, a restriction to private agent decision, either in terms of production or consumption. This means that private costs and benefits will be altered. On the other hand, environmental standards are aimed toward generating social benefits. Ideally, to maximize social well being, environmental standards should be fixed at a level that equalizes social costs and social benefits. This is far from being an easy task. In practice policy makers tend to fix a technical environmental standard and not an economic environmental standard. This tends to originate inefficiency in policy implementation (Jardim Jr., 2006).

In spite of the fact that environmental standards are chosen without explicitly consider economic optimality, choices of environmental policies must not refrain from applying such reasoning. As it is well known, command and control instruments of environmental policies are not substantiated in searching of economic efficiency and of maximizing social welfare. Nevertheless, levels of compliances should be guided by considerations of its costs and benefits (Perman et al., 1999, pp. 297-300). Policy instruments should be, according to Pereira (1999, p. 40), either cost-effective policies or efficient policies. Once again, there is a conflict between what is theoretically best and possible in practical level. Efficient policies are those where social benefits and costs are equal. Difficulties in establishing optimal pollution levels lead to the choice of policies that minimize costs. Cost-effective policies lead to lower costs to reach a pollution goal or provide the best results for any given amount of resources.

This differentiation is essential to the analysis developed in this paper. Therefore, we shall detail it a bit further. Environmental economists argue that they have an appropriate theoretical tool that allows us to select the lowest cost alternative to achieve an environmental standard. This tool is called the Equimarginal Principle. Perman et al. (1999, pp. 297-300) point out that "the necessary condition to achieve the lowest total cost of pollution abatement is that the marginal cost of abatement, or reduction of damage, is the same for all polluters". To facilitate the understanding of this principle, the use of Figure 2 is timely.

In Figure 2, marginal cost functions for the reduction of pollution are drawn for two different polluters (A and B). The Equimarginal Principle states that the condition of minimum overall cost to reduce pollution load (ΨT) is obtained when the marginal costs of pollution reduction are identical in A and B, i.e. where CMgIA = CMgIB. Individual reduction costs of pollution are represented by α for firm A and β for firm B. Therefore, to the desired total pollution reduction, ΨT, which is equal to the sum $\Psi A + \Psi B$, the total cost of abatement will be minimal and equivalent to the sum of areas $\alpha + \beta$ (PERMAN et al., 1999, p. 299).

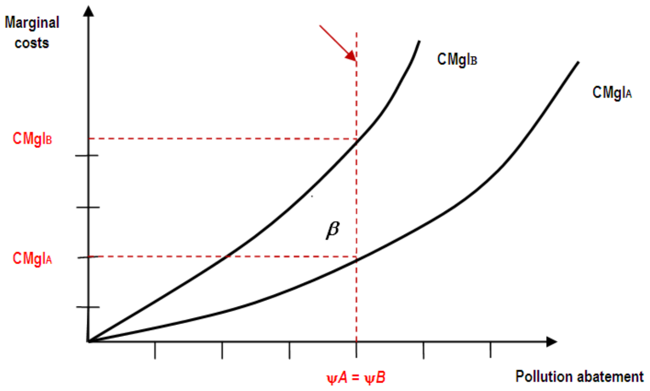
As mentioned above, governments have, for different reasons, a tendency to implement command and control policy instruments to reduce pollution from several sources. To establish the same environment pattern for agents with different reduction cost functions is not a cost-effective solution (Perman et al., 1999, p. 299). This can be visualized in Figure 3. In it we have drawn the same pollution reduction cost functions of firms A and B. When a government seeks to establish equal reduction goal for all polluters, there is no concern to examine the marginal cost of abatement involved. Therefore, according to the Equimarginal Principle, this will not allow to achieve the lowest overall cost reduction for all polluters. Total pollution load ΨT is the sum of individual polluters resulting from establishing the same environmental standard by the government. Similarly, individual reduction costs of pollution abatement are represented by α for firm A and β for firm B. As this solution is not effective in costs, total cost of reduction is not minimized (Perman et al., 1999, p. 299).



Equal marginal costs of pollution abatement firms have equal marginal cost of damage reduction, leading towards smallest total cost given a certain desirable total pollution reduction.

Source: Perman et al. (1999, p. 299).

Fig. 2. Abatement of a pollution load, assuming equal marginal pollution reduction costs for both firms A and B



Source: Perman et al. (1999, p. 299).

Fig. 3. Marginal costs of pollution reduction, assuming the same reduction load for firms A and B

2. Few winners get all: wastewater treatment and environmental standards

Brazilian waterwaste treatment systems are typical examples of using environmental standards in public policy. They are designed to promote net reduction of water pollution in obedience to state and national laws. The National Council for the Environment (CONAMA in Portuguese) classifies water bodies and establishes environmental standards for effluents that can be disposable into them. As far as wastewater treatment plants (WWTPs) are concerned, the CONAMA specifies conditions that water courses should have after receiving the material treated by them. This is a typical example of using environmental standard in environmental policy. According to Jacobs (1995, pp. 228-232), the use of primary standards is more efficient, because they take into consideration the absorption capacity of the environment. Their use is, therefore, preferable to the uniformity that characterizes the emission standards.

Metcall & Eddy (1991, p. 1195) agree with Jacobs (1995) in relation to primary standards. They argue that the fundamental element for wastewater disposal must be quantitative and qualitative characteristics of the water course that receives the effluent after treatment. They assume, therefore, that water treatment and final disposal are interconnected and cannot be considered independently. After all, the capacity to dilute determines the level of treatment required. Factors such as heterogeneous distribution of water over time and natural geographic space; natural interferences by hydrological cycle; changes in the hydrological cycle resulting from human interventions; land use in urban and in rural areas; increasing in pollution due to economic development; mismatch between frontiers of nations and limits of watersheds; the multiple use of water; among others aspects, give more complexity to water resource management (Braga et al., 2002, pp. 72-81; Carrera-Fernandez and Garrido, 2002, pp. 21-37).

To be efficient, policy makers in selecting a natural resource management strategy should know the utility functions of all actors (stakeholders) and, in particular, the production functions of all companies located in each watershed. In a context like this, they would be able to set the level of intervention that would maximize total utility without reducing anybody utility. This would mean that public policy planners should assign correct water prices and fees per unit of pollution (Mueller, 2003, pp. 61-65). Environmental standards for wastewater dilution represent cost for wastewater treatment companies, which are classical cases of natural monopoly. There is a high probability that these costs will be transfer to users of the service, who will ultimately be responsible for this new expenditure. Therefore, public policy planners must observe, in addition to the current and desirable level of degradation, community's ability and willingness to pay for pattern to be provided, mainly in developing countries (Jardim Jr., 2006).

It is clear, therefore, that water resource management and water sanitation management decisions should be taken in a complementary faction, because they are interrelated. However, economic characteristics of sanitation management makes difficult this ideal integrated decision-making process. The sanitation sector, as other public service infrastructure services, has as basic characteristics the presence of high and specific fixed costs. The main consequences of this setting, associated with the idea of natural monopoly, are dilemmas between productive efficiency and allocative efficiency and a low investment incentive (Turolla, 2002, pp. 7-8). Another consequence is related to the overall diffusion of wastewater treatment systems in developing countries.

Briscoe and Garn (1995, pp. 256-257) argue that the diffusion of sanitation services in developing countries shall probably be a long-term task. They recognize some hierarchy in terms of society demand for this type of service. Initially there is a social desire for public water supply. In a second moment, demand changes for domestic wastewater collection. The final stage would be related to environmental protection targets. They also point out that this guideline has been followed by the World Bank in financing wastewater programs in developing countries.

An example at the policy level is provided by Brazil, with the implementation of the national sanitation plan (PLANASA) since 1971. During the 1970s and mid-1980s, PLANASA promoted major qualitative and quantitative stimuli to the sector: approximately 3,200 of 4,100 Brazilian counties joined to the plan. Water distribution coverage increased from 60% in 1970 to 86% in 1990. However, coverage of urban wastewater collection went from 22% in 1970 to 48% in 1990. Wastewater treatment diffusion was much modest. These numbers were, nevertheless, very significant if one takes into account the accelerated urbanization process that the country faced at the time (Motta, 2004, pp. 3-7; Turolla, 2002, pp. 11-13)[1].

Brazilian wastewater treatment plants were designed to guarantee that water quality standards would be achieved. As a result, only 48% of Brazilian counties have wastewater collecting network and 18% of them have a wastewater treatment plant. The organic load estimated for the wholly country is of 6,389 tonnes/day of BDO_{20} (MMAb, 2006 p. 185). Therefore, the low attendance level of wastewater treatment service is an evidence that high financial amount must be spent for reducing current pollution and to also guarantee the diffusion of this service. This paper questions the effectiveness of present strategy to deal with this situation.

3. Cost-effectiveness in wastewater treatment: gradual search for pollution reduction?

3.1. Selection of wastewater treatment plant. The design of wastewater treatment plants is a significant challenge for engineers. Theoretical knowledge and practical experience are required to analyze and to select operational flows and processes that lead to the best results. There are many aspects to be observed, including knowledge of required properties; regulatory requirements; compatibility between the chosen design and equipment required by structural and operational characteristics; cost estimates, in special construction, operation and maintenance costs; environmental considerations, to mention only the most relevant. In particular, environmental impacts arising from a particular treatment plant represent determinant factors in choosing a specific plant (Metcall and Eddy, 1991, pp. 130-137).

Sperling (1996, p. 216), in reference to the analysis and selection of WWTPs, establishes a comparison between rich and poor nations. Developing countries alternatives fall upon simpler processes, more stable under alternative operational conditions, based upon low investment and operational costs. On the other hand, developed countries prefer more reliable models, with far-reaching pollution reduction achievements, providing specific requirements of slime and requiring smaller area for implementation. For Brazil, Andrade Neto (1997) argues in favor of WWTPs with simple design as the strategic path to achieve a high diffusion of wastewater treatment plants in the country.

To contribute to this debate our modelling evaluates two paths to a modular implementation of WWTPs. Our simulation is based upon collecting systems that are currently diluting raw wastewater into water courses. We estimate present value of financial costs, as well as the accumulated reduced pollution, for each alternative, during a 20-year time horizon. In the modelling exercise, we evaluate investments made available in 6 constant parcels, each one of them every 4 years, i.e. in the years 0, 4, 8, 12, 16 and 20. It was sought to establish models in line to common aspects found in developing countries (from Sperling, 1996). Thus, the choice was in terms of a treatment system with low-cost of installation and operation, with simplicity and stability in the process. WWTPs composed of stabilization lagoons satisfy adequately all these aspects and, as highlighted by Andrade Neto (1997), represent a more usual alternative in Brazil.

In this context, the study aims to evaluate the project[2] of a WWTP that serves the western portion of the city of Rio Verde in the State of Goiás, in the central-west part of Brazil. This WWTP was chosen because it was designed in units symmetrically modular. The size of this WWTP allows the treatment of a population of 105,000 inhabitants. In our simulation this full capacity will be reached in 2019. The "layout" of WWTP of Rio Verde can be seen in Figure 4.

Engineering projects designed to reconcile the economic viability of a WWTP with environmental regulations, often modulate WWTP, enabling their implementation by phases. This is so due to two basic reasons. First, urban districts experience population growth during the life-time of the project. Second, because implementation of the wastewater collection network rarely happens for the entire city. Two environmental goals are often chosen by public authorities in water related activities: BOD and termotolerants coliforms. Significant reductions in BODs are obtained trough anaerobic lagoon systems, and more significant

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[1] By the second half of the 1980s there were deep financial restrictions for the Brazilian sanitation program. With the collapse of PLANASA individual and disconnected initiatives have characterized sanitation planning in the country. In special, sanitation planning has been disconnected from water resource management. Water resource planning emphasises upon river watershed approach.

[2] We used a "Project Review of the Wastewater Treatment System of the City of Rio Verde" prepared by Interplan Company in 1999, which updates the original project developed by Estática Engenharia de Projetos Ltda in 1988. Jardim Jr (2006) shows the summary description of this project.

trough anaerobic lagoons followed by optional lagoons. However, significant reductions of termotolerants coliforms happen only through more advanced level of treatment, i.e. trough maturation or polishing lagoons. For this reason, engineering projects are often design to contemplate all steps to implement the lagoons. They allow, therefore, that complete series of treatment are achieved. This can be seen in Figure 5.

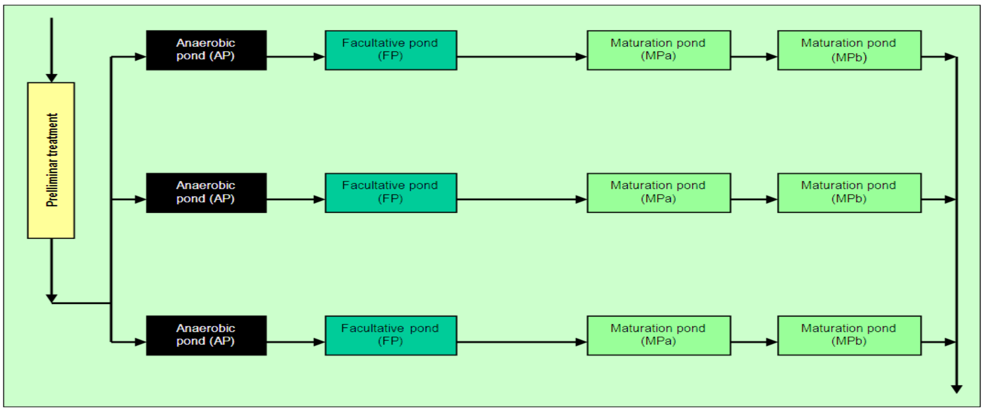

Fig. 4. Rio Verde' WWTP flowsheet – Goiás, Brazil

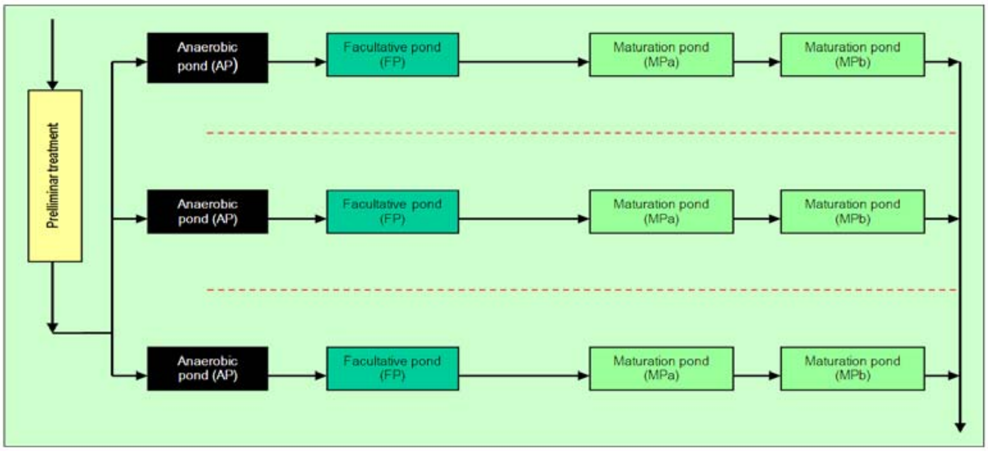

Fig. 5. Usual project in engineering design of WWTP built in a complete, all steps at once, implementing stabilization ponds in series as treatment process

On the other hand, from an environmental economic perspective, the marginal abatement cost of pollution increases with an increasing rate of pollution reduction. Therefore, a process of construction of lagoons in stages should happened following levels of treatment, as discussed using Figure 6. This differentiation in terms of a proposal by steps is justified by the fact that an engineer wishes to achieve the best technical and cost-effective solution from a single system. However, the environmental economist seeks to analyze the issue in aggregate form, aiming the highest net social benefit.

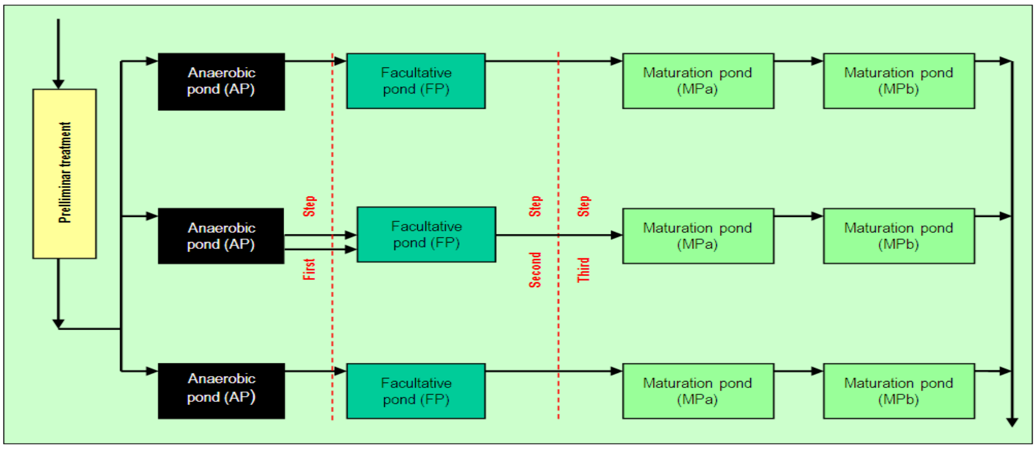

Fig. 6. Proposal of this paper to design stages for implementation of stabilization ponds in the construction of WWTPs

3.2. Basic information on WWTPS for modelling. In choosing CEA one eliminates the need to estimate socio-economic benefits arising from the project. Therefore, our CEA will compare two different forms of modular implementation of a WWTP. We will find out which alternative reaches greater environmental goal using the same amount of resources. Our selected goal for this simulation is the total accumulated pollution reduction. Given that the developed analysis is comparative, we do not take into consideration operational costs of the systems. We assume, for the sake of simplicity, that both systems demand virtually the same human and material resources for their operating conditions. In both cases, operation requires only removing debris in the preliminary treatment and to conserve and to keep the WWTP area. Similarly, there are other expenses necessary for any kind of modulation in a WWTP. For example, we do not take into consideration expenditures required for the acquisition and urbanization of the area where the WWTP is located. Construction of the control house and of preliminary treatment and control structure also has equal costs to both alternatives and they are not explicitly mentioned in our calculations. The same occurs for the mobilization and demobilization of the construction site for the various deployment steps. These costs have relevant differences in terms of the size of a WWTPS, i.e. only small units their values represent considerable weight.

Finally, it is not considered any delay between disbursement of financial resources and beginning system operations. Our hypothesis is that the period of a WWTP implementation is very short in relation to the period of study. An unit implementation is a relatively simple construction process, requiring a few months to be completed. These activities do not interfere significantly in a comparative analysis that covers a period of 20 years. For the same reason expenses related to the interconnection of lagoons are also not considered. From the foregoing considerations, costs considered for modelling are obtained from the actual budget of the Rio Verde WWTP. Table 1 presents a breakdown of cost components of this WWTP.

Table 1. Costs of WWTP components

Component	Unit costs (1 000 R$)	Quantity	Total costs (1 000 R$)
Anaerobic pond (AP)	536.1	03	1,608.3
Facultative pond (FP)	1,438.5	03	4,315.5
Maturation pond “A” (MP “A”)	532.4	03	1,597.2
Maturation pond “B” (MP “B”)	532.4	03	1,597.2
Complements (input and output boxes, interconnections) and Final Emissary (EF) of the treated wastewater into the receiving water course	33.9	01	33.9
Total	-	-	9,152.1

Source: Revisão do Projeto de Esgotamento Sanitário da Bacia Oeste de Rio Verde – Estado de Goiás, Brasil.
Note: R$ = real, the Brazilian currency, equivalent to US$ 1.70.

The effective rate of pollution reduction in a wastewater treatment unit depends upon the flow of wastewater treated, i.e. depends on organic load applied to the process. To simplify our modeling, our rates (or pollution abatement efficiency) by steps are those adopted by the project designer to explore the maximum capacity of each unit. Thus, the wastewater to be treated in a given phase is limited to the capacity installed at that phase. The remaining wastewater (collected but not treated) is discharge in the water body without receiving any treatment. In analyzing the project of Rio Verde WWTPS, it becomes clear that it was designed with three phases of treatment. Initially the wastewater is directed towards the anaerobic lagoon; then it is conducted to the facultative lagoon and, at last, toward the maturation lagoon. Table 2 shows original values of pollution reduction adopted by the project. During the implementation of the WWTP Executive Project it has been decided to subdivide the maturation lagoons into two consecutive tanks. This decision was motivated by topographic and geotechnical characteristics of the geographical area where the WWTP was going to be constructed. This change was not followed by new values of pollution abatement rates for each module. In this paper we estimated these rates following the same principles presented in the project. These rates are summarized in Table 3. It is important to realize that the “Project Review” took into consideration a production per capita of 54 g of BOD per day for a population of approximately 105,000 inhabitants at its maximum capacity. Thus, in the wastewater treatment system there is a production of approximately 5.67 tons of BOD daily. Our modeling will be based upon reduction data related to this pollution load presented in Table 3 to estimate pollution accumulated over time.

Table 2. Values adopted by the project for pollution reduction rates, expressed in BOD, by phase of treatment

Process phases	BOD (mg/l) affluent	BOD (mg/l) affluent	Phase efficiency (%)	Aggregate efficiency (%)	Cumulative efficiency (%)
Anaerobic pond (AP)	232	93	60	60	60
Facultative pond (FP)	93	38	60	24	84
Maturation pond (MP)	38	28	26	4	88

Source: Revisão do Projeto de Esgotamento Sanitário da Bacia Oeste de Rio Verde.

Table 3. Pollution reduction rates, by treatment phase

Process phases	BOD (mg/l) affluent	BOD (mg/l) affluent	Phase efficiency (%)	Aggregate efficiency (%)	Cumulative efficiency (%)
Anaerobic pond (AP)	232	93	60	60	60
Facultative pond (FP)	93	38	60	24	84
Maturation pond (MP) “A”	37	32	14	2	86
Maturation pond (MP) “B”	32	28	14	2	88

As defined earlier in this paper, investments are divided into six fractions, each one of them done every four year. For each fraction financial resources are enough to implement four systems for collection of wastewater that is currently disposal into a particular waterway or into different water courses in the same region. Table 4 shows nominal values needed to implement four WWTP in six fractions over a twenty years period. To make our simulation even closer to real life situation, each investment fraction has its nominal value increased up to 2% (approximately R$ 122,000.00), since financial disbursement must be related to implementation stages of a physical-financial timeline. In the case of residual balance of disbursement in relation to the original fraction value (positive or negative), this residual must be financially updated and incorporated into the next disbursement.

It should be noted that in a simulation model that focuses upon only financial costs, the discount rate used was that adopted by credit institutions for this type of project. According to the *Caixa Econômica Federal* (CEF) in the Annals of the First Seminar for Evaluating the Sanitation Regulatory Framework (2007), this type of interest rates vary between 6% and 8%, plus an administration fee of 1.5% per year. Thus for modeling purposes we adopted the total annual financial rate of 8.5%.

Table 4. Nominal and present values of investment fractions to construct 4 WWTP

Fraction	Disbursement period	Fraction nominal value (thousand of R$)	Fraction present value (thousand of R$)
1	Year zero	6,101.40	6,101.40
2	4th year	6,101.40	4,402.61
3	8th year	6,101.40	3,176.81
4	12th year	6,101.40	2,292.31
5	16th year	6,101.40	1,654.07
6	20th year	6,101.40	1,193.53
Total		36,608.40	18,820.74

4. Evaluating a WTPP project

4.1. The usual engineering approach. The usual path of WTPP projects from an engineering perspective proposes the establishment of sequential units that contemplate all levels of the process, focusing upon a specific pattern of disbursements. Figure 7 reflects this path of engineering project perspective. Meanwhile, Table 5 resumes financial information related to the execution of each step in accordance with proposed disbursements, as well as present value of these financial estimates. Similar figure and table for the alternative proposed are shown later in this paper. Table 6, on the other hand, provides a summary of financial values applied in this engineering alternative. It also shows respective environmental gains by each four-year period and cumulatively. This summary will be of great importance to the establishment of the comparative analysis later on in our discussion.

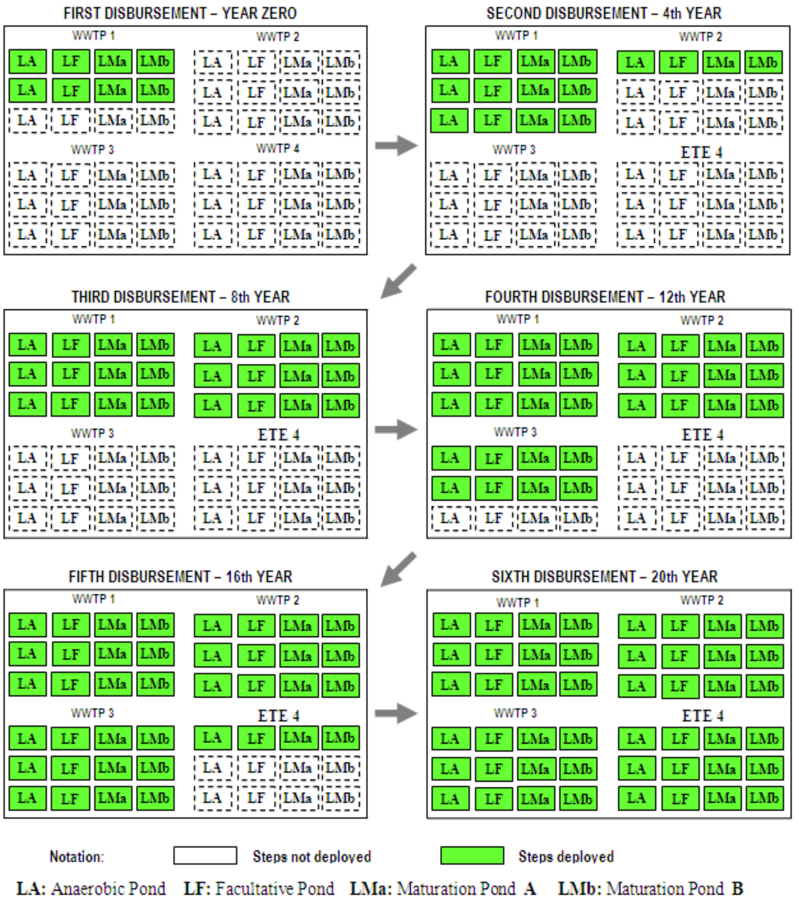

Fig. 7. Four WWTPs deployment by 6 releases, disbursements in 20 years, according to the usual approach to engineering: meet environmental requirements individually for each project

Table 5. Financial values for the execution of deployment works for the common approach to engineering (thousand R$)

Disbur-sement	Steps deployed in the works	Quant.	Unit. cost (mil R$)	Nominal total cost (1000 R$)	Nominal value provided for disbursement (1000 R$)	Nominal balance to download (1000 R$)	Present value of step (1000 R$)	Investment (1000 R$)
1	Anaerobic pond (AP) WWTP “1”	02	536.10	1,072.20				
	Facultative pond (FP) WWTP “1”	02	1,438.50	2,877.00				
	Maturation pond (MP) “A”WWTP “1”	02	532.40	1,064.80				
	Maturation pond (MP) “B”WWTP “1”	02	532.40	1,064.80				
	Complements (input and output boxes, interconnections) and Final Emissary (EF) of the treated wastewater into the receiving water curse WWTP “1”	01	33.90	33,9				
	Total			6,112.70	6,101.40	-11.30	6,112.70	6,112.70
	Updated past parcel balance			0.00				
2	Anaerobic pond (AP) WWTP “1” and “2”	02	536.10	1,072.20				
	Facultative pond (FP) WWTP “1” and “2”	02	1,438.50	2,877.00				
	Maturation pond (MP) “A”WWTP “1” and “2”	02	532.40	1,064.80				
	Maturation pond (MP) “B”WWTP “1” and “2”	02	532.40	1,064.80				

Table 5 (cont.). Financial values for the execution of deployment works for the common approach to engineering (thousand R$)

Disbur-sement	Steps deployed in the works	Quant.	Unit. cost (mil R$)	Nominal total cost (1000 R$)	Nominal value provided for disbursement (1000 R$)	Nominal balance to download (1000 R$)	Present value of step (1000 R$)	Investment (1000 R$)
	Complements (input and output boxes, interconnections) and Final Emissary (EF) of the treated wastewater into the receiving water curse WWTP "2"	01	33.90	33.90				
	Total			6,112.70	6,101.40	-27.00	4,422.10	10,534.8
	Updated past parcel balance			15.70				
3	Anaerobic pond (AP) WWTP "2"	02	536.10	1,072.20				
	Facultative pond (FP) WWTP "2"	02	1,438.50	2,877.00				
	Maturation pond (MP) "A"WWTP "2"	02	532.40	1,064.80				
	Maturation pond (MP) "B"WWTP "2"	02	532.40	1,064.80				
	Total			6,078.80	6,101.40	-14.80	3,184.50	13,719.30
	Updated past parcel balance			37,4				
4	Anaerobic pond (AP) WWTP "3"	02	536.10	1,072.20				
	Facultative pond (FP) WWTP "3"	02	1,438.50	2,877.00				
	Maturation pond (MP) "A"WWTP "3"	02	532.40	1,064.80				
	Maturation pond (MP) "A"WWTP "3"	02	532.40	1,064.80				
	Complements (input and output boxes, interconnections) and Final Emissary (EF) of the treated wastewater into the receiving water curse WWTP "3"	01	33.90	33.90				
	Total			6,112.70	6,101.40	-31.80	2,304.20	16,023.50
	Updated past parcel balance			20.46				
5	Anaerobic pond (AP) WWTP "3" and "4"	02	536.10	1,072.20				
	Facultative pond (FP) WWTP "3" and "4"	02	1,438.50	2,877.00				
	Maturation pond (MP) "A"WWTP "3" and "4"	02	532.40	1,064.80				
	Maturation pond (MP) "A"WWTP "3" and "4"	02	532.40	1,064.80				
	Accessories and Final Emissary (EF) ETE "4"	01	33.90	33.90				
	Total			6,112.70	6,101.40	-55.30	1,669.10	17,692.60
	Updated past parcel balance			44.0				
6	Anaerobic pond (AP) WWTP "4"	02	536.10	1,072.20				
	Facultative pond (FP) WWTP "4"	02	1,438.50	2,877.00				
	Maturation pond (MP) "A"WWTP "4"	02	532.40	1,064.80				
	Maturation pond (MP) "A"WWTP "4"	02	532.40	1,064.80				
	Total			6,078.80	6,101,40	-	1,204.10	18,896.70
	Updated past parcel balance			76.70				

Source: Primary research data.

Table 6. Investments made and environmental gains arising from the deployment of the usual alternative ETEs according to engineering

Period of disbursement	Parcel	Nominal cost (1000 R$)	Present value of costs (1000 R$)	Installed capacity (% of final plan)	Environmental gain per period (T BOD) (1000 R$)	Cumulative environmental gain (T BOD) (1000 R$)
Year zero	1	6,112.70	6,112.70	16.67	0.00	0.00
4th year	2	6,128.36	4,422.07	33.33	4,856.50	4,856.50
8th year	3	6,116.16	3,184.50	50.00	9,713.10	14,569.60
12th year	4	6,133.16	2,304.24	66.67	14,569.60	29,139.30
16th year	5	6,156.71	1,669.06	83.33	19,426.20	48,565.40
20th year	6	6,155.46	1,204.11	100.00	24,282.70	72,848.20
Total	-	36,802.55	18,896.68	-	-	72,848.2

Source: Primary research data.

To conclude this subsection, Table 7 presents estimates of the increase in the total costs caused by a 1% reduction of pollution. Putting in more rigorous terms, it shows estimates of the marginal cost of pollution reduction. Figure 8 shows a function of marginal cost of wastewater pollution reduction. It can be observed that in the anaerobic stage a reduction of pollution of 60% can be achieved at a relatively low marginal cost. In facultative phase there is an increase in the marginal cost of pollution reduction. This increase is even greater at the maturation phase of pollution reduction process. In this final phase it is necessary an expenditure of approximately R$ 798,600.00 for each percentage point of pollution reduced. This significant increase trend justifies to take the Equimarginal Principle into consideration in planning the implementation of a WWTP.

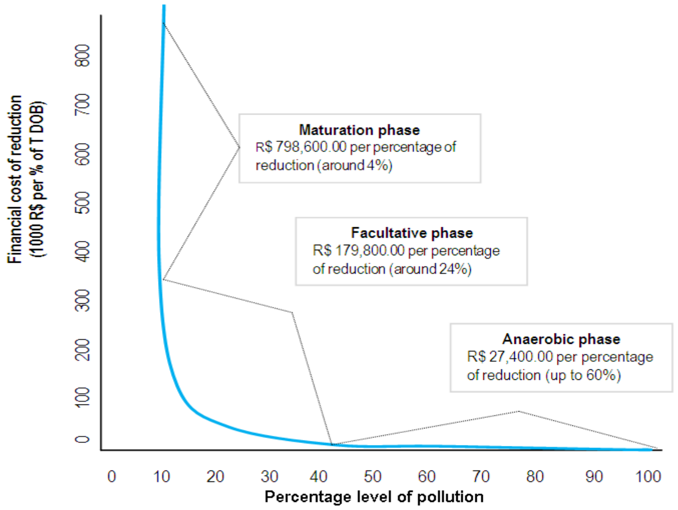

Fig. 8. Marginal cost of wastewater pollution recovery

Table 7. Obtaining the marginal cost of reducing pollution at each stage the WWTP treatment

Phases of treatment in ETE	Costs of each phase (1000 R$)	Cumulative costs (1000 R$)	Aggregate efficiency (%)*	Cost (1 000 R$) per % reduction of BOD
Anaerobic treatment (3 LA)	1,642.2	1,642.2	60	27.4
Facultative treatment (3 LF)	4,315.5	5,957.7	24	179.8
Maturation treatment (3 LM “A and B”)	3,194.4	9,152.1	4	798.6

Source: Primary research data.
Note: * Percentage reduction of T BOD.

4.2. The Equimarginal Principle into consideration. An alternative approach is based upon principles of environmental economics is used in our simulation. Figure 9 resumes our model, in which sewage treatment occurs in sequential levels for a set of WWTP. Table 8 shows nominal financial values necessary for the execution of all activities and steps to implement WWTP according to a cycle of environmental recovery. Table 9, on the other hand, presents a summary of financial values applied and their respective cumulative environmental gains for each four-year period. This estimates were made in accordance to the procedure of environmental recovery cycle, i.e. achieve greater reduction of BOD given the financial parcel committed to implementing the WWTP.

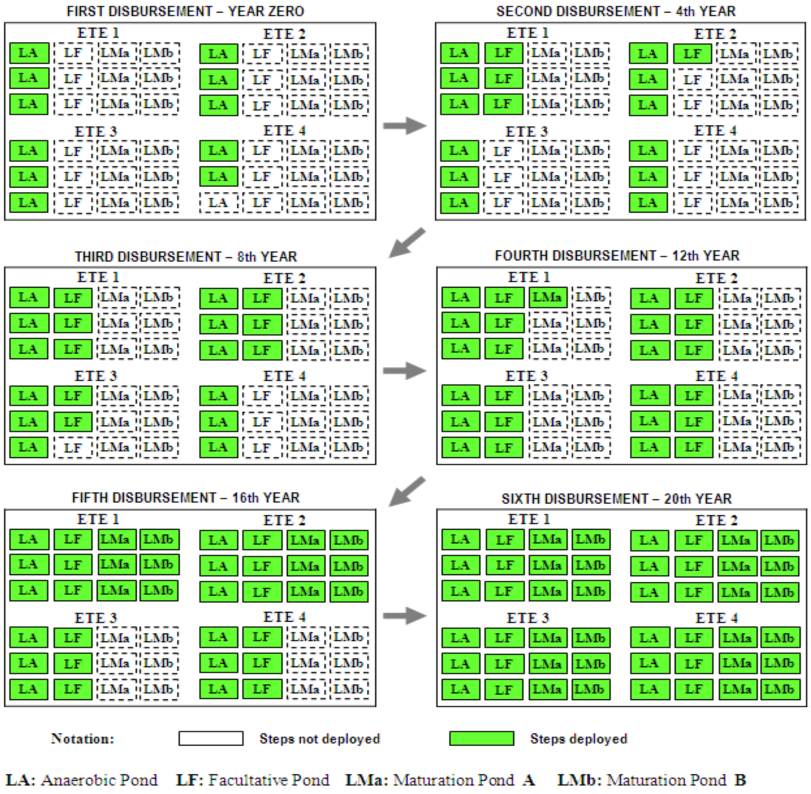

Fig. 9. Four WWTPs deployment by 6 release, disbursements in 20 years, according to the aggregate analysis approach of reducing pollution in a basin, using the Principle of Equimarginality

Table 8. Financial values for the execution of works for the common environmental economy approach

Disbur-sement	Steps deployed in the works	Quant.	Unit. cost (mil R$)	Nominal total cost (1000 R$)	Nominal value provided for disburs. (1000 R$)	Nominal balance to download (1000 R$)	Present value of step (1000 R$)	Investment (1000 R$)
1	Anaerobic pond (AP) WWTP “1, 2, 3 and 4”	11	536.10	5,897.10				
	Complements (input and output boxes, interconnections) and Final Emissary (EF) of the treated wastewater into the receiving water curse. WWTP “1, 2, 3 and 4”	04	33.90	135.60				
	Total			6,032.70	6,101.40	68.70	6,032.70	6,032.70
	Updated past parcel balance			0.0				
2	Anaerobic pond (AP) WWTP “4”	01	536.10	536.10				
	Facultative Pond (FP) WWTP “1” and “2”	04	1,438.50	5,754.00				
	Total			6,290.10	6,101.40	- 93.50	4,470.10	10,502.80
	Updated past parcel balance			-95,2				
3	Facultative Pond (FP) WWTP “2” and “3”	04	1,438.50	5,754.00				
	Total			5,754.00	6,101.40	217.80	3,063.70	13,566.50
	Updated past parcel balance			129.60				
4	Facultative Pond (FP) WWTP “3” and “4”	04	1,438.50	5,754.00				
	Maturation Pond (MP) WWTP “1”	01	532.40	532.40				
	Total			6,286.40	6,101.40	116.90	2,248.40	15,814.80
	Updated past parcel balance			- 301.90				
5	Maturation Pond (MP) WWTP “1 and 2”	11	532.40	5,856.40				
	Total			5,856.40	6,101.40	406.99	1,556.00	17,370.80
	Updated past parcel balance			- 162.00				
6	Maturation Pond (MP) WWTP “3 and 4”	12	532.40	6,388.80				
	Total			6,388.80	6,101.40	-	1,139.40	18,510.20
	Updated past parcel balance			-564.00				

Source: Primary research data.

Table 9. Investments made and environmental gains arising from the deployment of ETEs according to alternative proposed

Period of disbursement	Parcel	Nominal cost (1000 R$)	Present value of costs (1000 R$)	Installed capacity (% of final plan)	Environmental gain per period (T BOD) (1000 R$)	Cumulative environmental gain (T BOD) (1000 R$)
Year zero	1	6,032.70	6,032.70	62.50	0.00	0.0
4th year	2	6,194.89	4,470.07	72.27	18,212.00	18,212.00
8th year	3	5,883.57	3,063.69	86.36	22,516.70	40,728.70
12th year	4	5,984.51	2,248.39	95.63	25,165.70	65,894.50
16th year	5	5,739.51	1,555.96	97.77	27,869.90	93,764.40
20th year	6	5,824.77	1,139.42	100.00	28,477.00	122,241.40
Total	-	35,659.95	18,510.23	-	-	122,241.40

Source: Primary research data.

Our results clearly show the positive consequence of taking the Equimarginal Principle into consideration in the planning process of WWTP. Our proposed alternative shows advantages in comparison to the usual process of individually meet the legal standards for establishing WWTPs. The resultant accumulated pollution reduction during the 20 years of WWTP implementation is 68% bigger than that achieved in the traditional engineering model. Figure 10 highlights cumulative abatement for both options throughout stages of implementation. Results are even more significant if one analyzes abatement costs for each one of the implementation stages. For instance, through the path proposed in our model, already in the first stage of implementation there is a pollution reduction 3.75 times greater than in the usual engineering approach. As far as the marginal cost of reducing pollution is concerned, it can be observed that the primary treatment, through anaerobic ponds, brings the biggest environmental gains with the same amount of resources invested. Measured in units of thousands of real (Brazilian currency) per % reduction of pollution in terms of BOD, the lowest marginal cost of reducing pollution can be found in the phase of anaerobic pond implementation. This is due to the greatest percentage reduction of sewage impact upon the studied watershed. On the other hand, the question of pollution abatement per period can be assessed in terms of installed capacity per period relatively to the final plan of disbursement for each stage. While the path based upon the environmental economics brings a 62.5% capacity installed with the application of first disbursement, the usual engineering alternative represents only 16.67%, as it is highlighted in Figure 11.

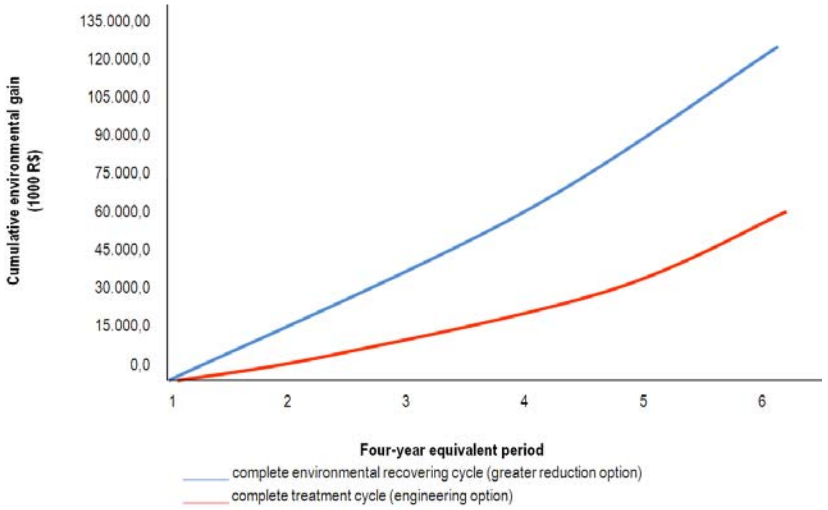

Fig. 10. Cumulative environmental gain by chosen option for WWTP construction, over a 20 year period

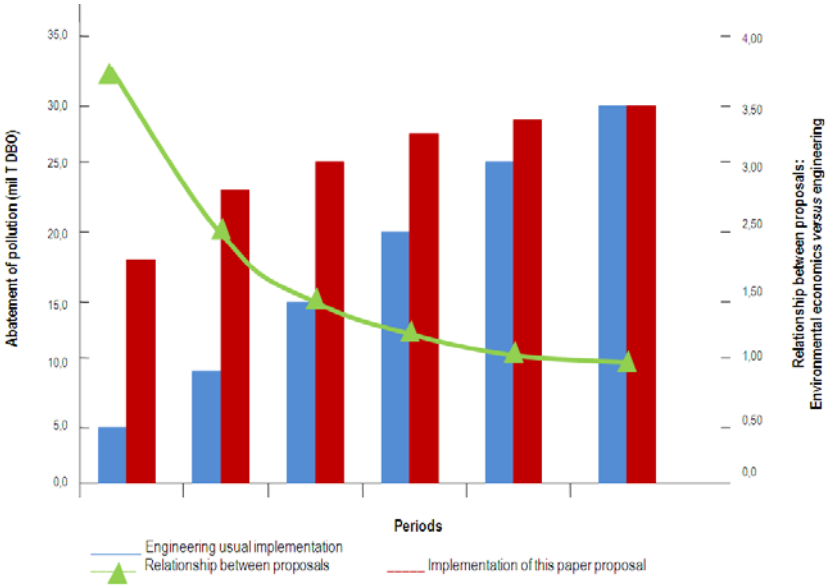

Fig. 11. Comparative pollution abatement in each period

Conclusions

The case study presented here demonstrates the fact that in a short period of time, a greater reduction of environmental pollution caused by wastewater can be obtained when changes are made on WWTP implementation process. The importance of these results minimized for countries that have strong financial restrictions for execution of projects which, in most cases, will only be completed with the extension of deadlines for deployment. Only as an example, in the case of Brazil, restrictions on the expansion of sanitation services are motivated by the scarcity of resources for investments. These limitations have caused a significant pollution of waterways by sewage with long-term health consequences.

There are, therefore, comparative advantages of deploying WWTPs by assimilation of marginal costs of pollution reduction in relation to a desirable standard individually achieved by each system. In this case, results of our modeling, focusing on the cost-effectiveness of the proposal, represent a tool in favor of spreading water treatment services with lower costs. Results of our modeling also offer a new approach to the sanitation sector in terms of a gradual implementation of environmental standards. Local specificities on self-debugging of water bodies, regional agglomerations, among other aspects may lead to differentiated solutions and, therefore, need to be evaluated.

It is relevant to point out that for water bodies that are not yet affected by sewage, it is not simple to apply the equimarginal principle. After all, our modeling assumes a high pollution load condition since the beginning of the period of study. How to consider increasing pollution loads, where sewage treatment would represent only part of necessary investments for the expansion of the treatment system? The theoretical base for this initiative would have to consider that the construction of the treatment system, with the gradual deployment of treatment, will represent a comparative advantage in relation to the initial sanitary conditions of the area under study.

As a final comment, it is important to highlight that our modeling focused on reduction of BOD. Therefore, to consider a set of environmental standards to be achieved in the sewage treatment process still needs further investigation. The incorporation of aspects linked to the reduction of termotolerant coliforms will require a more refined process of measurement of the marginal costs of reduction of pollution from sewage. Nevertheless, basic conceptual framework and methodological procedures will be those proposed in this paper.

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