Economic Criteria for Applying the Protector-Receiver Principle: Case Study of Três Picos State Park, Rio de Janeiro, Brazil*

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Abstract

Apart from river basin water charges, another payment is due for water uses in Brazil within the regulatory framework of the National System of Conservation Units. The legal text is clear in stipulating the possibility of charging a financial contribution from users of a water resource for the establishment and maintenance of the conservation unit that protects this resource. This charge has been called an application of the "protector-receiver principle" (PRP). Our view is that this charge is payment for a service in which the dominant criterion is recovery of costs. Therefore, we present a conceptual and theoretical description of the economic water-pricing criteria to justify our regulatory approach to the protector-receiver principle. Based on these criteria, we propose a method to determine the application of the PRP. Then we carry out some exploratory exercises with this methodology in the case of Três Picos State Park. We conclude by discussing the procedures necessary to apply the proposed model in other parks.

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Introduction

A new phase in the management of water resources (WR) in Brazil began in January 1997 with the enactment of Law 9433, which established the National Water Resource Policy (*Política Nacional de Recursos Hídricos*, or PNRH). Besides this national law, nearly all the states have passed similar legislation. Four principles of this law are responsible for the new treatment of water resources: management by basin; uniqueness of the grant of water use; requirement for a management plan; and charging a fee for water use. All these laws are still in the phase of regulation, during which the criteria for their full implementation are being defined.

Management by basin recognizes that water use is multiple, excluding and generates externalities, and thus the basin represents the locus where users interact. The uniqueness of the grant permits a better definition and guarantee of water use rights. The management plan introduces the objectives of availability and demand for the resource in time and provides an investment plan for the basin. And finally, the fee charged directly determines a price for the water.

This tariff will be guided by the principle of user/polluter pays[1]. The new Water Resource Law explicitly recognizes that water has an economic value and that the instrument of charging for its use aims at rationalizing this use, but also must be determined by the investments called for in the management plan.

This dual objective creates complexity in defining the criteria for assessing water charges, a fact that has been revealed in the pioneering experience of the Paraíba do Sul Basin, where the regulation is mainly based on financing objectives (see Seroa da Motta *et. al.*, 2004b).

Apart from these water charges, another payment is due for water uses in Brazil that was stated in Articles 47 and 48 of Law 9985/2000 which reformed the National System of Conservation Units. This dual conflicting objective of financing and behavior appears not to exist in this case. The legal text is clear in stipulating the possibility of charging a financial contribution from users of a water resource for the establishment and maintenance of the conservation unit that protects this resource. This charge has been called an application of the "protector-receiver principle" (PRP). Our view, explained below, is that this charge is payment for a service in which the dominant criterion is recovery of costs. Therefore, in the following sections we present a conceptual and theoretical description of the economic water-pricing criteria to justify our regulatory approach to the protector-receiver principle. Based on these criteria, we propose a method to determine the application of the PRP. Then we carry out some exploratory exercises with this methodology in the case of Três Picos State Park. We conclude by discussing the procedures necessary to apply the proposed model in other parks.

[1] In this context of charging, this principle refers to payments *ex-ante* the generating fact, while in the case of lawsuits it is applied to *ex post* payments, such as indemnifications.

1 – The Economic Criteria of the PRP

In the context of the protector-receiver principle (PRP), a conservation unit (CU) acts as a monopoly provider of a public asset, since such a protected unit ensures the water affluence with its conservation of the soil and forest cover. Its activity is similar to that of a water utility, except that instead of treating the water chemically, the CU does this naturally, as a conservationist. Although conceptually similar, the CU act as a supplier of the sanitation operator that serves the basin protected by the CU, and hence the operator will have to pay for the CU's protective service, just as any protected user.

This charge via the PRP, however, differs conceptually from that promulgated in Law 9433. The water charges under the PNRH aims, as mentioned before, to satisfy the objectives of rationalized use, and hence prices are signals of scarcity and the management costs associated with this objective. The CU's provision costs are independent of the scarcity level, and thus differ from the level of prices charged under the PNRH. In other words, the prices under the PRP are exogenous costs to the PNRH system. Once again, like a sanitation utility, the CU passes on costs to users in addition to those charged under the PNRH.

The water charges in the PNRH, in using prices to regulate water scarcity or to finance its projects, will have to consider the charges of the PRP, because the latter raises the costs to users, and thus affects how much they use. There is nothing new in this, since the models for analysis and simulation in the ambit of the PNRH already do the same thing regarding the costs incurred by users, whether by paying the operators or incurred themselves for catchment and treatment. The PRP would only add a cost to users already incurred and internalized in the models.

To sum up, the charge for water under the PRP is a price whose objective is to finance the management of the CU, and thus is part of the charge for provision of a public good in the form of a natural monopoly.

In this case, the monopolist can ask each user to pay the average cost given by the quotient of the total cost divided by the quantity consumed, but does not do so because it knows the users will modify their demand at different rates as the price rises. Hence, the monopolist will seek to act in the more inelastic part of the demand curve of the user or type of use, because there demand reductions are proportionally smaller than price rises, thus not causing falls in the monopolist's marginal revenues. In other words, the elasticities delineate the levels of cross subsidies among users or uses.

Since this is the case of a public monopolist that does not maximize revenue, but instead maximizes recovery of its costs, the prices should maximize the welfare generated by the water consumption, given the restriction that the marginal revenue must equal the need to finance provision and expansion. A simplified expression of these prices (t) is that a differentiated portion (t - Cmg/t) per user charged above the marginal cost (Cmg) to finance the cost of expansion will be directly proportional to the β that captures the marginal utility of the income (the value of an additional monetary unit) and inversely proportional to the elasticity of demand of each user i (e_i), in the following form:

$$t_i - Cmg/t_i = \beta\ t_i / e_i \tag{3}$$

Thus, users with less elastic demand will pay more than those with more elastic demand. The intuition of this rule is (i) not to collect more than necessary to recover costs, and (ii) that more elastic users receive lower prices because they tend to alter their demand less when faced with positive price variations. This has been the basic rule for pricing public goods, or the Ramsey/public pricing rule [2] when these are not financed directly by the public treasury. This criterion applies to any monopolistic service.

In this form, the inelastic demands finance the elastic demands, since the latter generate greater gains from economic excess. In the case, the most appropriate inelasticity would be that which considers the reaction of both users and producers of substitute goods, which is generally called residual elasticity. In other words, this is a higher elasticity than the marshalian elasticity, which is only the partial derivative of the demand in relation to the price, all else constant.

Note that this rule can also be applied to consumption by quality, in which the user's demand for pollution clean-up services is given by its pollution control cost curve, i.e., its willingness to pay is given by the control costs.

1.2 – The Limitations in the Case of the PRP

Next we address the main limitations of applying the public pricing rule and how these would affect the regulation of the protector-receiver principle.

Tariff: The application of the public pricing rule in the case of the PRP would be to charge a tariff t_i above the marginal cost of each user's present water consumption in inverse proportion to its elasticity, assuming β equal to one, that is, $t_i = t/e_i$, where t would be the CU's average protection cost.

Estimates of the parameters: So far no pure application exists of the Ramsey rule due to the complexity of estimating the parameters β and e_i **of** its function for all users, whether due to unavailability of data or technical difficulties of the method. In practice, regulators determine (i) a reference for the costs to be recovered, and (ii) an average tariff that recovers these costs (in the case of concessions, this tariff can be subject to public auction to the lowest bidder), according to a forecast

[2] This is the Ramsey rule of public prices. Note that we are assuming that the cross elasticities are nil. For a more detailed analysis of pricing of public services, see for example, Starret (1988) and Atkinson (1980).

demand and the social subsidies that the legislation demands. The operators choose the differentiation of tariffs among the types of services (or consumers) according to these subsidies and rough estimates of the demand elasticities, which they revise with the observed revenue results.

Tariff adjustments: To guarantee the monetary value, the tariffs are adjusted through two mechanisms: (i) variation in the operating cost plus a maximum rate of return on capital (average cost); or (ii) variation of a general price index less an expected productivity gain in the sector (price cap model)[3]. In the case of the PRP, the approach of close monitoring to calibrate the tariffs will also have to be followed. For periodic adjustments the identification of productivity gains would be very complex and controversial, while the variations in costs would be very simple to determine, and hence, the average cost approach is the most advisable.

Sector conflict: Generally the industrial and agricultural sectors have higher price elasticities than urban users due to the technological options of their industrial production functions and the high sensitivity of agricultural output to the water input. In these cases, with the use of this public pricing rule, the prices charged to urban users will be higher than to other users. This situation winds up creating a source of sector conflict that generally results in a practice of cross subsidies among users that are not the ones derived from the Ramsey rules.

For example, the financial unfeasibility of agriculture in the face of realistic water prices causes, all over the world, agriculture either to be exempt from charging by the user/polluter principle, or to be benefited with highly subsidized water tariffs from public irrigation projects (see a review of the international literature in Tsur *et. al.*, 2004 and Seroa da Motta *et. al.*, 2004a)

Residential use also has enjoyed subsidized rates (i.e., lower than those derived from the rule described above) by distributive justifications[4], although in this case with progressive tariffs that in a certain form increase in proportion to consumption to try to distribute the provision cost between rich and poor.

Industry, in turn, is considered the user with the greatest capacity to pay, since the cost of water is quite low in relation to its total costs. It thus tends to attract a higher tariff, even with its political force and importance in generating jobs. Studies (see, for example, Feres *et. al.*, 2005 of the case of the Paraíba do Sul Basin in Brazil) show that in these cases reduced consumption can occur and result in lower revenues than desired.

Thus, it is not surprising that the recovery of costs is often incomplete by providers of public services, which are affected by political administration of tariffs, particularly in cases of government-owned water utilities. The best evidence of this is that the participation of private capital only occurs when there

[3] See, for example, Lafont and Tirolle (1993).
[4] Or social tariffs that subsidize certain consumers characterized as low income.

is a very clear and stable regulatory framework (see Salgado and Seroa da Motta, 2005 for cases in Brazil).

The above considerations are more perceived in public utility sectors that require huge investments, and hence high tariffs. If this is not the situation, that is, if the estimated tariffs are very low, the effects of demand will be marginal and consequently their impacts on the revenue collected will be low. In the case of the PRP, the costs to be recovered tend to be low, but such problems can arise because of a reduced number or users, which consequently exert significant individual charge levels. Hence, the risk of deficits is great due to the public operational nature of the CUs. On the other hand, the opposite can also happen with the application of abusive tariffs and tariffs subject to nonpayment or lawsuits. To eliminate these two types of risks, the regulation of charges under the PRP must be as complete and transparent as possible. This also means that distributive tariffs must be explicitly assumed and accounted for.

Interconnection between basins (sub-basins or segments[5]): Nearly always the consumption of a user in one sub-basin affects others in another basin, sub-basin or segment of a river. Thus, the prices in effect on one basin can affect the optimal level of another basin by diverting demand to it. This limitation could well be significant in situations of complementarity of the basin protected by one CU with other basins protected by other CUs. As discussed above, if these questions arise in relation to other basins outside the protection of a CU, these should be internalized in the ambit of the price charged under the PNRH, and thus should not be considered in modeling the PRP.

Measurement of consumption: The marginal cost of measuring consumption can be so high that it does not offset the additional revenue generated. In these cases it would be better to use approximations of consumption, even if underestimated, through technological parameters. Parameterized estimates are possible from production/revenue data. Since this form of measurement can be imprecise, it is common to allow the user to prove its actual use through independent auditing. In the case of the PRP, this approach would be very satisfactory, because of the possible concentration of consumption in a reduced number of users.

Rationing and seasonality: The availability of water is stochastic, i.e., it is associated with a probabilistic function. In certain periods, even with adequate revenue and no free riders, water may have to be rationed for purely hydrological reasons. In these cases, once again the consumption of water by one user excludes another user, and thus generates a negative externality. Rationing can also be caused by demand variations, because of seasonal use. This is typical of agriculture or residential use in tourist areas. The water supply solution is independent of the level of revenues, because in the short term there is no way to make more water available. Note that supply management that maintains consumption sufficiently below the maximum availability to avoid having to

[5] In the environmental literature, this problem is called the multi-zone problem. See Tietenberger (1996) in this respect. For a simulation analysis in the basins in the state of São Paulo, see Seroa da Motta and Mendes (1996).

resort to rationing would be a non-optimal allocation, because for various periods of non-rationing, users with positive benefits would be excluded.[6] Hence, if there is a risk of a mismatch between supply and demand in applying the PRP, seasonal prices will have to be created that rise as the risk of excess demand increases.

2. The Proposed Pricing Methodology of the PRP

In this section we present the method for determining the initial tariff level for application of the PRP and the rules on adjustments and governance according to the recommendations presented in the preceding section.

2.1 Tariff Determination Model

The formula below aims to represent all the parameters necessary to estimate the initial tariff level of the PRP (t_i), as follows:

The tariff, t_i, to be charged to user i would be composed of the following parameters:

$$t_i = t \times b_i \times d_i \times (1/e_i) \qquad (4)$$

where:
t = basic tariff per m^3 of protected water;
b_i = proportion of water use by user i that is due to the protector contribution of the park;
d_i = distributive weight attributed to user i;
e_i = price elasticity of the water demand of user i, and the parameter $(1+1/e_i)$ would be a compensation for its price sensitivity.

Note that we are disregarding the marginal utility of income or assuming it is unitary. For e_i we can obtain an estimate directly in the basin or use values estimated in the literature. Nevertheless, we will nearly always be estimating Marshallian and non-residual elasticities. For b_i we can have estimates from the results of the water balance. The imprecision regarding the use of estimates from other basins has to be evaluated against the costs of undertaking specific studies. These studies are statistically fragile if there is not data available from a large number of observations per user and in time, as generally occurs in basins where there are few users.

On the other hand, d_i is a strictly subjective parameter and its identification will be totally arbitrary based on some value judgment about the need to subsidize a certain group of users.

The basic tariff t from expression (4) would be estimated by resolving the following expression for all users i of the protected basin:

[6] This means to say mathematically that the congestion point must be reached for optimization.

$$TE = \Sigma(t \times v_i) \qquad (5)$$

where:
TE = total expenditure for protection of the CU to be recovered;
v_i = volume of water consumed by user i.

Note that the expression TE measures the potential expected revenue under the hypothesis that users would not react to the prices. However, since users are price elastic, there will be a diversion of demand resulting from a price increase given by:

$$\Delta TE = \Sigma\ (\%c_i \times e_i \times v_i \times t_i) \qquad (6)$$

where:
$\%c_i$ = price increase per m^3 of water for user i with application of t_i, estimated as t_i/c_i.

Note that no diversion of demand occurs if all the users are infinitely inelastic, that is, e_i = zero. In this situation, the tariff estimate only depends on TE and v from expression (5), and its application would then be similar to charging users purely in proportion to their consumption.

With the diversion of demand, the basic t values of expression (4) will have to be resolved iteratively until they converge to a demand diversion near zero. Hence, the estimates of t_i can adopt a very simple methodology with the following steps:

1- Calculate the quantity of t in expression (4) for each user.
2- Substitute these quantities for t in expression (5) to calculate a total value in terms of t.
3- Divide TE by this total in t to determine an initial value of t.
4- Substitute the initial t in expression (4) to calculate the initial values of each t_i.
5- Estimate with the values of t_i the demand diversions ΔTE of expression (6).
6- Vary the value of t incrementally upward or downward and calculate new values for TE, ΔTE and t_i.
7- Estimate the new difference (TE - ΔTE).
8- Repeat step 6 iteratively until the difference (TE - ΔTE) is near zero.
9- The value of t when this difference converges to zero is the final value of t.
10- With the final value of t, calculate the final values of t_i.

Note that this does not entail zeroing ΔTE, because with each iteration with a new t value the potential revenue to defray the TE increases. Hence, what matters is the difference (TE - ΔTE), which will be the effective revenue from water charges.

2.2 Rule for Adjustments

To apply the PRP as proposed above, it is necessary to know a large number of parameters in advance, many of which are imprecise and/or change over time. Since the above methodology intends to ensure that the revenue collected exactly matches the cost to be recovered, there need to be rules for periodic adjustments. Stable rules aim to limit the uncertainty in the tariff variations and thus to reduce the impact of the tariffs on the expansion of the basin's productive capacity and flow of revenues to the CU.

The parameters TE, e_i, v_i, c_i, and b_i that affect the estimation of the tariffs must be justified in the **Plan for Application of the PRP (PAPRP).** As described below, the rate adjustments can be either technically measurable or automatic, with specific rules for each type.

2.2.1 – Technical adjustments

The parameters TE, e_i, v_i, c_i, and b_i can be technically measurable and specific periodic studies can be conducted[7]. In the first year of applying the PRP, the CU determines benchmark estimates in the PAPRP based on studies and data in the literature as justification.

Revision of the TE: We propose that the TE be revised by the CU annually by rendering accounts of the previous year and making a forecast of the variation of costs or additional protective measures, in the form of a new PAPRP. This new PAPRP can also revise other parameters based on new studies or data in the literature. It must be made available to the users prior to end of the year that it is to take effect in order to be analyzed by any user or group of users as long as they pay the costs of the auditing process.

Revision of the specific parameters of each user: The parameters e_i, v_i, c_i, and b_i can also be revised for the next year by request of a user or group of users, through a technical study, again as long as it bears the respective costs.

In the two cases above, where there is a technical audit of the PAPRP and/or a technical study of parameters at the behest of users, a recognized technical institution will have to be engaged. The CU can request a technical opinion based on this study or audit by an institution of its choice, with the costs covered by the requesting user(s).

Note that a user will only seek such revision if it perceives that the expected value of the savings will be greater than the costs incurred in the revision. This decentralized form avoids inefficient outlays on revision studies or acting on controversial studies.

[7] As was done by Seroa da Motta et. al. (2004b) for the Paraíba do Sul River Basin.

2.2.2 – Automatic adjustments

Revenue mismatch: Given the imprecise nature of the model's parameters, as discussed in Section 1, no matter how good the calibration, there is a high likelihood that the revenue effectively collected will be below or above the expected amount in the PAPRP. Additionally, it is plausible to expect some default. Therefore, any surpluses from one year will be automatically deducted from the TE to be recovered in the following year, and any deficits will be likewise added.

Variation in the number of payers: The solution of expression (5) depends on the number of users i, and since this number can change from year to year, once this alteration is observed, a tariff revision will be carried out considering this new universe of payers. In this case, the values of t would be automatically recalculated for the next year in the presentation of the new PAPRP.

In both cases above, no audits or technical studies would be required.

2.3 Governance

In principle, it is the job of the chief officer of the CU to manage the PAPRP and implement it within the rules proposed above, along with deciding on users' revision requests. However, it would be efficient for the system as a whole to encourage cooperative actions and mechanisms to reveal private information.

Therefore, we propose the creation of a **PRP Committee (PRPC),** established in the CU bylaws, composed of five members: the chief officer of the CU, a representative of industrial users, one of sanitation operators, one of agricultural users and of the governments of the municipalities[8] in the area. The representatives of users will be elected by the support of at least 80% of the users (paying and exempt) of the respective sector, and these users cannot individually be responsible for more than 20% of the consumption in the basin as a whole.

The committee would meet twice a year or extraordinarily by request of the chief of the CU or three of its other members. The PRPC would decide by consensus of its five members and could decide the following matters:

1- To change the amounts and composition of the TE, including regarding expenditures on technical studies.
2- To decide on conflicts between technical studies and audits carried out in response to users' requests.
3- To determine the scale of values of the distributive weights d_i.

[8] Brazil is administratively divided into states and municipalities. The latter have qualities of both cities and counties, in that they have a single mayor and municipal council, but can take in more than one town or settlement in the case of rural municipalities.

3. An Application in Três Picos State Park

In this section we carry out an exploratory exercise applied in Três Picos State Park (TPSP). We first describe the park's ecological importance. Then we present a proposed PAPRP for the park that justifies the estimated parameters and run some simulations for tariff determination.

3.1 Três Picos State Park and the Guapi-Macacu Basin

The Serra do Mar [Coastal Mountain] Biodiversity Corridor, running through the states of Rio de Janeiro, São Paulo and Minas Gerais, contains forests with great biological importance near Brazil's two main metropolitan regions (São Paulo and Rio de Janeiro). This implies strong anthropic pressure on the natural resources in the region, especially water. Many remaining forested areas compose conservation units, among them Três Picos State Park, located in the state of Rio de Janeiro.

The park was created in 2002 by State Decree 31,343. It has a total area of roughly 46,350 hectares (about 115,000 acres), representing an increase of 75% in the area protected by parks and reserves in the state. It takes in the municipalities of Teresópolis, Nova Friburgo, Guapimirim, Silva Jardim, and particularly Cachoeiras de Macacu (2/3 of its area). Due to its recent creation, the park is still in the structuring process, and a good part of the funds currently used come from compensation under environmental licensing, which is set to end in coming years. After this occurs, new forms will be necessary of obtaining funds for adequate management of the park, since the government has limited money.

This conservation unit contains the headwaters of the Macacu and Guapiaçú rivers, the main components of the Guapi-Macacu Basin, with headwaters at an altitude of approximately 1,700 m. The two rivers join before emptying into Guanabara Bay, and the park's area extends to the mouth of the Macacu River Along the basin's course, its physiography is marked by two well-defined stretches. Near the headwaters there are regions of steep slopes and valleys, composed of forests and rocky massifs. Along the lower stretch, down to Guanabara Bay, there are flat and gently rolling lands, with easily flooded areas with low permeability.

The region of the Guapi-Macacu watershed was occupied by Europeans since the start of Portuguese colonization, which generated a historic loss of forest cover, essentially composed of dense ombrophylous forest. Because of this deforestation, there are still dense forest stands only in steeply inclined areas, where there are few possibilities for economic exploitation, particularly within the limits of TPSP. Currently natural forest regeneration can be observed, with appreciable stands of secondary vegetation in an advanced succession stage (arboreal size), and in initial and middle stages (herbaceous and bushy stages), in Cachoeiras de Macacu, and on a lesser scale in Guapimirim (CONSÓRCIO, 2005).

Starting in the 1940s, the main rivers in this basin underwent straightening work, with the purpose of eradicating malaria and draining land for agriculture, upsetting the natural drainage. Before this, the region of the lower Caceribu was subject to natural flooding in its extensive mangrove marshes and lowlands. To prevent this periodic flooding and open land for occupation, the National Department of Works and Sanitation (DNOS) opened the artificial Imunana Canal, interconnecting the course of the Macacu River, just downstream from the confluence with the Guapiaçu, with the Guapimirim River. As a result of these interventions, the Guapi marshlands received a shock of freshwater, because the river began to be responsible for the outflow of the Guapiaçú-Guapimirim-Macacu set of rivers, becoming the largest flow of freshwater into Guanabara Bay. As a consequence of these works, much of the marshes and mangroves disappeared, causing a great impact on the region's flora and fauna (CONSÓRCIO, 2005).

The Rio de Janeiro State Water and Sanitation Company (Companhia de Saneamento e Abastecimento do Estado do Rio de Janeiro – CEDAE) takes $7m^3/s$ of water from Imunana Canal, which goes to supply the municipalities of Niterói, São Gonçalo, Cachoeiras de Macacu, Guapimirim and Itaboraí (aprox. 1,675,000 inhabitants), as well as farms, ranches and industries located in these municipalities (FEEMA, 2004). Because of the excellent water quality of the headwaters of the Macacu and Guapiaçú rivers, various mineral water bottling companies set up in the region, along with other companies that rely heavily on water as an input, such as breweries and farms producing turf.

3.2 The Protection and Maintenance Costs of Três Picos State Park

To calculate the TE (total expenditure to be recovered for protecting the CU), we considered all the costs whose relation with the protection and maintenance of the headwaters within the CU can be justified. We did not consider spending not directly related to protecting the park, such as environmental education of tourists, preparation of hiking trails, setting up the visitor center, etc. Therefore, the tariff calculated will represent only the amount necessary to pay for the activities involved in protecting and maintaining the conservation unit, with direct repercussions on protection of its water resources.

To do this, we gathered information from the administration of TPSP regarding the main cost components to be employed in the calculation, resulting in the following list:

a) Landholding regularization: Total amount forecast for regularizing title to the lands in TPSP, discounted at 6% a year.
b) Payroll: Total annual amount of the salaries plus labor charges for the park administration, technical staff, guards and researchers, proportional to the time spent on protection of the area. The time spent serving tourists, laying out trails and in administrative meetings was not counted.

c) Training: Total annual amount spend on training staff in protective activities.
d) Equipment: Total annual amount for vehicles and equipment for overseeing the park and fire prevention equipment, discounted at 20% a year.
e) Fuel: Total annual amount spent on fuel for park protection activities.
f) Administrative expenses: Total annual amount spent on electricity, water and telephone, proportional to the time involved in park protection.
g) Buildings: Total amount spent on building the structures necessary to protect the park, discounted at 6% a year.

The total expenditures to be recovered for Três Picos State Park for 2006, given the above considerations, added up to R$ 635,680.00.

3.3 O Inventory of Users

The aim of this topic is to present, based on the water balance estimates, the rate of contribution of TPSP in water catchment from the regions hydrographic basins. The water balance can be defined as the intake of water into the soil (storage), that is, the difference between the water that enters and leaves the soil in a water basin. This involves quantification of the components of the water transfer by the basin. In detailed form, the water balance can be expressed by:

$$S = P - R - ET - G, \qquad (7)$$

where:

S = storage;
P = precipitation;
R = surface runoff;
ET = evapotranspiration;
G = underground runoff.

In the water cycle, a portion of the *rainfall volume* evaporates before reaching the ground (direct evaporation), another portion is intercepted by limbs and leaves, from where it *evaporates*. The water that reaches the ground divides into sub-portions: part of this volume *infiltrates* the soil, resulting in *underground runoff*, another part results in *surface runoff* and a part returns to the atmosphere through the *transpiration* of plants. Normally the term evapotranspiration is applied to the sum of the *evaporation* from the ground and plant *transpiration.*

These portions of the water balance are subject to the influence of a series of variables within the hydrographic basin. For example, the region's climate, plant cover, rainfall period, type and use of soil, declivity and volume of rainfall all vary. Different methods are used to estimate each of these components of the water balance. The use of these methods varies in function of the factors limiting their application, such as physical limits (minimum area for calculation or number of weather stations), or the quality and quantity of hydrometeorological data captured.

For example, to calculate a basin's average rainfall we can use the arithmetic method (arithmetic mean), the method of Thiessen (weighted areas, with the weight proportional to the area of influence of each point, forming polygons connecting the points), or isohyetal analysis (considering curves of equal precipitation). Besides the formula used for calculation, the differential factor for application of each of these methods is related to the data available for the calculation and the surrounding conditions affecting their application. The most accurate and correct way to estimate each of the portions of the water balance is to use specific data collection instruments. These instruments vary by virtue of the type of data collected, which must then be treated with mathematical and statistical formulas to measure the components. Perhaps the simplest instrument is the pluviometer, or rain gauge, which can give the rainfall at a particular point by the height of the water column accumulated, in millimeters (mm). With this information, along with the duration and intensity of the event, one can estimate the rainfall volume in a determined area.

Given the shortage or even absence of data on an adequate scale (micro-basin) for the TPSP region, to estimate the water balance we used data from regions with similar characteristics. The studies of OLIVEIRA JÚNIOR & DIAS (2005), RANZINI et al. (2004) and ARCOVA et al. (2003) present, by means of experiments, an estimate of the percentages of infiltration, evapotranspiration, surface runoff and rainfall in the micro-basins of the Serra do Mar region of the Atlantic Rainforest. The relatively small variations among these studies motivated us to use their estimates as proxies for the Serra dos Órgãos region, where TPSP is located, as shown in Table 1 (relation factor). With these percentages and the average rainfall of the region's basins – obtained by interpolation of isohyets and based on the historic rainfall series recorded at stations near the park – the other components of the water balance can be estimated. To collect the data necessary to estimate the contribution rate, we consulted the online databases of CEDAE, the State Office of Rivers and Lakes (SERLA), the Brazilian Geological Service (CPRM) and National Water Agency (ANA). We obtained information at the CEDAE and SERLA sites on the catchment points, data on the users, spatial location and annual consumption of the catchments. From the CPRM and ANA sites we obtained information on the average annual rainfall (isohyets map), drainage network and other hydrological information for the state of Rio de Janeiro.

In possession of this information, divided the micro-basins into portions inside (IN) and outside (OUT) the park we created a geographic information system (GIS) containing the limits of the contribution basins based on each water catchment point (CEDAE and SERLA), the drainage network, the park's limits and a map of total annual isohyets (1968-1995) generated by the CPRM in the Rio de Janeiro project.

Table 2 – Water Balance for Micro-Basins Related to Três Picos State Park

Water Catchment Station	Place-Park	Area	Precipitation Average	Rainfall Volume	Evotrans-piration	Infiltration	Surface Run-off Volume	Contribution of the Park
		km²	mm	m³/year	m³	m³	m³	%
Parque Serra da Caneca Fina	IN	1,639	2.300	3.769.700	1.130.910	2.261.820	376.970	**100,00**
	OUT	0,000		0	0	0	0	
		1,639					**376.970**	
Ney Souza e Silva	IN	2,740	2.450	6.713.980	2.014.194	4.028.388	671.398	**81,79**
	OUT	0,212	2.350	498.200	99.640	249.100	149.460	
		2,952					**820.858**	
Mineradora Costa D'água Ltda.	IN	2,882	2.350	6.773.252	2.031.976	4.063.951	677.325	**91,13**
	OUT	0,300	2.200	659.213	197.764	395.528	65.921	
		3,182					**743.247**	
Mineração Lucânia Ltda.	IN	0,000	1.350	0	0	0	0	**0,00**
	OUT	1,534		2.070.936	414.187	1.035.468	621.281	
		1,534				**1.035.468**		
Itograss Agrícola de Ipanema Ltda.	IN	106,271	2.400	255.049.440	76.514.832	153.029.664	25.504.944	**40,82**
	OUT	53,591	2.300	123.259.944	24.651.989	61.629.972	36.977.983	
		159,862					**62.482.927**	
Hugo de Vasconcelos Paiva	IN	13,146	2.450	32.207.722	9.662.317	19.324.633	3.220.772	**80,46**
	OUT	1,109	2.350	2.606.855	521.371	1.303.428	782.057	
		14,255					**4.002.829**	
Água Mineral Mariquita Ltda.	IN	3,136	2.500	7.840.750	2.352.225	4.704.450	784.075	**100,00**
	OUT	0,000		0	0	0	0	
		3,136					**784.075**	
Agropecuária Serra do Mar	IN	61,998	2.350	145.694.125	43.708.238	87.416.475	14.569.413	**50,23**
	OUT	20,925	2.300	48.127.937	9.625.587	24.063.969	14.438.381	
		82,923					**29.007.794**	
Primo Schincariol Ind. de Cerveja	IN	61,998	2.350	145.694.125	43.708.238	87.416.475	14.569.413	**50,23**
	OUT	20,925	2.300	48.127.937	9.625.587	24.063.969	14.438.381	
		82,923					**29.007.794**	
Primo Schincariol Ind. de Cerveja	IN	61,998	2.350	145.694.125	43.708.238	87.416.475	14.569.413	**50,23**
	OUT	20,925	2.300	48.127.937	9.625.587	24.063.969	14.438.381	
		82,923					**29.007.794**	
Primo Schincariol Ind. de Cerveja	IN	61,998	2.350	145.694.125	43.708.238	87.416.475	14.569.413	**50,23**
	OUT	20,925	2.300	48.127.937	9.625.587	24.063.969	14.438.381	
		82,923					**29.007.794**	
Agriculture Guapiaçu Ltda.	IN	61,998	2.350	145.694.125	43.708.238	87.416.475	14.569.413	**40,04**
	OUT	33,052	2.200	72.713.740	14.542.748	36.356.870	21.814.122	
		95,049					**36.383.535**	
Agriculture Guapiaçu Ltda.	IN	61,998	2.350	145.694.125	43.708.238	87.416.475	14.569.413	**70,63**
	OUT	33,052	2.200	72.713.740	14.542.748	36.356.870	21.814.122	
		95,049				**123.773.345**		
Reserva Ecológica Guapiaçu	IN	61,998	2.350	145.694.125	43.708.238	87.416.475	14.569.413	**70,63**
	OUT	33,052	2.200	72.713.740	14.542.748	36.356.870	21.814.122	
		95,049				**123.773.345**		
Captação - Rio Cachoreirinha	IN	0,000	1.800	0	0	0	0	**0,00**
	OUT	6,027		10.849.208	2.169.842	5.424.604	3.254.763	
		6,027					**3.254.763**	
Captação - Rio Cachoreira Grande	IN	0,000	1.750	0	0	0	0	**0,00**
	OUT	20,220		35.384.745	7.076.949	17.692.372	10.615.423	
		20,220					**10.615.423**	
Captação - Rio Agulheiro do André	IN	0,000	1.450	0	0	0	0	**0,00**
	OUT	**1,925**		2.790.670	558.134	1.395.335	837.201	
		1,925					**837.201**	
	IN	244,9367	2.300	536.354.410	169.006.323	338.012.646	56.335.441	

The GIS generated permitted us to estimate the area of each of the micro-basins containing the corresponding catchment points. We then. Superposing the information in the GIS with the area division also allowed us to estimate the mean rainfall in each of the constituent parts of the basins delimited.

From this information we estimated the water balance for each catchment basin, considering the following components: rainfall volume; infiltration; evapotranspiration; and surface runoff volume.

Table 1. Relation Factor

		Rainfall Volume	Evapotranspiration	Infiltration	Surface Ru-noff Volume
Relaction	IN	100%	30%	60%	10%
Factor	OUT	100%	20%	50%	30%

We attributed a relation factor to each of the main components in function of the characteristic of the basin – inside or outside the park. Once the area and precipitation were defined, their product gave the rainfall volume. Then, by applying the relation factors to the rainfall volume, it was possible to estimate the other portions in terms of volume: evapotranspiration, infiltration and runoff.

We calculated the contribution rate of the park for each basin as a function of the type of catchment. We computed the rate in function of the volume of runoff for the points where this is from the surface, and of the infiltration portion for cases where water is taken from wells.

The majority of the catchment points have some relationship with the park, which was evidenced by the contribution rates calculated. In some cases this rate ranged from 80-100%, as shown in Table 2.

3.3 Elasticities and Current Costs of Water Consumption

Unlike for the inventory, we did not conduct any specific study to estimate price elasticities. The estimation of elasticities would have had to be modeled through production or cost functions requiring at least 100 observations. Considering the small number of relevant users in the basin under analysis, it would have been necessary to gather time-series data from users. This was simply not possible given the time and funding constraints of the study.

Table 3 – Costs and Elasticities of Users

User	Sector classification and source of catchment	c_i (R\$/m^3)	e_i	b_i (%)
Mineradora Costa D`água Ltda *Industry- Headwaters*	*14 - NON-METAL MINERAL EXT. (MIN. WATER) - surface*	0.2707	0.22	91.13
Itograss Agrícola de Ipanema Ltda *Irrigation - River/Stream*	*Agriculture - surface*	0.2707	0.50	40.82
Hugo de Vasconcelos Paiva *Supply of 5 households – Headwaters*	*Residential - surface*	0.2707	0.74	80.46
Água Mineral Mariquita Ltda *Industry- Headwaters*	*14 - NON-METAL MINERAL EXT. (MIN. WATER) - surface*	0.2707	0.22	100.00
Agriculture Serra do Mar *Industry- Headwaters*	*Agriculture – surface*	0.2707	0.50	50.23
Primo Schincariol Ind, de Cerveja *Three catchment points for the industry*	*15 – PROD. OF FOOD AND BEVERAGES - surface*	0.2617	0.82	50.23
Primo Schincariol Ind, de Cerveja *Industry – Mariquita River*	*15 – PROD. OF FOOD AND BEVERAGES - surface*	0.2617	0.82	50.23
Primo Schincariol Ind, de Cerveja *Industry - Manoel Alexandre River*	*15 – PROD. OF FOOD AND BEVERAGES - surface*	0.2617	0.82	50.23
Agriculture Guapiaçu Ltda *Irrigation - River/Stream*	*Agriculture – surface*	0.2707	0.50	40.04
Agriculture Guapiaçu Ltda *Well - Water Table*	*Agriculture – underground*	0.2707	0.50	70.63
Reserva Ecológica de Guapiaçu *Shallow well – Water Table*	*Agriculture – underground*	0.2707	0.50	70.63

Captação – Imunana *With contribution of the park and a large area outside it*	*Mean of the Mean – surface*	0.2707	0.74	10.13

Note: Estimates of e_i and c_i based on Seroa da Motta et. al. (2004).

Therefore, to apply the methodology, we decided to use the elasticity estimates calculated in Seroa da Motta *et. al.* (2004b), where the authors applied a cost function to a sample of 500 users in the Paraíba do Sul River Basin. Likewise, to maintain the methodological consistency, we also used the estimates of this work of the average water consumption costs for each sector of that study.

These estimates are presented in Table 3 below, along with the percentages (b_i), which represent the contribution of the CU to the total consumption of each user.

3.4 Tariff Simulations

We now calculate the values of t_i for the following scenarios:

Neutral scenario: without cross subsidy, d_i and e_i equal for all users, the tariff only differentiated by b_i, which is the proportion of consumption that is the contribution of the CU.
Distributive scenario: besides the difference of b_i, there is a cross subsidy for residential users, where $d_i = 0.5$, coming from the other users, where $d_i = 1$.
Differentiated scenario: besides the difference of b_i, there is a cross subsidy defined by the public price rule in relation to the water price elasticity e_i of each user ($e_i \neq 0$), but $d_i = 1$ for all users.

The neutral scenario, since there is no calibration of t_i by the elasticities, raises the basic t value because users with less reaction to the price are charged the same rate as users that are more elastic, and hence the capacity to generate revenue is reduced. In the distributive scenario, the rise in t can also be higher if benefited users are more inelastic than those not benefited. The reason is that the non-benefited users will pay more than in the absence of a subsidized tariff, and since they are more elastic, they will divert more demand that requires higher t to compensate for the lost revenue.

The results of the exercise confirm these tendencies in the values of t, as indicated in Table 4below. It can be seen that a neutral t on the order of R\$ 0.02867/m^3 is approximately 40% of the value of a differentiated t, which would be 0.02095/m^3. A distributive t, estimated at 0.05183/m^3, is nearly twice the neutral t, indicating that the subsidy to residential consumption would require an effort to obtain additional revenue from some less elastic users.

Table 4 – Basic Tariff by Scenario

Scenario	Neutral	Distributive	Differentiated
Basic t (R\$/m^3)	0.02867	0.05183	0.02095

Although the basic t value is lower in the differentiated scenario, this does not mean that the tariff levels for all users in this scenario are also lower. On the contrary, in the differentiated scenario, less elastic users would be expected to pay more. Observing Table 5, which presents the tariff levels by user, it can be seen that Mineradora Costa D'Água, which has the least elasticity among the users inventoried, would pay 3.32 times as much as in the neutral scenario. In contrast, Primo Schincariol Ind. de Cerveja, which is the most elastic, would pay a tariff equal to 89% of what it would pay in the neutral scenario. Note that the objective of charging under the PRP is to generate revenue, so it needs to minimize diversions of demand. If on the contrary a charge is established to reduce water consumption, the tariffs should be directly proportional to the elasticities that result in the smallest demand.

Table 5 also shows that in the distributive scenario, the residential users, Hugo de Vasconcelos Piava and Imunana Catchment[9], which receive a weight of 0.5, would pay a tariff equal to 90% of what they would pay in the neutral scenario. To offset this subsidy, the other users would have to pay 81% more. Since residential users have a low elasticity, their tariffs in the differentiated scenario are only 9% higher than in the distributive scenario.

Table 5 – Comparative Analysis of Scenarios by User

Water Catchment Station	t_i neutral	t_i dist	t_i dif	t_i dist/ t_i neutral	t_i dif/ t_i neutral	t_i dif/ t_i dist
Mineradora Costa D`água Ltda *Industry- Headwaters*	0.02613	0.04723	0.08679	1.81	3.32	1.84
Itograss Agrícola de Ipanema Ltda *Irrigation - River/Stream*	0.01170	0.02116	0.01710	1.81	1.46	0.81
Hugo de Vasconcelos Paiva *Supply of 5 households – Headwaters*	0.02307	0.02085	0.02278	0.90	0.99	1.09
Água Mineral Mariquita Ltda *Industry- Headwaters*	0.02867	0.05183	0.09523	1.81	3.32	1.84
Agriculture Serra do Mar *Industry- Headwaters*	0.01440	0.02603	0.02105	1.81	1.46	0.81
Primo Schincariol						

[9] Although the Imunana catchment also serves for non-residential supply, residential use is the majority.

Ind, de Cerveja *Three catchment points to supply the industry*	0.01440	0.02603	0.01283	1.81	0.89	0.49
Primo Schincariol Ind, de Cerveja *Industry - Mariquita River*	0.01440	0.02603	0.01283	1.81	0.89	0.49
Primo Schincariol Ind, de Cerveja *Industry - Manoel Alexandre River*	0.01440	0.02603	0.01283	1.81	0.89	0.49
Agriculture Guapiaçu Ltda *Irrigation - River/Stream*	0.01148	0.02075	0.01678	1.81	1.46	0.81
Agriculture Guapiaçu Ltda *Well - Water Table*	0.02025	0.03660	0.02959	1.81	1.46	0.81
Reserva Ecológica de Guapiaçu *Shallow Well – Water Table*	0.02025	0.03660	0.02959	1.81	1.46	0.81
Captação – Imunana *With contribution of the park and a large area outside it*	0.00290	0.00263	0.00287	0.90	0.99	1.09

In summary, the results of the above exercise point to the following properties of charging according to the PRP:

(i) No matter what the tariff level charged, this will generate a price increase for use of the water, which will prompt users to react, by reducing their consumption, and consequently diverting demand and diminishing the effective revenue. So, a simple apportionment of costs without the methodology indicated here that considers this diversion will not result in the desired revenue.

(ii) Granting distributive subsidies to certain users necessarily will imply rate increases for other users if the revenue generation is maintained.

(iii) The most efficient way to calibrate the tariff differences among users is to estimate them in inverse proportion to their elasticities. In this form, users that are more reactive to prices, and thus with lower productivity in use and with less possibility of substitution, will pay more. Consequently, the basic tariff is lower than in any other allocative criterion.

4. Conclusions and Recommendations

Some considerations are in order regarding the methodological procedures employed in this study. Although we could collect hydrological data for the region, these data contained many flaws in reading and storage. For a better treatment of this subject, we suggest expanding the data collection, including by installing new rainfall gauges inside the park, thus enhancing the accuracy of the hydrological regionalization.

Another important factor to consider is the use of the GIS, which enabled the analysis and interpretation of various data on the region, generating fundamental information for the study, such as the areas of the sub-basins, location of the catchment points and analysis of mean rainfall.

The relation factors represent estimates of each portion of the water balance, and can vary even in each basin, due to its pedogenetic and stratigraphic characteristics, for example. Ideally, such characteristics should be considered, so there is a need to obtain data on the type of soil and carry out other specific studies within the park. These additional data should increase the precision of the estimates of the water balance.
Lastly it is paramount that elasticity estimation reflects price responsiveness of users and effort should be placed to elaborate field surveys that could improve such estimation overtime.

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