

WATER SAVING TECHNOLOGY AND EFFICIENT RATES

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A dynamic model has been built for the distribution of water resources coming from two natural sources (groundwater and surface water) in the presence of a circulating water supply technology with a given throughput capacity. It is shown that with a constraining restriction on the intensity of the use of technology, it is possible to temporarily refuse to take water from a natural source with a subsequent return to it in the future. It is shown that the effective trajectory of water consumption can be decentralized with an appropriate choice of tariffs. Comparison of effective tariffs for two consumers, differing only in the presence of recycling water supply technology, is carried out.

Key words: depleted resources, circulating water supply, decentralization.

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1. Introduction

To meet water needs, economic agents use various natural sources of water resources. In particular, in the Russian Federation about 80%² water is taken from surface sources, and the remaining demand is met by underground (12%) and sea (7%) waters. The main consumer of water is industry, which accounts for 65% of the water used.¹...

As can be seen from Table 1, industrial enterprises combine several methods of water supply, using, along with water intake from various natural sources, the technology of circulating water supply. The intensity of the use of these technologies varies significantly from industry to industry, but on average, the technology of recycling water gives the industry of the Russian Federation about 80% savings.

The technology of recycling water supply allows the water taken from a natural source after working out to be sent back to production process. Thus, in a certain sense, water from a natural source serves the consumer as a durable

¹ State report, 2009, tab. 3.40 on p. 227 of the model is valid only in relation to the dynamics of the price of the resource stock, and not the flow. However, the results obtained in this work cannot be directly extended to the technology of circulating water supply, since water needs some processing for reuse in the production process, i.e. we must also take into account the costs associated with the use of recycled water technology

product with the only difference that its subsequent consumption is associated with certain additional costs.

According to the model of exploitation of a depleted durable resource proposed in (Levhari, Pindyck, 1981), for such resources, a distinction should be made between the cost of the consumer and the price of a unit of the stock. The traditional Hotelling rule in this

Attempts to consider the impact of recycling of secondary raw materials on the trajectory of extraction of depleted resources have been undertaken in a number of studies. For example, Hoel (1978) analyzed the relationship between the production of an inexhaustible substitute resource and the extraction of a depleted resource, taking into account the different effects of these processes on environmental pollution. However, this work did not introduce a relationship between the volume of recyclable materials available for processing and the previously extracted resource, but, on the contrary, it was assumed that the volume of recyclable materials available for processing was infinitely large.

In (Ding, Song, 2006), a model was built, where the relationship between the volume of the extracted and the resource available for subsequent processing is explicitly assumed. However, the volume of the processed resource is not a choice variable in the model, but is set exogenously as a fixed production share.

In this paper, we will consider how the technology of recycling water supply should be taken into account in the formation of water tariffs. The relevance of this issue is explained by the fact that even in developed countries, as a rule, there is no water market, and therefore market mechanisms for pricing water resources do not work. Ineffectiveness of tariffs leads to irrational use of water resources, which can provoke a water crisis.

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Таблица 1
Источники воды и экономия воды
за счет оборотного водоснабжения по отраслям РФ в 2008 г.

Вид производственной деятельности	Забор пресной воды		Экономия свежей воды ¹ , %
	из поверхностных источников, %	из подземных источников, %	
Производство и распределение электроэнергии, газа и воды	86	14	72
Сельское хозяйство, охота и лесное хозяйство	96	4	78
Обрабатывающие производства	86	14	91
Добыча полезных ископаемых	23	77	94
Рыболовство и рыбоводство	97	3	64
Строительство	...	...	50
Транспорт и связь	92	8	58
Предоставление прочих коммунальных, социальных и персональных услуг	84	16	20
Итого по России	86	14	79

Источник: Государственный доклад, 2008, табл. 3.1, 3.2, с. 170–172.

There are many theoretical studies dealing with water pricing issues. They addressed the following questions: should tariffs be based on average or marginal costs of water supply (Riordan, 1971; Brill, Hochman, Zilberman, 1997); how seasonal fluctuations in water demand and supply should be taken into account (Zarnikau, 1994; Schuck, Green, 2002); what are the optimal tariffs for asymmetric information regarding the types of water consumers (Elnaboulsi, 2009); how to take into account the effect of depletion of water resources (Moncur, Pollock, 1988); how tariffs should depend on the spatial differentiation of water consumers (Chakravorty, Umetsu, 2003).

In (Fridman, 2009) it is shown that for different consumers the rent component of effective tariffs varies in accordance with the coefficient of irrevocable water consumption. The calculations were based on the assumption that waste and non-utilized water in the process of consumption goes back to a natural source. However, the technology of recycled water supply implies the absence of a return flow of water, which entails several changes in relation to the components of the effective tariff. Water taken from a natural source provides not

only an immediate benefit from water consumption, but also has a residual value (non-reclaimed water can be reused after appropriate treatment). However, due to the absence of return flows, there is no need for the costs of cleaning the discharged (unused in the process of consumption) water to the standard level. Since in Russia most of the water is consumed by industrial enterprises, and these enterprises use both natural waters and the technology of recycled water supply, the question of the formation of effective tariffs, taking into account the peculiarities that arise when using the technology of recycling water supply, seems to be very relevant.

In sect. 2 shows a formal model describing the efficient use of water from two natural sources (groundwater with a given, but replenished supply, and surface water) in the presence of the technology of circulating water supply with a given

2. Model with recycled water supply technology

Consider a region where, as a source of usable water⁶ groundwater, the supply of which is limited, and surface water with a deterministic volume of annual runoff (sufficient to meet current demand) may appear. The agent can use the technology of recycling water supply with a fixed capacity.

The groundwater supply is limited and at the initial moment is equal to S_0 ... At each moment of time, there is a deterministic replenishment of the stock by the amount g ... Denoting water intake from underground sources at time t through g_t , we obtain the equation for the dynamics of this stock: $\dot{S} = g - Sg$... Since the stock at each moment of time must be non-negative, then when the stock is completely depleted, the water intake from underground sources is limited by the level of their natural replenishment. Note that not all of the withdrawn water is utilized in the process of consumption, but in the presence of recirculating water supply technology, the remaining water does not go back to the source, but after appropriate processing it enters production again.

Let's introduce the recycling water supply technology into the model. These technologies are most widely used in industries where water serves as a cooler, and this direction of water use is predominant for recycling water supply systems, and therefore this direction is considered as a model in this work.eight... Apparently, the widespread use of recycling water supply technologies when pumping water for cooling equipment is associated with the low marginal costs of recycling water supply technology, since in this case the lion's share of costs is formed from the costs of cooling the waste water. Cooling can be carried out:

1) in specially created reservoirs (ponds, pools, etc., where water is accumulated, cooled, and then used as needed, in this case, the capacity limitation of the corresponding reservoirs should be taken into account);

2) without storage (for example, using cooling towers or radiators, then the capacity of the cooling devices is of decisive importance);

3) a combination of two cooling methods...

If only a fraction of the water is disposed of ($0 < \alpha < 1$), then in the presence of a circulating water supply system, the remaining part ($1 - \alpha$) available for re-use after appropriate processing, which comes with a marginal cost c_z ... We will assume that the company can use the treated waste water immediately or store it in a tank and use it in production after some time. At the same time, there is a limitation on the throughput of wastewater treatment technology z ... Letting $z(t)$ the volume of water passing through the circulating water supply system at time t , we obtain the following equation for the dynamics of the stock of waste water: This equation of dynamics assumes that there is no need to instantly consume the formed stock of waste water, i.e. this water can accumulate in a reservoir. Natural or artificially created ponds or basins can serve as such reservoirs. Since the volume of these reservoirs is limited, the water supply cannot exceed the storage capacity for a given reservoir. We will not introduce this limitation explicitly, assuming that the volume of these reservoirs is large enough and the corresponding limitation is not restrictive. This premise is quite reasonable if the water recycling technology is the cheapest water source available.

The recycling water supply system is associated with rather high installation costs, but at the same time the marginal costs can be very low, since transport costs in this case are absent, and in the case when the technological consumption process under consideration is characterized by a low level of pollution (which, for example, is true when using water as a coolant), the costs are low. Note that these costs are still non-zero. First, the waste water can be contaminated with mechanical impurities during the cooling process in reservoirs. Secondly, during transportation through pipelines and in contact with heat exchange equipment, corrosion products may appear in the circulating water, which reduces the efficiency of the cooling process. Waste water pre-treatment and treatment,

So, if the circulating water supply corresponds to the cheapest resource, then this resource will always be selected first. Taking into account the absence of the initial stock of waste water, this means that this resource will not accumulate. In this case, the storage capacity will not be involved at all. However, if there is a limitation on the throughput of the recycling water supply technology, if at some point the intensity of the technology operation reaches the capacity

limit, a part of the waste water will still go to the reservoir for storage. Moreover, if the throughput is not too small (namely, this case is considered in the article), then, as will be shown in section. 4, waste water accumulation is BPechangeable: the tank will not be used in a stationary state. Due to these considerations, we will not introduce an explicit restriction on the capacity of the reservoir.

Let l_t the volume of water intake from surface sources at time t , and after c_l - marginal costs; $c_l = \text{const}$. The model assumes that the volume of river flow is large enough to meet the needs of the region, and therefore we will not introduce a limitation on the volume of flow, i.e. in this case, surface water acts as an inexhaustible substitute resource.

Let the marginal costs of water supply for each source be constant, and the following relationship holds $c_{gzz} < c_{gz}$, where the subscript indicates the type of water source. Let us comment on the introduced premises regarding the relationship between the marginal costs of various natural sources. As a rule, groundwater requires less water treatment costs compared to surface water, which generates lower marginal costs, and this ratio can take place not only for drinking water, but for water used in industry. Usually, surface waters are characterized by higher pollution with mechanical impurities, oil products, metals, and also have a higher level of microbiological and radiological pollution. As a result, even when water is used in industry as a transport medium or as a coolant, there are significant treatment costs. For example, in the absence of cleaning from biological contaminants, the build-ups of biomass appearing in the pipes significantly reduce the thermal conductivity and require a periodic shutdown of the process for cleaning. In this case, preliminary water purification avoids production interruptions.

The above ratio of marginal costs can also take place with the same water quality, if groundwater reserves are located closer to consumers, while surface waters require transportation.

Naturally, in some cases, an inverse relationship between the marginal costs of surface and groundwater is possible, for example, with a very high salinity of groundwater or with their emergency pollution, but these situations are not considered in this article.

Note that, due to the lowest marginal costs, circulating water supply is the most preferable source of water, and therefore, in the absence of restrictions on the intensity of the application of this technology, efficiency requires continuous use of waste water. In principle, in this case, the capacity for storing waste water is not needed. However, if there is a limitation on the throughput of the technol-

ogy, it may be necessary to reduce the withdrawal of waste water, and in this case there is a need for water storage. The work does not explicitly introduce a restriction on the volume of the reservoir, since it is implicitly assumed that the capacity of the available reservoirs is sufficient to store the resulting stock of waste water.

If there are two identical resources in the economy that differ in marginal costs, then, in accordance with the Herfindahl principle, these resources should enter production sequentially, starting with the cheaper one. However, the peculiarity of our model is that the use of a cheaper technology of circulating water supply is possible only with the formation of a stock of waste water, which is initially absent in the economy. As will be shown below, this feature allows you to simultaneously use in production an expensive resource from a natural source and the technology of recycling water supply.

Let us show that in the case of a large throughput of the recycling water supply technology, groundwater will be used at each moment of time, and only in a situation when the recycling water supply technology has been operating at full capacity for a certain period, the water consumption needs can be satisfied without involving groundwater.

When comparing effective tariffs, two points should be noted. Recycling water supply technologies, on the one hand, allow saving on wastewater treatment costs, and on the other hand, in this case there is no return water, i.e. the coefficient of irretrievable water consumption becomes equal to one, which increases the rental component of the tariff.

Consider, for example, a region where there are two consumers, the only difference between which is the presence of the technology of recycling water supply in one and the absence of this technology in the other. Then the shadow estimate of groundwater will be the same, i.e. $\lambda = \lambda \square \dots$ As a result, the effective tariff for an agent using circulating water supply, before reaching a stationary state, is characterized by a lower component associated with marginal costs, but a higher rental component. In addition, the availability of recycling water supply technology allows using a lower tariff in a stationary state due to the absence of costs for wastewater treatment.

Conclusion

We have analyzed the problem of efficient use of natural sources of water resources and the technology of recycling water supply, provided that the intensity of attracting this technology is limited by its capacity. Since the use of a cheaper (in comparison with natural sources) technology of circulating water supply is possible only in the presence of waste water, then, as shown in Sec. 3

and 4, in this situation, expensive and cheap resources can be simultaneously involved, and this conclusion does not depend on the power level of the recycling water supply technology.

In the case of a restraining restriction on the intensity of the use of recycling water supply technology, a situation is possible in which at some point it is optimal to stop using groundwater and satisfy all needs only through recycling water supply, and after the exhaustion of the waste water supply, return to the operation of underground sources.

It is shown that in this model, a distinction should be made between the marginal benefit of current water consumption and the benefit from the last unit of water taken from a natural source, since it also includes an assessment of the increase in the waste water supply formed as a result of water use. Thus, effective water tariffs must reflect the marginal public benefit, and therefore will be higher than the marginal utility of current water consumption. The establishment of tariffs constructed in this way allows the efficient consumption trajectory to be decentralized.

The performed analysis of comparative statics for two consumers, differing only in the presence of recycling water supply technology, indicates that the tariffs for these agents will be different both in terms of marginal costs and in terms of the rental component. With a circulating water supply, there is no wastewater, and therefore the marginal cost is reduced. The absence of waste water means that there is no partial return of water to the natural source, i.e. the coefficient of irretrievable water consumption turns out to be equal to one, which increases the rental component of the tariff.

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