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# Variable Unit Pricing: An Alternative to Increasing Block Rate Pricing for Water Utilities

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**Variable Unit Pricing:**
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## 1. Introduction

Water pricing by water utilities and public water management agencies is becoming increasingly contentious as water scarcity increases. Increasing Block Rate pricing has been developed to address needs to conserve water. The use of IBR is increasing among utilities. For example, from a survey of 119 utilities in the Southwest Florida Water Management District: 11.8% used IBR in 1991 and 29.4% used IBR in 1997; the number of utilities with decreasing block and uniform rates decreased over this period..

Because there is no set prescription for setting the blocks, rate setting with IBR is fairly ad hoc (in contrast to average cost pricing). At the same time, many utilities are suffering revenue insufficiency as water users respond to both price and educational efforts by reducing use.

This paper introduces a new method of pricing – Variable Unit Pricing. This method addresses both cost recovery and conservation simultaneously. It also is designed to satisfy economic efficiency – an aspect often ignored by utility rate-making procedures.

Economic efficiency means maximization of aggregate net benefits from water utilization and supply methods. It requires that the last water unit consumed by each water user should have the same marginal benefit for each user. There is also a requirement regarding the relation between marginal benefit for each user and marginal cost of supply: if there are no user specific costs, marginal benefit should equal marginal cost of supply. The reason for these conditions is that – if they do not hold – then net benefits for the system could be increased, either by shifting from some uses of water to others, or by changing supply methods.

VUP produces a quadratic total bill schedule, i.e. the price for all water units consumed increases with increasing consumption (assuming increasing marginal and average costs). Therefore, DRP is expected to be more effective for conservation needs than IBR in which only the marginal units are affected by the "marginal price."

In contrast to IBR, VUP is determined objectively from demand and cost information specific for a utility service area. In effect, there are two parts to pricing: a base charge that is the same per unit for all water users and a charge that varies with user type (e.g. households, muli-family, commercial, and industrial users) determined by demand elasticity. The reason for the demand charge by type of user is to satisfy economic efficiency: with varying benefits of use by type of water user, equalizing marginal benefits through pricing can only be achieved if pricing is personalized by type of user.

The basic cost recovery method can be extended to accomplish cost recovery with supply limits or drought restrictions and cost recovery with requirements for service quality or reliability. Below we present the basic method and give two applications (for Amman, Jordan and Boulder, Colorado).

### 1.1 Other Approaches to Conserving Water

As an alternative method of meeting supply limits, some geographic areas have resorted to the "water budget method" in which it is determined what is a household or business should be allotted based on limited information such as lot size or number of employees. Then, higher rates are charged to users that exceed their individualized water budgets to provide incentives to cut back. Furthermore, if there is a drought, then users are asked to cut back proportionally in their allotments. While this method of allocation sounds equitable on the surface, it violates two important economic principles: individual choice based on willingness to pay relative to cost of service, and decentralization of information. It can also lead to revenue insufficiency of demand conditions are not observed.

The water budget method is actually a case of central planning, when a planner or water manager determines what is the "right" water consumption. Economists generally consider central planning systems to be inferior to pricing systems because of their heavy information costs. That is, to be really equitable, water planners would have to know specific user information such as the number and ages of family members and land uses (e.g. house size relative to lot size, horticultural plantings, and whether or not there is home gardening).

Another method of meeting supply constraints is use restrictions, e.g. time limits and other restrictions on watering. Such use regulations cause many complaints due to inconveniences (e.g. if a person is not able to water at the allotted time) and inequities. Of course, regulation is utterly unresponsive to revenue needs.

## 2.0 Simple Description of VUP

This section gives a brief description of VUP and parameter determination. Variable Unit Pricing (VUP) is a form of nonlinear pricing, i.e. the total charge for service is not a flat rate times quantity purchased.

"Nonlinear pricing refers to any case in which the tariff is not strictly proportional to the

quantity purchased... If offered a menu of prices, each consumer chooses a preferred quantity and pays the associated charge" (Wilson, 1993). (Block rate pricing and two-part pricing also satisfy this definition.)

For VUP, all units will have the same price but the price per unit varies with the quantity purchased. Compared to an increasing block rate structure, four distinguishing aspects of VUP are:

1) Unit pricing schedules are linear in form;
2) Parameters (intercept and slopes) are objectively determined to satisfy efficiency, cost recovery, and any other supply constraints.
3) Different types of water users will have differently sloped VUP schedules.
4) VUP is completely volumetric: both fixed costs and variable costs are covered.

The rationale for price discrimination is efficiency when there is heterogeneity among water users. The identification of user types could be based on volume of use, e.g. low, medium, high; or it could be based on indicators of demand, such as size of house and yard.
The identification of user types is a question of information cost. Ideally, each user would be its own "type" but this would be costly in terms of utility record-keeping and billing.

VUP could be increasing or decreasing. "Increasing Unit Pricing"(IUP) is shown to be appropriate when average cost is increasing or when a supply constraint is sufficiently stringent. Thus, Increasing Unit Pricing achieves the conservation intent of IBR, at the same time providing cost recovery and economic efficiency. Similarly, "Decreasing Unit Pricing" applies when average cost is decreasing. (See Loehman, 2004.)

## 2.1 Form of Variable Unit Pricing

VUP is based on a linear price schedule: i.e. UNIT PRICE = a + b WATER USE. This linear form is sufficient to address a variety of supply situations, as demonstrated below. The *a* or intercept parameter (the same for every user) gives the base charge per unit. The *b* or slope parameter – which varies by type of user – gives a demand charge per unit. The total user charge is the unit price – evaluated at the water use – times water use.

To simplify, Unit Price and charge schedules can be given in discrete form, with a different schedule for each user type. For example for one user type, with a = .0333 and b = .00001, the unit price can be represented by ranges, here evaluating price at the mid-point of each range.:

| WATER USE (gal.) | Unit Price | Total Charge |
|---|---|---|
| 0 - 2000 | .0433 | $43.30 |
| 2000 - 4000 | .0633 | $189.90 |
| 4000 - 6000 | .0833 | $416.50 |

Then, to calculate the Total Charge, a water user only has to multiply the unit price from the

schedule by the water use (or anticipated use). Computation is simpler than with IBR which requires cumulation of charges over a number of unequal-sized blocks. Note the quadratic nature of the charge schedule, providing more incentive for conservation than flat rate pricing.

2.2 Efficiency and VUP

The following example employs a simple equilibrium system with one water user and a water utility. The water user has a benefit function for water of B(w) and the utility has a supply cost of C(w). Efficiency – maximizing net benefits – requires that marginal benefit (MB) be equal to marginal cost (MC). .

Charging the water user R(w) for the water consumption, an increase in consumption causes an increase in the total bill of marginal revenue MR(w) = a + 2bw. This revenue is received by the profit-maximizing water utility. A supply-demand equilibrium w* satisfies MB(w*) = MR(w*) for the water user and MR(w*) = MC(w*) for the water supplier. Thus, efficiency – MB(w*) = MC(w*) is satisfied.

Suppose the marginal benefit for the water user is MB = .05 - .02 w, and the cost function is $C(w) = .0027 + .025w + .0088w^2$. The resulting efficient water use is w* = 0.666, where MB* = MC*. Given the efficient quantity, efficiency and cost recovery conditions determine pricing parameters *a* and *b* for p(w) = a + bw. There are two equations and two unknowns: MR* = MC*, and revenue equals cost (R* = C*) at w*.

$$a + 2bw^* = .025 + .0175w^* \equiv MC^*$$

$$(a + bw^*)w^* = .0027 + .025w^* + .0088(w^*)^2 \equiv C^*$$

To satisfy the requirement that revenue equals cost (R*=C*), average revenue is equal to average cost (AR* = AC*) at w*. Resulting parameters are a = .0333 and b = .0026.

Figure 1 demonstrates the construction of parameters for this simple case. The MR schedule increases from the intercept and intersects the MC schedule at w*. The indicated shaded area equals the total charge paid. The resulting consumer surplus or net benefit for the water user is the area above AC* and below the marginal benefit schedule, to the left of the efficient consumption.

2.3 Pricing Parameter Determination with Multiple User Types

With multiple users, economic efficiency means maximizing aggregate net benefit (the sum over benefits for all users minus system cost). For this, each water user's consumption should satisfy equality between marginal benefit and marginal cost.

For VUP, the pricing function for user type *i* is $p_i = a + b_i w_i$ ; the corresponding charge schedule is $R_i(w_i) = (a + b_i w_i) w_{i..}$ The intercept is the same for all user types whereas the slope

varies by water user type.

Assume that each water user takes the pricing schedule as given to maximize individual net benefits. For benefit functions $B_i(w_i)$ for water use $w_i$ for each water user type, each water user will determine demand to set marginal benefit equal to the marginal charge:

$$MB_i(w_i) = MR_i(w_i).$$

Receiving user charges as revenue, and also taking the pricing schedule as given, the profit maximizing water utility will determine supply such that the marginal charge for each user is equal to the marginal cost of joint water supply:

$$MR_i(w_i) = MC(\Sigma w_i).$$

A supply-demand equilibrium of water consumers and water utility will combine these two sets of conditions. Thus, an equilibrium $\{w_i^*\}$ will satisfy the conditions that marginal benefit for each user is equal to marginal cost. Therefore any supply-demand equilibrium will be efficient.

Pricing parameters are determined so that both conditions – efficiency and cost recovery – are simultaneously satisfied. More specifically, parameters satisfy the following conditions:

1) marginal charges equal marginal cost for each user

$$a + 2\, b_i\, w_i^* = MC^*;$$

2) cost recovery

$$\Sigma\, (a + b_i\, w_i^*)\, w_i^* = C^*.$$

With the VUP specification, given the equilibrium/efficient allocation, there are (n+1) equations and (n+1) unknown parameters, providing a solution for parameters if the system is not redundant or inconsistent. Note that the intercept is the same for all users because there is insufficient information to determine more parameters. Although this parameter solution appears to be specified only in terms of cost properties, demand conditions also affect parameters through evaluation at the equilibrium allocation.

The form of the solution is obtained as follows: from 1), taking *k* to be a reference user type, for any users *i* $b_i\, w_i^* = b_k\, w_k^*$. This implies that at an equilibrium, the unit price will be the same for all users. Substitution in the cost recovery condition in terms of the reference user type k, where average cost $AC^* = C^*/ \Sigma\, w_i^*$, shows that the equilibrium unit price is equal to average cost:

$$a + b_k\, w_k^* = AC^*.$$

Now we can combine this condition with $a + 2\, b_k\, w_k^* = MC^*$ to solve for the parameters *a* and $b_k$. Then, for a general user *i* at $\{w_i^*\}$:

$$b_i\, w_i^* = MC^* - AC^*$$

$$a = AC^* - (MC^* - AC^*).$$

Thus, pricing parameters can be determined to satisfy both efficiency and cost recovery when there is full information regarding benefits and costs. The slopes are positive when both marginal cost and average cost are increasing (and MC*>AC*); also the parameter *a* is less than average cost AC*. While only cost data appear in these formulas, the demand relationship enters in determining the efficient allocation w*.

2.4 Supply Limits

With a supply limit, efficiency now requires that marginal benefit for each user be equal to short term marginal cost (SMC) plus the shadow price of the supply constraint (equal to the marginal cost of expanding capacity -- MCC). The rules for the intercept and slope parameters are the same, with marginal cost (MC) replaced by LMC = SMC + MCC. Marginal and average costs should be evaluated at the supply limit.

## 3.0 Empirical Methods

3.1 Full Information: Example for Amman, Jordan

With known demand and cost functions, pricing parameters can be readily calculated. However, only a few water utilities have estimated demand functions, most often only for households. Constructed demand and cost functions for Amman, Jordan provide a realistic example of calculating parameters for VUP. Two user types – household and commercial water users – are used. (Demand and cost were constructed from World Bank data.)

Table 1 shows that as a supply constraint level is made more restrictive, the slope of the charge schedule increases and the intercept decreases. The equilibrium price (average cost at the equilibrium) actually decreases as the supply limit decreases, because total cost decreases. The shadow price increases as the constraint level becomes more restrictive.

3.2 Iterative Parameter Determination

Utility services often deal with incomplete preference information by applying average cost pricing iteratively, i.e. total cost from the previous year is divided by the total supply volume to set a rate for the next year. Marginal cost pricing also implies an iterative process: marginal cost for one year becomes the price for the next year. Similarly for VUP, an iterative price-taking process based on revealed preferences and VUP rules can be used to determine pricing parameters.

Iterative rules for VUP for basic cost recovery are described briefly below. The public agency could execute the pricing process drawing on cost information from the private water utility. (Of course, there could be revelation problems by the private water utility regarding cost, but we do not address this problem here.)

It may not be feasible to fully execute the process to find an efficient equilibrium for a given set of water users. However, the utility could apply the rules over time to set pricing parameters; such a pricing process could be applied with monthly, seasonal, or yearly iterations. The descriptions below are merely suggestive of an approach when there is limited demand information.

Start with initial water user demands $w_i^t$ ($w_i^0$ on the first step) and aggregate demand $\Sigma w_i^t$.

1. Given demand, pricing parameters are based on rules for solving the equilibrium problem:

$$a^t = AC(\Sigma w_i^t) - [MC(\Sigma w_i^t) - AC(\Sigma w_i^t)]$$

$$b_i^t = \frac{MC(\Sigma w_i^t) - AC(\Sigma w_i^t)}{w_i^t}$$

2. Update charge functions for each water user type:

$$R_i^{t+1}(w_i) = (a^t + b_i^t w_i) w_i.$$

3. Given the new charge functions, water users propose new demands $w_i^{t+1}$.

Note that the process always results in cost recovery at each step. In theory, the process could be repeated until quantities demanded and pricing parameters were no longer changing. The UCRE would then be located and social efficiency satisfied.

3.3 VUP Application for Boulder, Colorado

The iterative approach is demonstrated with demand and cost data for Boulder, Colorado. Rate-setting reports for Boulder Colorado were the source of demand and cost information. Only very basic data were available, i.e. in contrast to the Jordan example above which drew on a cost function for supply expansion, only point estimates (here for 2001) were available.

Currently, Boulder uses Average Winter Consumption (AWC) for the first block, then has two other blocks (Block 2 and Block 3) for higher summer water consumption. Summer consumption roughly doubles winter consumption. Block 2 is anything greater than AWC and Block 3 is anything equal or greater to 350% of AWC. Thus, pricing is personalized according to AWC. In 2001, the Block 1 rate was $1.50 per thousand gallons, the Block 2 rate was $2.55 per thousand gallons, and the Block 3 rate was $3.85 per thousand gallons. The last block is set at marginal cost for expanding supply. There is also a fixed monthly charge based on meter size.

Boulder is in the process of reviewing alternative rate-setting methods, for example having a set rate per block for set "jumps", i.e. not personalized by AWC, and water budget methods in which the city determines appropriate water usage by lot size, etc.

User types for Boulder include single family residents, trailor parks, multi-family residences, commercial and industrial, and sprinklers, both inside and outside the city limits. User types are further differentiated as to whether summer consumption is in Block 2 or Block 3.

The talk will describe the application of VUP for Boulder. Methods include:

1. Estimate the volumetric winter and summer demands by type of user (estimated from volume by block, # of meters, and summer/winter proportions) and with assumed price elasticities for summer and winter, model summer and winter demand functions by type of user.
2. Determine average cost from cost (annual revenue requirement) and total volume. Determine marginal cost from revenue requirement for peaking supply.
3. Apply the intercept and slope formulas to estimate the corresponding parameters. for summer and winter seasons.
4. Given the resulting VUP charge schedules and demand functions by user type, estimate resulting demands and annual bills by type.

## 5.0 Conclusions

This paper has described a pricing method for achieving economic efficiency with cost recovery. The method can also satisfy any supply limits made necessary by expanding demands and droughts. We have argued that this method is better than Increasing Block Rates because it is objective and provides stronger incentives for conservation. IBR does not guarantee cost recovery or efficiency.

Economic efficiency is often equated with market solutions, e.g. trading in water rights. However, water markets have not been heavily utilized because of issues of property rights and externalities. New types of water markets – leasing and long term options – may yet prove to be useful tools for water efficiency. While these institutional changes are pending, appropriate water utility pricing may be more easily accomplished and can be complementary to other market methods.

**Table 1: Supply-Constrained Pricing for Amman, Jordan**

| Supply Constraint (mcm): | 181 (unconstrained) | 151 | 131 |
|---|---|---|---|
| Price Intercept a (jd/mcm) | 453393 | 319213 | 127540 |
| Price Slope (jd/mcm): | | | |
| b, household | 306.5 | 1811.5 | 4570.0 |
| b, commercial | 455.36 | 2633.2 | 6476.2 |
| Average Revenue at Equilibrium (jd/mcm) | 484691 | 481272 | 478535 |
| Shadow Price (jd/mcm) | 0 | 138063 | 336766 |
| Equil. Demand (mcm): | | | |
| household | 102.1 | 89.4 | 76.8 |
| commercial | 68.7 | 61.5 | 54.1 |

1. Current consumption is 54 mcm for households, 36 mcm for commercial sector. Current price is 0.47 jd/cm. 1 jd = $1.428 US.

2. Current supply is 90 mcm. An increased supply from agriculture of 18 mcm is assumed available at a price of .045 jd/mcm. All supplies are assumed to require treatment and piping cost (operating cost) of 0.47 jd/cm. (No long distance piping costs are included.)

3. Long term cost function for new supply expansion is

C(newwater) =100000*exp(-3.40)*newwater**1.7;

this put on an annual basis by dividing by 22.39, representing a 2% interest rate for 30 years.

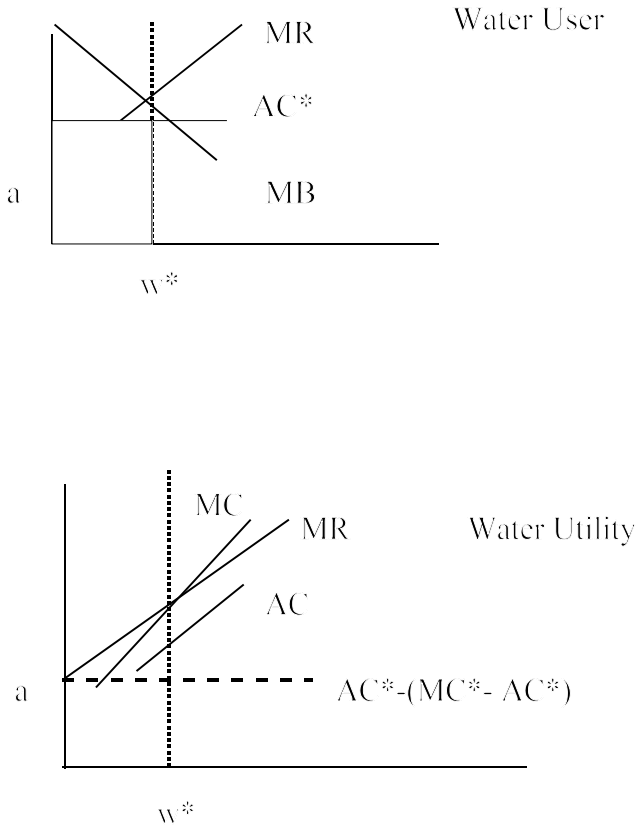
4. Inverse demand functions are

priceh = 1000000*1151.16*(housewater)**(-1.667)

pricec = 1000000*2436.48*(comwater)**(-2.0)

corresponding to assumed demand elasticities of 0.6 and 0.5 for households and commercial sectors. The constant terms are estimated to match the current demand at the current price.

Figure 1. VUP Equilibrium for One Water User and Water Utility



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