ECONOMIES OF SIZE AMONG MUNICIPAL WATER AUTHORITIES IN PENNSYLVANIA

Arthur B. Daugherty and J. Dean Jansma

INTRODUCTION

Water utilities are being subjected to progressively greater economic pressures. The demand for water is increasing, due to both a growing number of customers and rising per capita consumption. Consequently, many utilities are faced with declining reserves of water, necessitating additional investment to develop sources of supply. Frequently, new or enlarged facilities to treat, store and distribute the larger volume of water are required. Public policies, also, are promoting the extension or development of public water systems to serve sparsely populated suburban communities, small towns, and rural areas [15]. All these changes affecting the demand for water, combined with rising construction costs, are causing water utility costs to skyrocket.

One solution suggested for the problem of increasing water system costs has been to develop regional public water systems – systems that would serve several townships or an entire county. These systems could supposedly take advantage of economies of larger size and thus facilitate the provision of public water to persons in sparsely populated areas. Also, the ratio of peak-period water demand to average demand tends to decrease as the size of the utility and number of customers increase [16, p. 230]. As a result, the total capacity required should be less for one large system than for the sum of a number of small water systems.

THE MUNICIPAL WATER AUTHORITY IN PENNSYLVANIA

A municipal authority in Pennsylvania is a type of public corporation, established for one or more purposes authorized by the enabling legislation.[1] The projects or facilities of authorities are financed by the sale of revenue bonds. Authorities have no general taxing power, but must depend on project or service user fees to pay all expenses.

Authorities in Pennsylvania are created by the governing body of one or more municipalities. Once established, they are governed by a board of at least five members, including representatives from each of the organizing municipalities. Bird has concluded that the most outstanding advantage these authorities offer "is a method of overcoming traditional political boundary lines for the purpose of servicing areas or regions that are economically but not politically united" [4, p. 19]. This characteristic makes them an attractive organization for developing regional public water systems.

The municipal authority has been rapidly adopted in Pennsylvania. During the 1960-70 period, authorities increased rapidly in absolute as well as relative terms. In contrast, municipal systems declined relatively and absolutely. The number of privately owned water systems increased slightly during the 10-year period, but declined relative to the number of authorities. At the end of 1970, there

Arthur B. Daugherty is an agricultural economist with the Natural Resource Economic Division, Economic Research Service, USDA, stationed at The Pennsylvania State University. J. Dean Jansma is an associate professor of agricultural economics at The Pennsylvania State University.

[1] The first general enabling law was passed in 1935 [9]. This legislation was completely rewritten and a new law was passed in 1945 [10].

were 298 municipal water authorities in the state with more than $566 million invested in facilities. These authorities accounted for about 36 percent of the public water systems in Pennsylvania, in both number and investment.

Because of the rapid development of water authorities and their advantages in encompassing several governmental units, their economies of larger size were investigated for this study. If economies of larger size occur, it would suggest that larger, "regional" water systems should be encouraged through the policies and institutions at all levels of government.

ECONOMIES OF SIZE AMONG WATER AUTHORITIES

The economies of size in water utilities have been investigated in theoretical and empirical studies by a number of researchers. For example, Forste and Christensen [8] discussed economic theory with respect to water system planning. They indicated that the cost curves of water utilities are similar to the general theoretical cost curves. However, any given utility may be operating short of its economic optimum most of the time due to the necessity for maintaining a capacity to meet peak demands.

The cost-size relationships of various components and of total water systems have also been studied [1, 2, 3, 5, 7, 11].[2] Most of these empirical studies have utilized regression analysis with logarithmic transformations of the cost and size variables. The same general approach was also used in this study.

The economies of size of water authorities in Pennsylvania were analyzed, using cross-section data for 1970. Data from several state agencies were matched to broaden the scope of the analyses. Information on expenses, customers, and water sold were obtained from published and unpublished material of the Pennsylvania Department of Commerce [12, 13]. Information on water sources and treatment facilities were secured from the Pennsylvania Department of Health [14]. This information provided a complete data set for 246 of the 298 Pennsylvania authorities. These authorities ranged in size from 55 to more than 42,000 customers and from 3 million to 9,553 million gallons of water sold. Of these systems, 102 utilized ground water as their primary source and 144 depended on surface water. Some type of advanced treatment, that is, some treatment in addition to disinfection, was reported for 83 of the authorities.[3] The remaining 163 authorities reported only disinfection.

Data for these 246 authorities were used to implement a regression model designed to test a set of hypotheses concerning the effect of various factors on the per unit cost of water. A single-equation, least squares dummy variable model was used. Variables included in the analysis were as follows:

Y = log of total utility cost per million gallons of water sold;
X_1 = log of total number of customers served;
X_2 = log of total water sold in millions of gallons;
X_3 = proportion of total expenses that are nonoperating expenses;
X_4 = 1 if surface water was the authority's primary source, 0 if not;
X_5 = 1 if authority provided advanced treatment of water, 0 if not;
X_6 = 1 if authority served metered residential customers, 0 if not;
X_7 = 1 if authority served metered commercial customers, 0 if not;
X_8 = 1 if authority served metered industrial customers, 0 if not;
X_9 = 1 if authority served metered public customers, 0 if not;
X_{10} = 1 if authority served other metered customers, 0 if not;
X_{11} = 1 if authority sold water to other utilities (unmetered), 0 if not; and
X_{12} = 1 if authority served other unmetered customers, 0 if not.

In addition, interaction-type variables were computed as the product of each of the discrete variables, X_4 through X_{12}, and the continuous size variables X_1 and X_2. These variables were included to determine whether there were significant differences in the cost-size relationship between authorities having any of the characteristics represented by the discrete variables and authorities not having those characteristics. Including the 12 variables defined above and the interaction-type variables, 30 independent variables were included in the single equation model.

The independent variables X_1 and X_2 were the basic size variables considered in analyzing economies of size among water authorities in Pennsylvania. These variables and the dependent variable were introduced into the model in logarithmic form. This procedure was selected after investigation of

[2] These and other related studies have been reviewed by Daugherty [6].

[3] Advanced treatment included filtration and/or iron removal and softening, in addition to disinfection.

alternative forms of the relationship and of other research, such as that recently reported by Andrews [3]. The log of total customers served, X_1, was expected to be positively related to the dependent variable. Variable X_2, the log of total water sold, was expected to be negatively related to the log of unit water cost.

Variable X_3 measures primarily effects of indebtedness on unit water costs, as nonoperating expenses are largely debt service costs. Since a large debt tends to be associated with recent development or expansion of a water system, variable X_3 also serves as a proxy measure of recent development or expansion of an authority's facilities. As a proportion, this variable was included in the model in linear form and therefore affects the level but not the slope of the cost-size relationship. A positive coefficient was expected.

The discrete variables, X_4 through X_{12}, were added to the model to determine whether these water source, treatment, and customer characteristics affected the constant value of the basic relationship. Positive coefficients were expected for variables X_4, X_5 and X_6; while negative coefficients were expected for the remaining discrete variables because of the water use characteristics of the respective customer classes.

The interaction-type variables formed as products of the discrete variables and size variables X_1 and X_2 were included to determine whether authorities having these characteristics had significantly different cost-size relationships than authorities without the characteristics. For example, the economies of size were expected to be greater in surface water-supplied systems than in systems using ground water.

Parameters of the model were estimated, using stepwise regression. This technique eliminates the least significant variables, one at a time, until all remaining coefficients have student t-values equal to or greater than a prespecified value. A t-value of 1.960 was specified for the analysis, so that all variables retained in the model would have coefficients significant at the five percent level.

Regression results are shown in Table 1. After all variables whose coefficients had student t-values less than 1.960 were eliminated, all the remaining variables had coefficients significant at least at the one percent level. The size variables in logarithmic form (X_1 and X_2) were highly significant, as expected, as were the proportion of total expenses that were nonoperating expenses (X_3).

The dummy variable indicating a surface water source was retained, as were the interaction-type variables of surface water source with number of customers served and volume of water sold. This

Table 1. RESULTS OF REGRESSING LOG OF COST PER MILLION GALLONS OF WATER ON SELECTED VARIABLES FOR 246 WATER AUTHORITIES IN PENNSYLVANIA, 1970.

Item	Regression Coefficient	Standard Error	Student's t^a	Beta Coefficient
Log of Total Number of Customers Served, X_1	0.94646	0.07744	12.22	1.62
Log of Total Water Sold, in Millions of Gallons, X_2	-0.95569	0.05959	16.04	-2.04
Nonoperating Expenses as a Proportion of Total Expenses, X_3	0.16905	0.05759	2.94	0.11
Surface Water Source Dummy Variable, X_4	0.47000	0.17904	2.63	0.68
Advanced Water Treatment Dummy Variable, X_5	0.10737	0.02780	3.86	0.15
Residential Customers Dummy Variable, X_6	0.18745	0.03822	4.90	0.18
Log of Total Customers Served by Authorities Utilizing a Surface Water Source, (X_1 x X_4)	-0.30870	0.10098	3.06	-1.48
Log of Total Water Sold by Authorities Utilizing a Surface Water Source (X_2 x X_4)	0.24135	0.07979	3.02	0.87
Constant	1.55206	0.13456	11.53	

R^2 = 0.6899
F – Ratio = 69.15

[a]All regression coefficients are significant at the one percent level.

indicates not only a different cost level but different slope coefficients of the unit cost-size relationship for authorities utilizing surface water sources of supply.

The advanced water treatment dummy variable was significant. However, the interaction-type variables formed as the product of this dummy variable and the size variables in logs were not. That is, advanced water treatment shifted the cost level but not the slope of the unit cost-size relationship.

Among the dummy variables representing classes of customers served, only one was significant – metered residential customers. That is, authorities selling metered water to residential customers had a significantly higher cost level than authorities not selling to such customers. All the interaction-type variables between classes of customers served and size variables were dropped.

The regression coefficients in Table 1 provided parameters for a number of different unit-cost estimating equations, depending on water source, water treatment, whether or not the authority serves metered residential customers, and proportion of total expenses that are nonoperating expenses. However, there are only two different sets of parameters for the size variables – log of total customers served, X_1, and log of total water sold (in millions of gallons), X_2. Equations which include these sets of parameters to estimate log of cost per million gallons of water, $\hat{Y}$, are:[4]

1. Ground water source and disinfection treatment – $\hat{Y} = 1.78177 + 0.94626X_1 - 0.95569X_2$
2. Surface water source and disinfection treatment – $\hat{Y} = 2.25177 + 0.63756X_1 - 0.71434X_2$

Other estimating equations differ only with respect to the constant value. For example, advanced treatment adds 0.10737 to the constant value ($X_5 = 1$). This is equivalent to an increase in unit water costs of a little more than 28 percent, other variables constant, regardless of utility size.

Unit water cost estimates were computed for authorities using either ground water or surface water sources of supply and providing either disinfection or advanced water treatment. These estimates are presented in Table 2.

SUMMARY

This study investigated economies associated with size and other characteristics of Pennsylvania water authorities. Multiple regression analysis, using logarithmic transformations of the unit water cost and authority size variables was used to provide empirical measures of the significant relationships.

Unit cost estimates computed from the regression coefficients indicate slight reductions in unit water cost when customers served and water sold increased at the same rate (Table 2). The unit cost reductions of ground water-supplied systems were quite small, however. To determine whether significant economies of size did occur, the regression coefficients involving X_1 and X_2 were tested. The sum of these coefficients did not differ significantly from zero. Thus, no significant economies of size were observed for ground water-supplied systems. Significant reductions in water cost were estimated to occur only if water sold increased at a faster rate than customers served – that is, an increasing ratio of average water use per customer. This result implies that if a ground water-supplied authority increases in size without a change in water use per customer, there will not be significant reductions in cost per unit of water sold. However, if a heavy water using customer (such as an industry) is added, we would expect the unit water cost to decrease. Conversely, if a number of residential customers were added, these would likely lower the average water use per customer and a higher unit water cost would be expected. Thus, the average amount of water used per customer as influenced by the customer mix would be expected to influence the unit water cost of these authorities. An increase in size with constant customer characteristics would not be expected to affect unit water cost.

A test of the coefficients of X_1 and X_2 for surface water-supplied systems did indicate significant economies of size. However, the estimated cost level was higher over the relevant size range. As with ground water-supplied systems, greater reductions in unit water cost would occur if water use increased at a greater rate than customers served (higher average water use per customer).

The model used produces monotonically decreasing cost estimates when customers served and water sold continue to increase proportionately. This model fitted the data for the size range in authorities studied better than alternative models investigated which permitted unit costs to increase for larger authority sizes. This implies the water systems studied were within the decreasing cost segment of

[4] The constant values of these equations assume a utility paying one-fourth of total expenses as nonoperating expenses and selling metered water to residential customers. These assumptions add 0.18745 and 0.04226, respectively, to the constant value of the unit water cost estimating equations.

Table 2. **ESTIMATED COST PER MILLION GALLONS OF WATER SOLD BY AUTHORITIES OF THE STATED SIZES AND CHARACTERISTICS IN PENNSYLVANIA IN 1970.**[a]

Authority Size[b]		Utilizing Ground Water Source		Utilizing Surface Water Source	
Number of Customers Served	Millions of Gallons of Water Sold	Disinfection Treatment of Water	Advanced Treatment of Water	Disinfection Treatment of Water	Advanced Treatment of Water
50	8	$336.00	$430.30	$489.60	$626.90
100	16	333.80	427.50	464.20	594.40
500	80	328.80	421.00	410.30	525.40
1,000	160	326.60	418.30	389.00	498.10
5,000	800	321.70	412.00	343.80	440.20
10,000	1,600	319.60	409.30	326.00	417.40
50,000	8,000	314.80	403.10	288.10	368.90

[a]Based on authorities paying one-fourth of total expenses as nonoperating expenses and selling metered water to residential customers.

[b]Based on an average annual water use of 160,000 gallons per customer. An analysis of water use per customer in relation to number of customers indicated this to be the best relationship. Water use per customer did not increase significantly in larger water systems as has been reported by some researchers.

the cost curve. A study of other areas or sizes of water system may require a different model.

Advanced water treatment increased the unit cost level, but did not affect the coefficients of the size variables. However, because of a constant percentage shift, the unit water costs of authorities providing advanced water treatment were estimated to decline faster as size increased than did costs of authorities providing disinfection water treatment, other variables being constant.

The estimated cost level was also significantly higher for authorities that metered residential customers than for systems that did not. However, because of cost-demand relationships, per customer and total system costs could be less in metered systems, ceteris paribus.

The remaining variable found significantly related to unit water cost was proportion of total expenses required for nonoperating expenses. As this proportion increased by 10 percentage points, unit water cost was estimated to increase about 4 percent.

The results of this study should be useful in preliminary planning for development of water systems in small communities and rural areas not presently served by public systems. An extension of the results presented here has indicated little likelihood of economic "regionalization" of water supply services when supplied from ground water sources [6]. However, the cost-size relationships of surface water-supplied systems are more favorable for providing public water supplies in larger service areas.

REFERENCES

[1] Ackerman, William C., *Technical Letter 10, Costs of Wells and Pumps,* Illinois State Water Survey, Urbana, Illinois, July 1968.

[2] Ameen, Joseph S., *Community Water Systems Source Book,* Fourth Edition, Technical Proceedings, High Point, North Carolina, 1967.

[3] Andrews, Richard A., "Economies Associated with Size of Water Utilities and Communities Served in New Hampshire and New England," *Water Resources Bulletin,* Vol. 7, No. 5, Oct. 1971, pp. 905-912.

[4] Bird, Frederick L., "Authorities and Efficient Municipal Management," *Monthly Bulletin,* Department of Internal Affairs, Commonwealth of Pennsylvania, Vol. 18, No. 2, Jan. 1950, pp. 17-22.

[5] Bourcier, Donald V. and Robert H. Forste, *Economic Analysis of Public Water Supply in the Piscataqua River Watershed, I: An Average Cost Approach,* Bulletin 1, Water Resources Research Center, University of New Hampshire, Durham, New Hampshire, March 1967.

[6] Daugherty, Arthur B., "Feasibility of Developing Regional Public Water Systems With Emphasis on the Municipal Authority Form of Organization," Ph. D. Dissertation, The Pennsylvania State University, June 1973.

[7] Dawes, J. H. and Magne Wathne, *Cost of Reservoirs in Illinois,* Circular 96, Illinois State Water Survey, Urbana, Illinois, 1968.

[8] Forste, Robert H. and Robert L. Christensen, *Economic Analysis of Public Water Supply in the Piscataqua River Watershed, II: Economic Planning for Water Systems,* Bulletin 2, Water Resources Research Center, University of New Hampshire, Durham, New Hampshire, March 1967.

[9] Laws of Pennsylvania, "Municipality Authorities Act of 1935," Act Number 191, Session of 1935, pp. 463-475.

[10] ____, "Municipality Authorities Act of 1945," Act Number 164, Session of 1945, pp. 382-401.

[11] Orlob, Gerald T. and Marvin R. Lindorf, "Costs of Water Treatment in California," *Journal of American Water Works Association,* Vol. 50, No. 1, Jan. 1958, pp. 45-55.

[12] Pennsylvania Department of Commerce, Bureau of Statistics, 1970 Statistics for Water Utilities in Pennsylvania, Release No. U-4-70, Harrisburg, Pennsylvania.

[13] ____, "1970 Census of Water Utilities in Pennsylvania," Form 6, Harrisburg, Pennsylvania (Unpublished).

[14] Pennsylvania Department of Health, Sanitary Engineering, "Case Status-Water Works," Harrisburg, Pennsylvania, April 15, 1970 (Unpublished).

[15] U.S. Senate, "Rural Development Legislation as Amended by The Rural Development Act of 1972, Analysis and Explanation, Public Law 92-419," 92d Congress, 2d Session, Committee Print, Committee on Agriculture and Forestry, Dec. 12, 1972.

[16] Wolff, Jerome B., "Forecasting Water Requirements for Distribution Systems – Forecasting Residential Requirements," *Journal of American Water Works Association,* Vol. 49, No. 3, March 1957, pp. 225-235.