Dual Water Supply for British Towns

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INTRODUCTION

The vital importance of good quality water for human consumption, agriculture, and industry is recognized. A fundamental need of any community is an adequate supply of biologically and chemically safe, palatable water of good mineral quality. The demand for good quality water is high but its availability is limited. If the present rate of growth of population and industry continues, the quality of natural water will deteriorate and it will be difficult to guarantee the high quality of water supply for domestic uses. With the development of new chemical compounds day by day and the increasing use of chemicals in agriculture and industry, new micro-pollutants are finding their way into natural water courses.

Although it is possible that by treatment the mineral quality and palatability of water can be improved, the additional treatment costs required to produce high quality drinking water would be very high. An analysis of domestic, industrial, and public uses of water indicates that a large percentage of total water usage in a community does not require very good quality with respect to dissolved solids and trace chemicals which would cause potential harm if ingested.

However, if it is assumed that only a small fraction of water used in a community must be of the quality of drinking water, the volume of water to be treated by expensive, sophisticated treatment process would be small enough to allow economy in treatment. The remaining, non-potable portion of the water could receive only the usual treatment but would nevertheless have to be disinfected to allow for occassional ingestion. Two qualities of water, potable and non-potable, could therefore be supplied economically through separate systems of distribution mains.

In cases where water of good quality is scarce, such sources may be kept reserved for potable supply and local polluted sources or recycled wastewater be used for non-potable supply. Sometimes it is necessary to collect and store good quality water in the upland areas to supply drinking water in the downstream towns.

In dual supply, potable water would come from high quality sources or would be treated beyond present standards to improve its quality.

The non-potable supply is envisaged as being hygienically safe, but from poorer sources and subjected to limited treatment.

This study was initiated at the University College, London in early 1971. The objective of this study was to develop a general methodology for examination of technological and economic feasibility of using a dual supply system, compared with the single supply system, in order to identify the possible application areas of a dual water supply system. Two hypothetical new British cities, with populations of 100,000 and 500,000 have been considered in order to develop general mathematical models of twelve alternative schemes of treatment and supply.

The various cost functions needed to formulate the mathematical models are developed. The cost sensitivities of conventional and dual systems are examined, with variation of potable/total flow ratio, and rate of interest in capital and operational costs. Data required for the mathematical models are obtained from several existing typical British towns. The results of this study are applicable to new British towns.

REVIEW OF THE LITERATURE

The first systematic cost study of dual water supply systems was made by Haney and Hamann[1]. They assumed that the potable supply (27 percent of total water usage) was used for drinking, cooking, bathing and laundering, and limited industrial and commercial uses. The non-potable supply would be used for toilet flushing, lawn irrigation, fire fighting and other commercial and industrial uses. They assumed two sources of supply: one of good quality but limited in quantity for potable supply only, the other of inferior mineral quality but adequate in quantity for non-potable requirements. They also emphasized that both supplies were equally safe. They made a cost analysis of six systems of conventional and dual supplies, including the cost of plumbing changes. They found that when demineralization is required for potable supply, the dual system is cheaper than the conventional system.

Okun and McJunkin[2] made a case study in which they proposed to use a second supply to cope with increased demand for Releigh, NC. The second supply proposed for non-potable uses would be taken from the polluted Neuse River. They estimated that the costs of the dual system would be 21 percent greater than the cost of a conventional system, but that the consumer would be assured a good quality water supply which had not been exposed to urban and industrial wastewaters.

Jackson[3] made a study to utilize the heavily polluted Trent River in England as a source for industrial water supply, eventually to replace about one-third of the demand for potable supply.

In the United States, St. Petersburg, Florida plans to use reclaimed municipal wastewater for lawn sprinkling in order to conserve the available fresh water. Thus, up to 40 percent of good-quality ground water will be conserved[4]. In Colorado Springs, Colorado, about one-third of the wastewater is treated and disinfected, stored, and then distributed through a second distribution system for serving non-potable water to customers using more than 10,000 gallons per day. The water is sold at two-thirds the price of the potable water that had previously been used; both the purveyor and the user profit[5].

DOMESTIC WATER USAGE

Domestic water demand in England is increasing at a steady rate and presumably it will continue to do so in the future[6]. According to an estimate by the British Water Resources Board, the domestic water consumption of Southeast England in 1970 was 174 liters per capita per day and will increase to 267 liters per capita per day in the year 2001. The way in which water is consumed in residences is a matter of importance in dual water supply systems. Table 1 shows an analysis of domestic water usage in England for the year 1967 and 1971.

Table 1

Usage of Domestic Water in 1967 and 1971

Usage	For 1967 Liters/ Capita/day	For 1967 Percent of Total	For 1971 Liters/ Capita/Day	For 1971 Percent of Total
1. Drinking and Cooling	4.5	3.2	5.0	3.1
2. Dish Washing and Cleaning	13.0	9.6	16.0	10.0
3. Laundering	13.5	9.6	20.0	12.5
4. Personal Hygiene	50.0	35.5	54.0	33.7
5. Toilet Flushing	50.0	35.5	54.0	33.7
6. Gardening and Car Washing	9.0	6.6	11.0	7.0
TOTAL	140.0	100.0	160.0	100.0

In dual domestic systems of potable and non-potable water supplied through separate pipelines, the potable system should be capable of furnishing water for drinking, cooking, and dish washing. The rest of the household uses of water may be taken from the non-potable supply. Many in-house water supply systems in England and Wales consist of one direct connection from the street main to the cold water tap at the kitchen sink and a continuing pipe for all other hot and cold water fixtures connected through the house storage tank. To provide experimental data on the pattern of domestic water usage, a study of local authority flats in North London was made by the Building Research Station[7]. It has been found that the average consumption of water through cold water kitchen sink tap is about 15.2 percent of total water use in the household. For a dual domestic water supply system, the potable supply capacity may be considered to be 15 percent (Table 1) of the total supply; the remaining 85 percent will be supplied from the non-potable sources. In the development of the mathematical models of the various systems of water supply considered in this study, however, the ratio of potable to total supply has been taken as a variable.

PROJECTED WATER DEMAND

In this study, the planning period was taken as 1971 to 2001. The demands on public water supply for domestic and industrial uses are assessed separately. Instead of projecting the total demands of past years, the contributing factors are separated into per capita domestic demand, per capita industrial demand, and population growth. Considering the per-capita water demand in the year 1971 as unity, the values of the demands in the past years have been converted to ratios of 1971 consumptions. These ratios are termed the "demand index", and instead of projecting the per-capita water consumption values, the values for the demand index have been projected for domestic and industrial consumption.

WATER QUALITY AND TREATMENT

In dual supply systems, two qualities of water (one potable and the other non-potable) would be supplied through separate distribution systems. The quality of the potable water should conform to established drinking water standards. The quality of the non-potable supply should be maintained at such a level that its occasional inadvertent use for drinking will not cause harm. The quality of water from the single supply is assumed to be the same as that of the potable supply in a dual supply system.

In developing the mathematical models for dual supply systems, basically five types of treatment have been considered: storage; conventional treatment consisting of coagulation, sedimentation, and filtration; disinfection; activated carbon treatment; and electrodialysis. Activated carbon treatment will be used to reduce the levels of color, taste and odor, and TOC from polluted sources. In this study, electrodialysis has been adopted in the treatment system to produce potable water when raw water contains high total dissolved solids.

COST FUNCTIONS

To develop mathematical models for single and corresponding dual supplies, the capital costs and O&M costs of various units of treatment and distribution as functions of flow are required. Cost data for various units of treatment and distribution which are valid for England and Wales have been taken from recent literature[8,9,10] updated, and formulated in mathematical functions valid for 1971, the base year in this study.

All the components considered in this study are divided into two groups: a) treatment; b) pumping and distribution. A list of various components are assumed useful life periods is tabulated in Table 2.

Table 2

Useful Life Periods of Various Components

Unit Nos.	Units of Treatment	Useful Life Years
1	River Intakes	30
2	Impounding Reservoir	60
3	Conventional Treatment	30
4	Chlorination Equipment	15
5	Contact Tank	40
6	Wells	30
7	Activated Carbon	15
8	Electrodialysis	15
9	Pumping Mains	30
10	Pumping Stations	15
11	Service Reservoirs	40
12	Distribution Mains	30

ECONO-MATHEMATICAL MODELS

Depending on the sources and quality of the raw water, 12 systems of treatment using these treatment units for single supply and corresponding dual supply are considered, in order to develop 12 econo-mathematical models. These systems are tabulated in Table 3. It may be noted from Table 3 that if no good quality source is available for potable supply, the available source will be used for potable supply after appropriate treatment. For surface water, the main problem may be taste and odor, TOC, and micro-pollutants, and in those cases carbon treatment has been provided after conventional treatment to produce potable water. A groundwater source may contain high dissolved solids which require treatment by electrodialysis.

Two typical hypothetical British cities with 1971 populations of 100,000 (City A) and 500,000 (City B) have been considered to develop treatment systems and distribution system models of dual supply. Total treatment and distribution costs of conventional supply and of dual supply for all 12 treatment systems have been formulated, and the difference of treatment and distribution costs between single and dual supplies for all the 12 systems have been calculated. In formulating the mathematical models, the parameters such as potable-to-total-flow ratio, r; interest rate, i; annual capital cost increase rate, c_c; and annual O&M cost increase rate, c_o, are considered as variables.

The econo-mathematical models for all the systems have been developed on the following basis: 1) the models represent hypothetical new British towns and therefore are general theoretical models rather than specific ones. 2) cost functions are derived from the literature and provide only approximate costs; they are indicative, not definitive. They are certainly not applicable, without adjustments,

Table 3

Various Treatment Systems Considered for Dual Supply

System Nos.	Single Supply		Dual Supply			
			Potable		Non-potable	
	Source	Treatment	Source	Treatment	Source	Treatment
TS1	Surface[1]	Storage + Conventional + Chlorination[3]	Surface	Storage + Conventional + Chlorination	Surface	Storage + Chlorination
TS2	Surface	Storage + Conventional + Carbon bed + Chlorination	Surface	Storage + Conventional + Carbon bed + Chlorination	Surface	Storage + Conventional + Chlorination
TS3	Surface	Storage + Conventional + Electrodialysis[4] + Chlorination	Surface	Storage + Conventional + Electrodialysis + Chlorination	Surface	Storage + Conventional + Chlorination
TS4	Ground[2]	Electrodialysis + Chlorination	Ground	Electrodialysis + Chlorination	Ground	Chlorination
TS5	Surface	Storage + Conventional + Carbon bed + Chlorination	Ground (limited)	Chlorination	Surface	Storage + Conventional + Chlorination
TS6	Surface	Storage + Conventional + Electrodialysis + Chlorination	Ground (limited)	Chlorination	Surface	Storage + Conventional + Chlorination
TS7	Surface	Storage + Conventional + Electrodialysis + Chlorination	Ground	Electrodialysis + Chlorination	Surface	Storage + Conventional + Chlorination
TS8	Surface	Storage + Conventional + Carbon bed + Chlorination	Ground	Electrodialysis + Chlorination	Surface	Storage + Conventional + Chlorination
TS9	Ground	Electrodialysis + Chlorination	Ground (Separate limited)	Chlorination	Ground	Chlorination
TS10	Surface	Storage + Conventional + Carbon bed + Electrodialysis + Chlorination	Surface	Storage + Conventional + Carbon bed + Electrodialysis + Chlorination	Surface	Storage + Conventional + Chlorination
TS11	Surface	Storage + Conventional + Electrodialysis + Chlorination	Ground	Electrodialysis + Chlorination	Ground	Chlorination
TS12	Surface	Storage + Conventional + Carbon bed + Chlorination	Ground	Electrodialysis + Chlorination	Ground	Chlorination

[1]All surface source systems would include river intakes and pumping.

[2]All ground source systems would include boreholes and pumping

[3]Chlorination includes chlorination equipment and contact tank.

[4]For electrodialysis a reject ratio of 20 percent is assumed.

to specific cases. 3) the quality of water from the single-supply source is assumed to be the same as the potable supply in a dual-supply system. 4) Quantities of water required are obtained by projecting per-capita domestic and industrial demand; however, the rate of growth has been kept as a variable so that other rates of growth can also be incorporated in the model. 5) A leakage loss of 15 percent has been assumed. 6) Administrative costs have been included in all cost functions.

In comparing the costs of single supply and corresponding dual supply, all the costs incurred during the planning period (1971-2001) have been converted to the present value of the base year (1971). If some of the treatment or distribution units have residual design life remaining at the end of the planning period, the residual values of the units have also been considered as assets in the calculation of the system cost.

TREATMENT SYSTEMS

The present values of all capital and O&M costs incurred during the planning period of all treatment units have been calculated using corresponding cost functions for design flow, Q; potable flow, rQ; and non-potable flow, (1-r)Q. As the design period for chlorination equipment, activated carbon treatment, electrodialysis and pumps has been assumed to be 15 years, the design flow for these units has been taken as the water demand in the year 15 years after installation. The design period for all other units has been assumed to be the same as that of the water demand at the end of the planning period.

The operational cost functions for various units have been related to the variable water demand, Q_t, during the planning period. The present value of the total operation cost of a unit throughout the planning period has been obtained by summation of the present values of all yearly operational costs. The model has been developed to calculate present value of capital, and total costs of 12 treatment systems for the single supply and dual supply.

DISTRIBUTION SYSTEM

The distribution system formulation of all the 12 treatment systems will be the same. Therefore, one model of a distribution system for single supply and another for dual supply for the A-type and B-type cities are developed. The total costs of a distribution system consist of capital costs and operation and maintenance costs of pumping mains, pumping stations, service reservoirs, gravity mains, and yearly addition of gravity mains in the distribution system.

In developing the capital cost model for the pumping mains, the following assumptions are made:

1. The pumping mains are assumed to be laid in open country and the corresponding pipe cost function coefficient has been taken.
2. The pipes are assumed to be coated cast-iron pipes.
3. The length of pumping mains in dual supply is twice that of single supply.

On the basis of these assumptions, the length of the mains has been expressed in terms of population and population density. Assuming a population density of 1,000 per square kilometer (the average population density of a typical British town) the length of the mains has been calculated. The cost functions of both the capital costs and the operation and maintenance costs of all the components of the distribution system have been developed and incorporated in the distribution system model.

The annual repair and maintenance of mains and services, waste prevention, and inspection costs for 14 typical British towns have been analyzed, and incorporated in the model. When a town grows in population and new residences are built, the existing distribution gravity mains must be extended. Assuming that the population density will remain constant during the planning period has been related to the growth in population. The additional yearly capital and maintenance costs for the extension of the existing distribution systems have also been incorporated in the model.

All the distribution costs involved during the planning period have been converted to present values.

RESULTS AND DISCUSSION

The econo-mathematical models for single and dual supply for 12 treatment systems of total present costs of treatment and distribution of water as developed have been solved using a computer for various potable/total flow ratios (r values), interest rates (i) values, capital cost increase rates (c_c values), operational cost increase rates (c_o values) for A-type (base population 100,000) and B-type (base population 500,000) cities. The computer output comprises total treatment and distribution costs (capital and O & M) for all the 12 systems. The cost advantage of dual supply over single supply, DEL, is expressed by the difference of total present value costs of single and dual systems in pounds sterling.

RATIOS OF TOTAL COST DUAL SYSTEM/SINGLE SYSTEM AS A FUNCTION OF PROPORTION OF POTABLE FLOW (r)

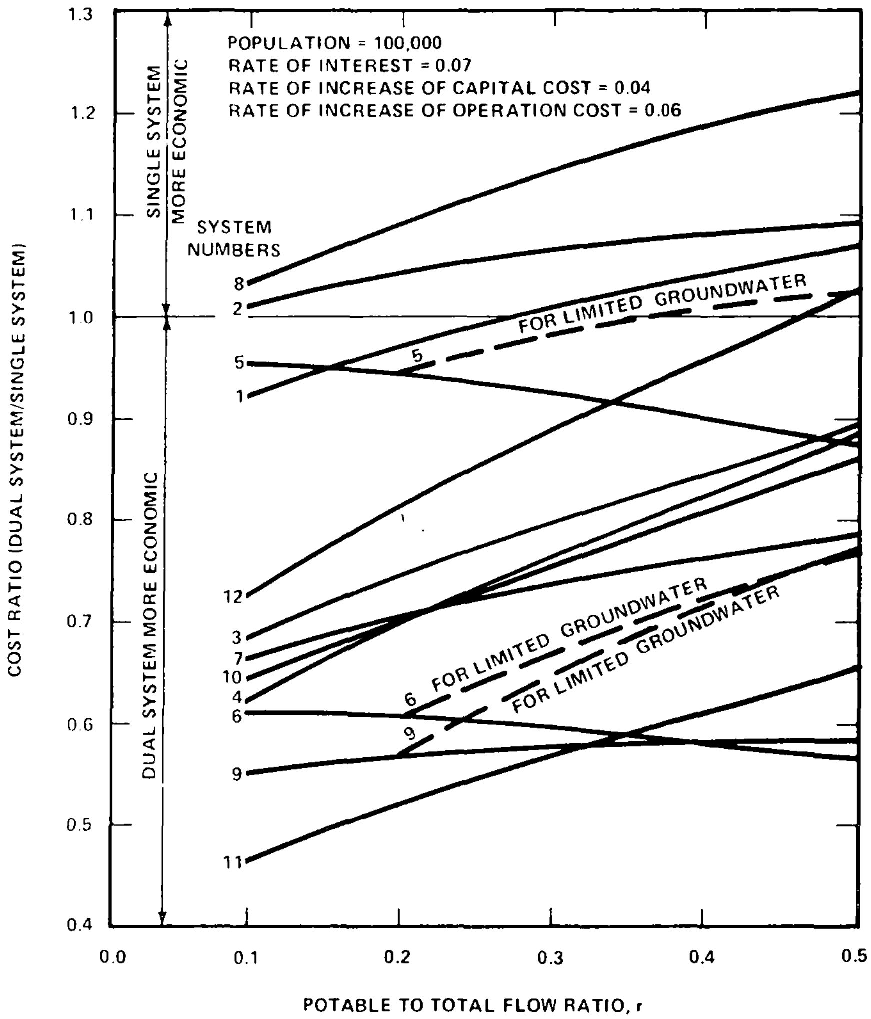
The ratios of total costs of dual supplies to single supply for all the 12 systems for various potable to total flow ratios, r, have been calculated for both A- and B-type towns and are presented in graphic form in Figure 1. When the cost ratio is more than 1.0, the single supply system is more economical.

In Treatment System 1, the source of water is a good quality surface source and the raw water quality is such that it needs conventional treatment and chlorination to produce potable water. Non-potable water of dual supplies in this case has been produced by chlorinating the water from the impounding reservoir. In this case it has been found that the dual supply would be more economical than the single supply when $r < 0.29$.

It can be seen from Figure 1 that Systems 2 and 8 are economical in single supply for all values of r. In both cases, the activated carbon treatment cannot balance the additional cost in distribution. Again, in System 8 the treatment of potable water of dual system is costly because of electrodialysis treatment for TDS, and, therefore, with the increase of r value, the cost ratio is rapidly increased.

FIGURE 1

COST RATIO OF DUAL TO SINGLE SYSTEM VERSUS FLOW RATIO



In Systems 3 and 4 (Table 3), the raw water contains high TDS, but the raw water in System 3 is derived from a surface source and that in System 4 is derived from a ground source by wells. From Figure 1 it can be seen that the dual system is more economical in both Systems 3 and 4 for all the values of r in the range of 0.1 to 0.5. As electrodialysis treatment for TDS is an expensive operation, the advantage of dual supply diminishes rapidly with the increase of r values in both the systems (Figure 1).

In Systems 7 and 11, there are two sources of raw water available, surface and ground, both having high TDS content. Electrodialysis treatment is therefore necessary for the single-supply system and for the potable water in the dual-supply system. Dual water supply is more economical in Systems 7 and 11 for all the values of r in the range of 0.1 to 0.5.

Treatment System 10 is an example of a polluted surface source which has a high organic content and TDS and therefore needs activated carbon treatment and electrodialysis to produce potable water, whereas for non-potable water, conventional treatment has been adopted. The dual supplies are found to be economical for all ranges of r values plotted. In System 12, it is assumed that two sources of water are available, one surface water having high organic content and another ground water with high TDS. For single supply, the surface source with activated carbon treatment was chosen; for dual supply, the ground source with electrodialysis treatment for potable supply was adopted. Dual supply is found to be more economical (Figure 1) for all values of r except r=0.5, where single supply is more economical. Because of the high cost of treatment of potable water in dual supply, the cost ratio increases very rapidly and becomes equal to 1.0 at r = 0.48. At this point, the cost of dual supply equals the cost of single supply.

In Systems 5, 6, and 9, it has been assumed that good-quality ground water of limited quantity is available for potable supply of the dual system. Systems 5 and 6 have surface water as a plentiful second source; System 9 has a ground source of inferior quality. If the good-quality ground source is available, up to r = 0.5, then the cost ratios decrease with an increase of r values in the Systems 5, 6, and 9, and these are shown by solid lines in Figure 1. Because the quality of the limited ground water is very good, the cost of treatment is very low; hence, the total cost of dual supply drops with the increase of r values in Systems 5 and 6 and is reduced slightly in System 9.

Again, all three systems have been computed on the assumption that the good quality ground water supply is limited to r = 0.2; if the potable requirement is more than r = 0.2, the excess potable water is drawn from the second large source with adequate treatment. The cost of treatment of this excess potable water is high, and as a result the cost ratio increases with the increase of r values as shown by the broken line in Figure 1.

Except for the special cases of Systems 5, 6 and 9, the economic advantage of dual supply reduces with the increase of r values for all the systems.

COST DIFFERENCE (DEL) AS A FUNCTION OF INTEREST RATE (i)

In Figure 2, DEL values have been plotted against the rate of interest for all the 12 systems assumed in this study, when r = 0.2, c_o = 0.06 and c_c = 0.04. All the systems, except Systems 8 and 12, show that the DEL value (i.e. economic advantage of dual supplies over the single supply) decreases with an increase of the rate of interest. In Systems 8 and

FIGURE 2

DEL VERSUS *i*

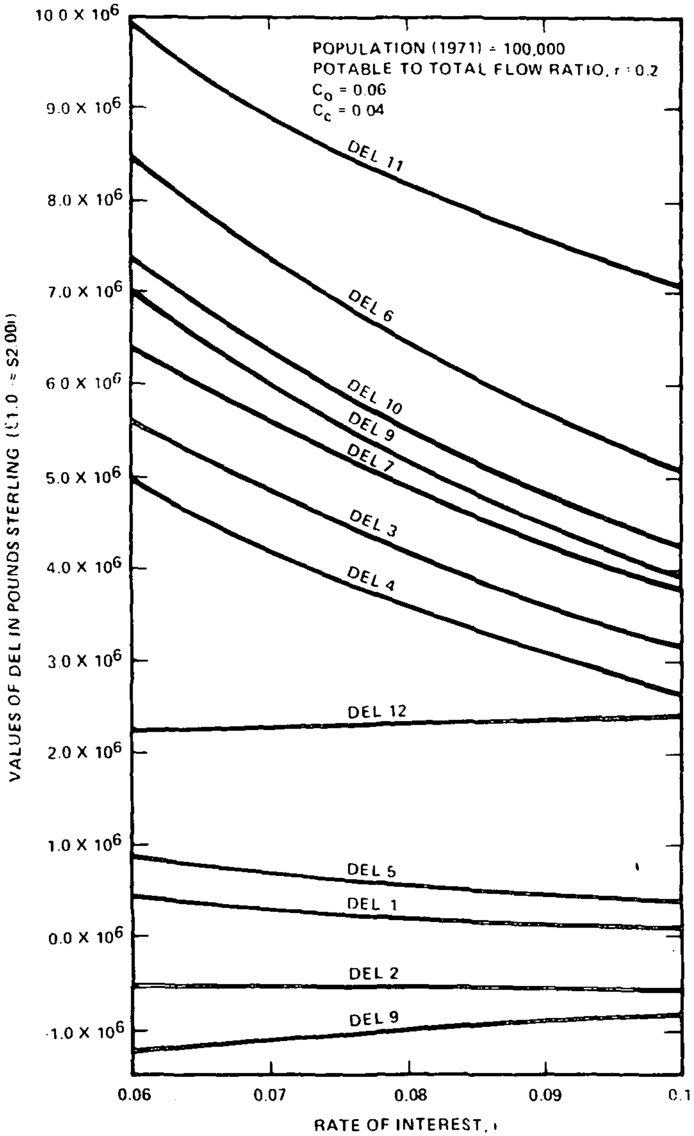
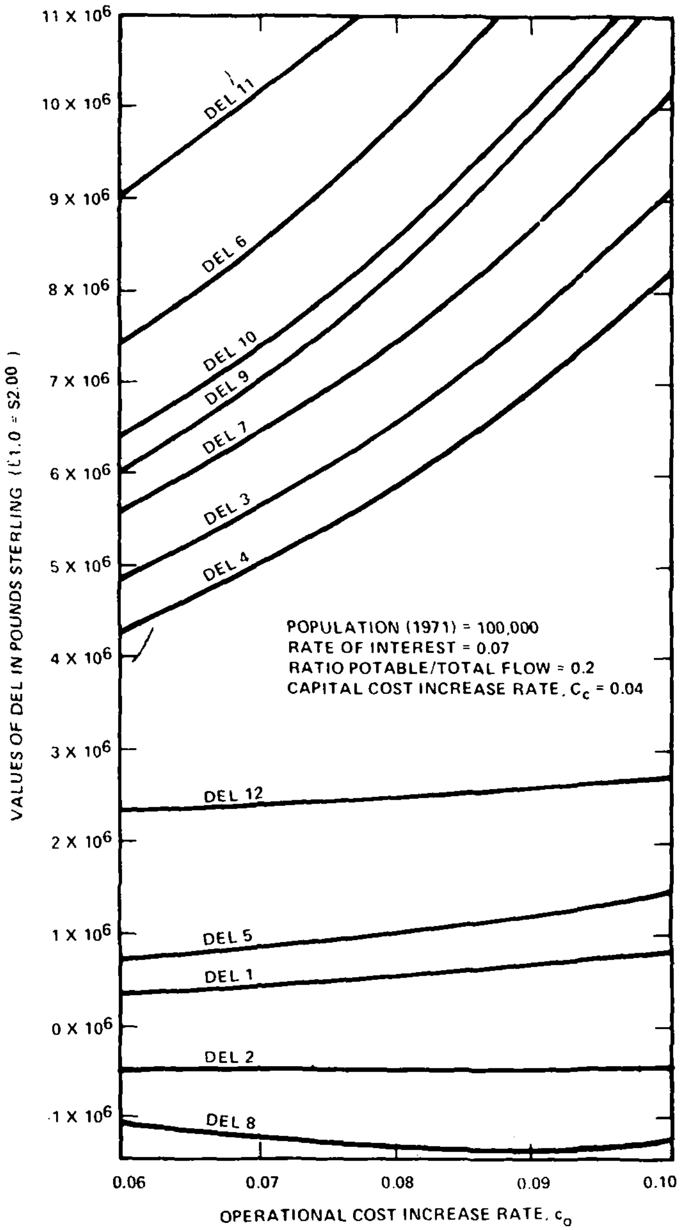


FIGURE 3

DEL VERSUS c_o



12, DEL values increase slightly with the increase in interest rates. It has been found from the result that the operating cost of electrodialysis is so high that it controls the slope of the DEL versus rate of interest curve. All the systems which include electrodialysis in the single supply have steep negative slopes of the DEL versus rate of interest curve (Figure 2).

COST DIFFERENCES (DEL) AS A FUNCTION OF RATE OF INCREASE OF OPERATIONAL COSTS (c_o)

In Figure 3, DEL values have been plotted with operational cost increase rate (c_o) for all the 12 systems when $r = 0.2$, $c_c = 0.04$, and $i = 0.07$. Here again, as the operational cost of electrodialysis treatment is high, whenever electrodialysis has been included in the single system, the DEL values increase rapidly with the increase of operation cost (Figure 3). The systems having more or less similar operational costs in single and in dual supplies give DEL values which are not so sensitive to operational cost increase rates. (Systems 1, 2, 5, 8 and 13 in Figure 3).

COST DIFFERENCES (DEL) AS A FUNCTION OF RATE OF INCREASE OF CAPITAL COSTS (c_c)

The total cost difference between the single and dual supplies (DEL values) is plotted against the rate of increase of capital cost per year, c_c, in Figure 4. Figure 4 shows that the DEL values are not very sensitive to the chance of c_c values. The annual capital cost increase rate (c_c) will only affect the future capital costs as well as the residual value of the capital costs of those units whose useful life periods are more than the planning periods. In all the systems except Treatment Systems 11 and 12, the DEL values increase with the increase of c_c values. This means that the future net capital and residual costs for dual supply are more than those for single supply.

TOTAL AND DISTRIBUTION COSTS

The cost of water in British pence (1971 value) per thousand liters (cubic meter) has been calculated for all the systems for single and dual supply for both A- and B-type towns (Table 4). In Table 4 an analysis is given of the distribution and treatment costs for an A-type town for all the systems. The cost of water has been calculated by dividing the total amount of water produced during that period. In Table 4 it can be seen that the extra cost of distribution of water by dual supply, even when $r = 0.5$, is 0.43 pence per thousand liters. The savings of costs of treatment in dual supply in the systems which include electrodialysis in single supply (Systems 3, 4, 6, 7, 9, 10 and 11) is always more than 0.43 pence per thousand liters. Dual supply is therefore cheaper in all the systems which include electrodialysis in single supply.

The ratio and difference of distribution costs of dual- to single-supply systems have been plotted in Figure 5. It can

FIGURE 5

DISTRIBUTION COST RATIO VERSUS r

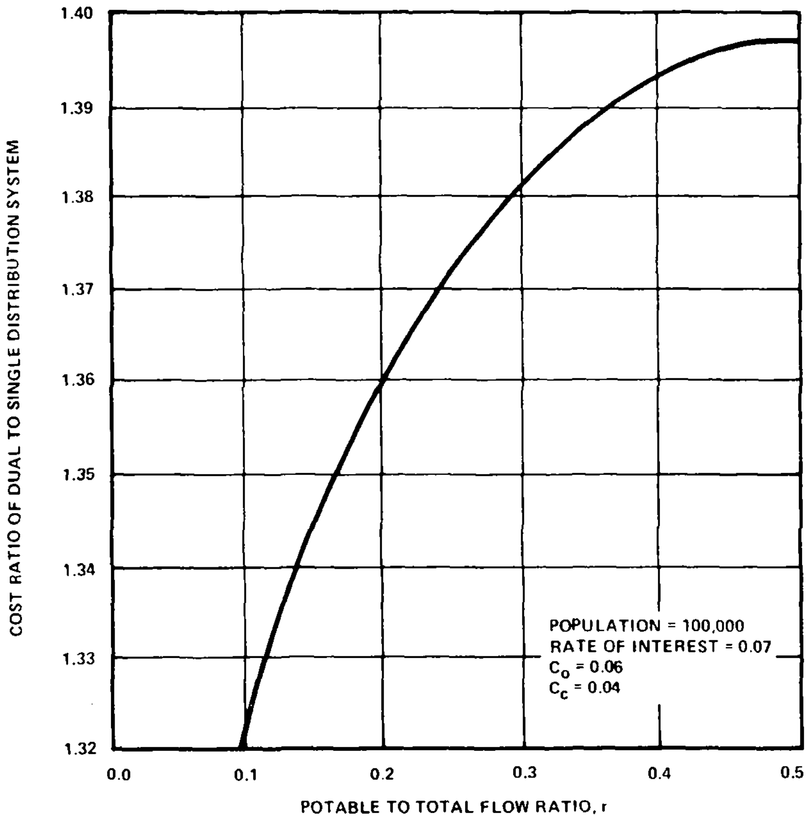


FIGURE 4

DEL VERSUS C_c

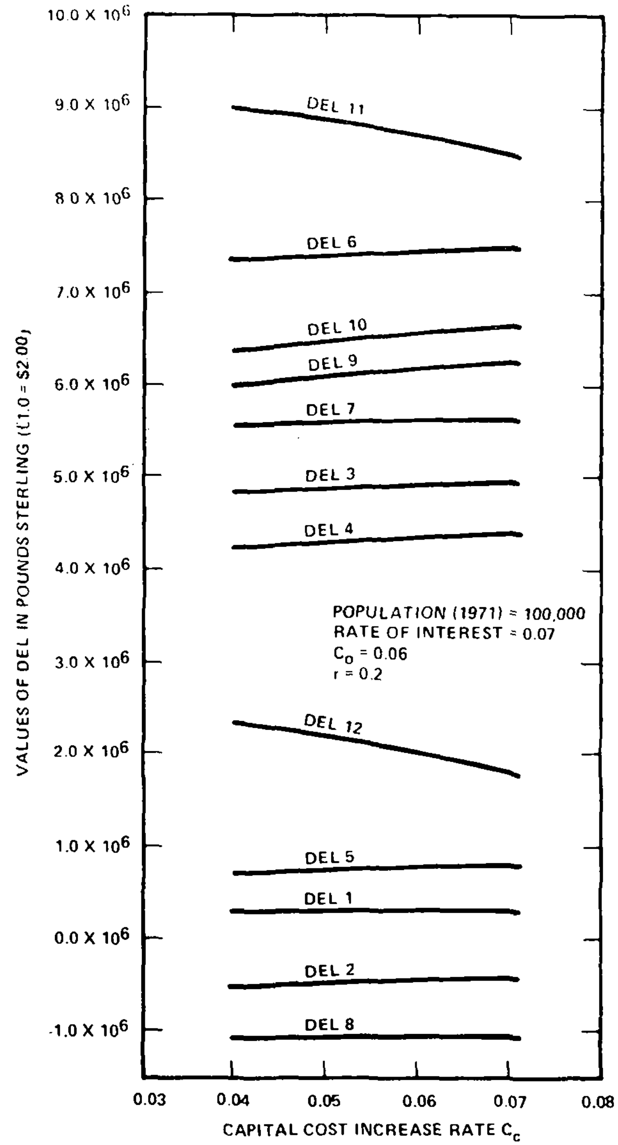


Table 4

Cost of Single and Dual Water Supplies

Population 1971 = 100,000

Rate of interest, i = 0.07

Rate of capital cost increase c_c = 0.04

Annual operation cost increase rate c_o = 0.06

Types of supply	Flow ratio of potable to total, r	Part of Cost	Cost of water in pence/1,000 liters (1971 value)**											
			System Number											
			1	2	3	4	5	6	7	8	9	10	11	12
Dual Supplies	0.1	Total	2.12	2.73	2.87	1.96	2.58	2.57	2.79	2.79	1.75	3.05	1.96	1.96
		Distribution	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
		Treatment	0.69	1.30	1.44	0.53	1.15	1.14	1.36	1.36	0.32	1.62	0.53	0.53
	0.2	Total	2.22	2.82	3.12	2.19	2.55	2.55	2.95	2.95	1.79	3.27	2.19	2.19
		Distribution	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
		Treatment	0.75	1.35	1.65	0.72	1.08	1.08	1.48	1.48	0.32	1.80	0.72	0.72
	0.3	Total	2.30	2.87	3.34	2.39	2.50 / 2.67*	2.50 / 2.80*	3.08	3.08	1.82 / 2.03*	3.53	2.39	2.39
		Distribution	1.49	1.49	1.49	1.49	1.49	1.49	1.40	1.49	1.49	1.49	1.49	1.49
		Treatment	0.81	1.38	1.85	0.90	1.01 / 1.18*	1.01 / 1.31*	1.59	1.59	0.33 / 0.54*	2.04	0.90	0.90
	0.4	Total	2.38	2.92	3.54	2.58	2.44 / 2.74*	2.44 / 3.02*	3.19	3.19	1.83 / 2.25*	3.78	2.57	2.57
		Distribution	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
		Treatment	0.88	1.42	2.04	1.08	0.94 / 1.24*	0.94 / 1.52*	1.69	1.69	0.33 / 0.75*	2.28	1.07	1.07
	0.5	Total	2.44	2.96	3.73	2.75	2.37 / 2.76*	2.37 / 3.22*	3.29	3.29	1.83 / 2.42*	4.02	2.75	2.75
		Distribution	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
		Treatment	0.93	1.45	2.22	1.24	0.86 / 1.25*	0.86 / 1.71*	1.78	1.78	0.32 / 0.91*	2.51	1.24	1.24
Single Supply	1.0	Total	2.29	2.71	4.20	3.14	2.71	4.20	4.20	2.71	3.14	4.71	4.20	2.71
		Distribution	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
		Treatment	1.21	1.63	3.12	2.06	1.63	3.12	3.12	1.63	2.06	3.63	3.12	1.63

*When ground water for potable supply in dual supply system is limited to r = 0.2 and excess requirements are taken from non-potable source

**1 British Pence = 2.4 U.S. cents

be seen from Figure 5 that the distribution cost of dual supply when r = 0.5 is 39.7 percent more than that of single supply.

SUMMARY AND CONCLUSIONS

The cost functions of various units of water treatment and distribution valid for England have been developed. From past data of per-capita domestic and industrial water demands of various typical A-type (1971 population = 100,000) and B-type (1971 population = 500,000) towns, projected water demands in the future years up to the year 2001 have been estimated.

The econo-mathematical models for single and dual supply from twelve typical water treatment systems have been developed using these variables: the potable to total flow ratio (r), rate of interest (i), rate of increase of capital and operating costs of the single and dual supplies of the system during the planning period have been computed in terms of present values by using a computer. The single-supply cost for each system has been compared with the dual-supply cost. The variation of these cost values with potable to total flow ratio, interest rate, and rate of increase of capital and operating costs have been studied.

In the case of a conventional treatment system with cholrination to produce potable water (Treatment System 1), the total cost of dual supply is less than the single supply cost when $r < 0.29$ in the case of A-type towns, and $r < 0.2$ in the case of B-type towns. Dual supply in all other Treatment Systems (except Systems 2 and 8) is found to be economical. Operational costs for electrodialysis are high; hence, dual supply for all the systems which include electrodialysis to produce potable water in the single system is cheaper.

Although certain general conclusions are possible, it would be unwise to accept these conclusions for all circumstances. It must also be stressed that the analysis assumes the development of new supplies and not the redesigning of an existing system using historically established treatment and distribution systems with all their complexities.

The important contribution of this study is that a general methodology has been developed for comparing the costs of single and dual supply. This method can be used in any specific case by putting the proper values of the various cost and other economic parameters in the econo-mathematical models. In this study, the cost of changing internal plumbing to suit dual supply has not been included.

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