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A METHODOLOGY FOR COMPARING WATER DESALINATION TO COMPETITIVE FRESH WATER TRANSPORTATION AND TREATMENT

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SUMMARY

The comparison between desalination and other water supply methods is usually based on a conventional economic evaluation which typically takes into account the direct capital and operating costs and utilizes techniques and criteria which differ from designer to designer. While this method is usually adequate when one of the alternative water supply methods is clearly superior, the comparison must be much more systematic and comprehensive where the alternatives are competitive. This paper presents a methodology for such a comprehensive evaluation, addressing the complete water supply-disposal chain and taking into consideration technical, environmental, economic, and political/legal aspects of the problem. Actual examples, mainly from the experience of the Southwest Florida Water Management District, are provided to illustrate the methodology. The economic analysis is based on a present-value life-cycle cost model which accounts for interest, tax, insurance and escalations in energy, labor and material costs.

INTRODUCTION

With growing shortages of easily developable water and the reduction in cost of treating marginally acceptable water, such as brackish, desalination merits increasingly more serious consideration as an alternative source of fresh water. The Southwest Florida Water Management District has been interested in the development of desalination processes, in particular reverse osmosis, for several years. It is felt that traditional means of fresh water resource development will continue to supply the majority of the District's demands. However, in areas far removed from adequate fresh water resources, and which have relatively small demands, desalination can provide an economically attractive alternative to the development and transmission of distant fresh water resources. Although desalination methods, in particular reverse osmosis and electrodialysis, make up only 4.5% of the District's total public water supplies, these methods supply 49% of the public supply in the counties where they are located (1, 2). Furthermore, it has been shown that the costs of fresh water produced by a system which at least includes desalination as one of its components (such as through blending or other conjunctive use) are becoming competitive with conventional supplies (cf. 3, 4, 5).

After the technical feasibility of competing water desalination, transportation, or treatment methods is ascertained, the comparison between them is usually based on conventional economic evaluation which typically takes into account the capital and operating costs and utilizes specific criteria which differ from designer to designer. While this method is usually adequate when one of the alternative water supply methods is clearly superior (say, desalination may be clearly superior in desert areas where other water supplies are scarce, or may clearly be inferior where fresh water supplies are abundant), the comparison must be much more systematic and comprehensive where the alternatives are competitive.

This paper presents a methodology for such a comprehensive evaluation, addressing the complete water supply-disposal cycle and taking into consideration technical, environmental, economic, and political/legal aspects of the problem. Before a detailed comparative analysis of water supply by desalination and conventional means is conducted, a preliminary evaluation may be made by recognizing some of the major aspects or applications where desalination has distinct advantages or disadvantages. A necessary premise for any evaluation is that desalination should not be considered in isolation, but should always be evaluated in the scope of a total water management program.

Desalination is practically the only method for supplying water to arid areas which are very remote from any fresh water supplies. It can also serve draught-stricken regions because it can be put into operation relatively quickly, when needed. In areas which do have some fresh water supplies, desalination is particularly attractive when used for blending with higher salinity water (cf. 3) and when various salt-laden effluents need to be desalted either for fresh water production or environmental protection or for both. With the increasingly strict government regulations for potable water, desalination may be the sole method or needed component of the most economical scheme to meet them. Also, if a dual-supply system is contemplated (one poorer and one better quality water supply source), desalination can provide the higher quality supply. When conventional water supplies need to be increased, an attractive method is the conjunctive use of desalination with a larger existing water reservoir when relatively small capacity increases are needed (cf. 6, 7). Compared to a conventional water supply project which must be prebuilt large enough to economically satisfy the demands which increase gradually, and which may thus be under-used and costly to operate during the initial period, desalination plant capacity can be matched to demand much more readily by adding similar units (or modules).

The major disadvantages of desalination are typically high costs, more complex operation and maintenance, a relatively lower load factor, and the high-concentratio brine effluent, which may also contain metals.

DETERMINATION OF FUTURE WATER DEMANDS

Essential to the proper planning of any water supply system, whether it is based on desalination or not, is the careful estimation of present and probable future demands Over or underestimation of these demands can result in serious damage to the economic and social well-being of the community. The minimum data requirement for determining future demands is a record of the overall water demand of the preceeding several years. By extrapolating the growth trend, the future demands can be estimated. This method is a rather rough guide and could lead to expensive miscalculations of water supply requirements. An improvement in the method can be made by subdividing the past and projected water demands into separate components corresponding to the variou: individual water uses within the overall demands of commercial, domestic, and industrial consumers. By the application of detailed information concerning the possible future characteristics in each category of water use and by taking into account the projected growth in population and economic activity, greatly improved estimates may be made of the future trend in each component water use. The combination of these separate trends will then provide an estimate of the future requirements for the total demand. A striking example of this within the District would be the phosphate mininc and processing water demands. The industry's present demand is approximately 250 MGD. As phosphate reserves become depleted, water demands for mining is expected to decrease from a high of approximately 330 MGD in the years from 1885 to 1990, to approximately 100 MGD by 2020. Use of a straight line projection would not have reflected this trend.

An identification of the nature of the major components will allow an improved assessment of seasonal and daily variations in demand, information which is mandatory for the detailed design of the water system.

The above type of analysis usually proves adequate in the situation where the proposed extension of the water supply system will leave unchanged the nature of the supply and its cost to the consumer. Under these conditions, it is reasonable to assume an essentially unchanged response of the economy in relation to water. Should there be significant changes in the overall cost of water, then significant changes in the water use of all categories can be expected. If similar communities are not available for comparison, then a more accurate assessment of the price-elasticity of demand can be obtained by the advanced introduction of higher water rates. Observation of the response of demand to these rates, preferably over a period of at least one year, would be important (though probably unpopular) for the forecasting of future demands (cf. 8).

In addition to the quantity of the future demand, the quality needs to be determined too. For example, government regulations will quite likely require purer drinking water (cf. 9), and a future change in agriculture may require either purer water for some types of crops, or that the present salt content requirement be relaxed for other types of crops (10).

ALTERNATIVE WATER SUPPLY SYSTEMS AND THEIR COMPARATIVE EVALUATION

Based on the projected water quality and demand, and existing potential resources and constraints, alternative design solutions are formed and evaluated. The criteria used throughout can be subclassified into the tangible direct and indirect benefits (or advantages) and costs (or disadvantages), and the 'intangibles'. The tangible attributes are those which can be readily quantified, but the intangibles, such as political and social, may become predominant*. In all comparative analyses we evaluate the differences between competing designs, as well as the difference between having a project or not having one at all. The latter is conducted by a "with and without" analysis (13) which takes into account also any changes in the existing situation if the project is not implemented. Conclusions are made easier if the tangible and intangible parameters show the same trend.

The formation and evaluation of design alternatives can be made in four general areas: technical, environmental, political/legal, and economic. Each one of these areas will be discussed separately.

Technical evaluation

This section includes the physical realm of water supply, i.e., where is it, how much is there, which methods of treatment need to be applied, and whether it can meet water quality standards. The first step would be to conduct an extensive search of all the possible water sources. This would include the identification of the various ground water and surface water sources, and the evaluation of the quantity of water that can be obtained from each. By knowing these quantities, the various sources can be ranked according to their ability to dependably supply the future water demands. For example, Chapter 16J-2&4 of the District Rules and Regulations (14) specifies the regulatory constraints in the quantity of water which can be withdrawn from a surface or ground water source, e.g., a withdrawal from a river must not exceed 10% of the average flow at the point of withdrawal.

Another variable that must be considered is the quality of water at each source. Once this is known, the type of treatment necessary to meet the required water use

*A special example is the "Strauss-Eisenhower Plan" to construct nuclear power desalination complexes in the Middle East to promote peace (11, 12).

characteristics can be determined. A combination of processes may be used to treat individual undesirable source-water components, and blending may be implemented to result in the most acceptable system. In every case, the amount of treatment depends on the eventual use.

The risk to the water quality of each source must also be evaluated. For example, a reservoir downstream from a phosphate mining operation can be affected should a spill occur. These phosphate slimes and mine tailings would be detrimental to the water quality and would possibly render normal treatment processes inadequate. Likewise, urban growth in upstream areas can pollute a river and jeopardize the water supply. This can also occur in brackish water aquifers where inadequate attention is paid to the movement of saline water, resulting in a reduction of plant capacity due to increased salt levels. For example, desalination has been used to produce and inject fresh water into aquifers and thus stop seawater intrusion (15).

Various types of treatment processes offer a flexibility in the scheduled construction of the physical system. Scheduling should be matched with the community's growth rate and available funds. Conventional water treatment projects that are characterized by a high investment and low annual costs can be very costly for the consumer. Its not at all uncommon to prebuild twenty or twenty-five years' future capacity into a system. Consideration should be given to a system that more closely follows the demand curve. A pipeline for the long distance transport of fresh water must be sized for the maximum flow even if this capacity won't be needed for twenty years. On the other hand, water desalination units can be added on an as-needed basis.

Environmental evaluation

This section discusses the necessity in water supply planning and management of meeting the various environmental regulations and requirements. In properly planning a system, the cost of protecting the environment and the integrity of the supply must be considered to evaluate the true costs associated with each alternative.

A water supply in the District is expected to meet the water quality requirements of the Florida Administrative Code based on Federal Standards of the Safe Water Drinking Act (16, 17). In some cases, extensive and costly treatment may be required to meet these standards. Once the water quality of each source has been analyzed, the type of contaminants-removal method that would be applied can be determined. In many cases more than one type of treatment may be necessary.

Another variable to be considered, besides the cost of the various treatment processes, is the quality of the waste effluent and its associated disposal. A type of treatment that appears relatively cheaper than others may not be so if the disposal of its waste effluent is closely evaluated. Disposal of some sludges and harmful chemicals may be more than a small community and its staff can handle. For example, the city of Sarasota eventually chose reverse osmosis over an ion exchange demineralization method because of the characteristics of the process waste (3). To allow for discharge into Sarasota Bay, the process waste must be neutral and contain less than 2700 mg/ℓ of sulfates. The reverse osmosis method could accomplish this objective, whereas the ion exchange could not without additional expense.

No matter what type of source is eventually chosen, careful consideration of the environmental and hydrological impacts of removing the water must be evaluated. If pumping from a large wellfield would significantly alter the natural water tables, consideration must be given to the impact this will have on the natural vegetation and on adjacent property owners. Within the District Rules and Regulations (14) it is specified that ground water removal must not cause damage to adjacent property owners. In order to avoid damage and to be allowed to pump the necessary amounts, many communities have purchased the lands within the drawdown area.

The trend towards larger wellfields is evident in the District. E.g., Section 21 Wellfield which was developed in 1963, contains 630 acres and is permitted for an average annual rate of 16.9 MGD. On the other hand, Cross Bar Wellfield, which was just permitted and is not yet pumping, encompasses 8000 acres and is allowed an average annual rate of 15 MGD*. The cost to purchase the lands and the subsequent loss to the tax base adds to the overall cost of the alternative. For example, Pinellas County acquired the 8000 acres for Cross Bar in order to mitigate damages from pumping and to meet their future demands. The approximately $4.8 million for this land added $0.26 per 1000 gallons capacity to the overall cost of the alternative**. Both local and regional environmental effects must be analyzed. Examples of this would be changes in the movement of the saltwater interface or the resulting change in estuarine production due to the lack of fresh water flow.

Besides requiring an environmental examination prior to construction, each alternative will require some monitoring after the system is in operation. Each alternative should be evaluated to determine what its monitoring requirements will be. Because the cost of environmental monitoring can be significant, this cost must also be included in an economic evaluation of each alternative.

Institutional (political/legal) evaluation

One of the most important variables to be considered in any institutional assessment is the institutions themselves. One of the major tasks is to identify all the federal, state, regional, and local institutions that serve some function in the management of water resources in the study area. Of course, these institutions would vary depending on the type of alternative that is being evaluated. Should a pipeline

* This is a temporary permit. Pinellas County, owners of the wellfield, would like to eventually pump 30 MGD from Cross Bar.

**Should Cross Bar be permitted to pump 30 MGD, as will be requested, the land cost would change to $0.13 per 1000 gallons capacity.

extend across a county line, then one more agency, the adjacent county government becomes involved. It is then required that permits for construction and crossing or road rights-of-way be acquired from the appropriate agency in that county. The identification of each agency should include information concerning its permitting process, such as requirements and the time frames needed for permitting. In evaluating each alternative, it must be determined if the choice can meet all agency requirements and at what cost.

Another variable to be considered is the identification of private and public interest groups that would become involved with each alternative. The problems and issues that would be of interest to each of these groups must also be identified. The effect these groups could have on stopping or slowing down construction or additional costs must be evaluated. The construction of a supply system in an ecologically endangered environment could severely delay the project past the time when the water is needed. When time is of essence, alternatives can be ranked low if the permitting processes and construction are unnessarily long. For example, the District has had experience in areas where local residents or civic groups feared damages due to a major wellfield being located nearby, and this delayed the permitting pending legal hearings and further inquiry.

Exceptional political/legal difficulties may be incurred if interbasin or intercommunity transfer is contemplated. Such a transfer should be subject to at least the conditions that proper water conservation should be instituted at the receiving system; all receiving basin resources should have been explored and utilized to a reasonable degree, and the donor basin water supply and environmental needs should have been protected (18). It is obvious that meeting these conditions at the two basins or communities could bring up a fair amount of controversy and dispute. Water desalination of local sources usually doesn't involve as many different communities and institutions as conventional water supply does, and thus may prove to be an easier route for water supply development. Another set of political/legal problems arises where a community does not have control of or long-term contracts for their water supply. E.g., the West Coast Regional Water Supply Authority (WCRWSA), a water supply agency for a three-county area within the District, recently had difficulty with its bond program because of a temporary (five-year) operating permit for the Cross Bar Wellfield. WCRWSA had originally requested 30 MGD, but instead, received a temporary permit for 15 MGD. As WCRWSA is a newly formed organization, it does not have a credit rating. To have a bond program, it needed a co-signer (with a credit rating) for a water sales agreement. Pinellas

County, the co-signer, was reluctant because of the reduced amount of pumpage and the short time of the permit. After some delay, a new "take on pay" clause to the water sales agreement was written and the bonds were sold. Should this be the case with any supply alternative, the penalties involved must be considered in the evaluation. Another community within the District's boundaries is developing a reverse osmosis system because of a similar constraint. They could have purchased water from a neighboring city, but could not get control over the water supply beyond a five-year sales agreement. In many cases, a desalination plant for local brackish or highly mineralized supplies is thus an attractive alternative for smaller communities, which would thereby have full control over their water supplies.

Price of water may have to be changed from that planned, either due to unforeseen changes in circumstances or due to errors in demand and quality predictions, or in design. However, price changes are also subject to complex political/legal constraints. Typically, rate increases for water are done in Florida in two ways, depending on ownership and location of the system. Investor-owned utilities in 27 of Florida's 67 counties must file for a rate increase from the Public Service Commission (PSC). The PSC has eight months to act after the minimum filing requirements are met and the filing fees are paid. In the process, the PSC performs or contracts for an audit of the company's financial records. When this is completed, a public hearing is held and the new rates are established. In the other counties, a rate increase must be filed with the local government. Procedures vary and should be determined on a county-by-county basis. Publicly owned utilities, on the other hand, do not have to file with the PSC for rate changes. The matter is discussed before the local government and rates are modified as needed. Normally, an audit is performed by an outside consulting firm.

Economic evaluation

Although several methods are in use for the economic evaluation of projects, probably the most appropriate and comprehensive one is that which utilizes the cost-benefit ratio, where the cost is the present-worth (C) of the water treatment or conversion system based on its life cycle, and the benefit is the actual quantity of fresh water produced over the same life-cycle. C here is the price of water for the end-user, and thus represents the sum of the cost to the plant's owner (water district, municipality, etc.) and of any added costs charged to the customer.

The system cost C in this scheme arises from two major categories: (1) initial costs C_i, and (2) annual (or periodic) costs C_a.

Typically, the initial cost C_i is the capital cost C_c, but may also include j direct or indirect costs C_{cj}, which either add to C_c or defray it. C_c is typically composed of all or some of the following components (19, 20): (1) source of supply (dam, wellfield, impoundment, intake), (2) conveyance, (3) treatment, (4) conversion (desalination), (5) disinfection, (6) distribution, (7) disposal (effluents, drainage) (8) business facility, (9) user's facility. C_{cj} may include one-time initial items such as an annexation fee imposed by the owner on the user (add to C_c) or a federal grant which reduces the initial cost (subtracted from C_c).

The annual costs may include the costs for all the above components, of: (1) energy, C_{ae}, (2) labor for operation, maintenance, safety and environmental inspection and business, $C_{a\ell}$, (3) equipment, replacement materials, and chemicals, C_{am}, (4) source water fees, C_{aw}, (5) right-of-way fees and land rentals, C_{ar}, (6) taxes, C_{at}, (7) outside (say federal) annual subsidies, C_{as}, (8) profit, C_{ap}.

It is important to note here that C_{at} is the sum of those taxes that may have to be paid by the system's owner, those which are paid to him by the user (such as a tax to a water district), and a possible annual loss of tax base due to land use for the water supply system (the latter becomes significant when large amounts of land are bought by the plant's owner for wellfield development, storage, conveyance, etc.).

Because of the increasingly important fraction of the annual cost represented by the energy expenditure, it is necessary to take into account <u>all</u> of the energy used in the Source-User-Disposal chain.

An initial grant or annual subsidy from an externalized source (say federal) could be to support the development and operation of a water supply system. Possible reasons for such support could be to encourage regional development, or to subsidize technology with a good export potential. The total present-value cost C is thus

$$C=E_1(C_c+C_{cj})+E_{2e}C_{ae}+E_{2\ell}C_{a\ell}+E_{2m}C_{am}+E_{2w}C_{aw}+E_{2r}C_{ar}+E_{2t}C_{at}+E_{2s}C_{as}+E_{2p}C_{ap} \quad (1)$$

where E_1 and E_2 are economic coefficients for converting cash flows to present-values (21, 22), denoted as follows:

$$E_1 = \alpha - \beta - \sigma\left(\frac{1+g}{1+d}\right)^n + [(1-t)p + h]\,P(d,g,n) + (1-\alpha)\cdot\left[(1-t)\frac{P(d,0,m)}{P(i,0,m)} + t\,\frac{P(d,i,m)}{P(0,i,m)}\right] - B \quad (2)$$

In general,

$$E_{2x} = (1-t_1)\,P(d,r_x,n) \quad (3)$$

where

α downpayment fraction of first cost

β investment tax credit fraction, if applicable

σ fractional salvage value at end of equipment life

g annual general inflation rate, (percent/100)

d annual discount rate, which could be chosen as either that for mere inflation, for an opportunity cost of money, or for a required return or investment, (percent/100)

t annual incremental income tax rate (only applicable in business applications, where the capital expenses are income tax deductible, otherwise t=0), (percent/100)

t_1 same as t, but only applicable if the C_a-type expenses are tax deductible, otherwise $t_1 = 0$

p actual annual tax rate, (percent/100)

h annual insurance cost, as a fraction of the first cost

$$P(d,r,n) \equiv \frac{(1+d)^n - (1+r)^n}{(1+d)^n (d-r)} \qquad \text{for } d \neq r \tag{4}$$

and

$$P(d,r,n) \equiv \frac{n}{1+r} \qquad \text{for } d = r \tag{5}$$

n period of economic analysis (usually life of system), years

i annual interest rate on loan, bond, or mortgage, (percent/100)

m period of loan, bond or mortgage, years

B cumulative present worth of depreciation tax credits per dollar invested: with straight line depreciation:

$$B_{SL} = \frac{t(1-\sigma)}{k} P(d,0,k) \tag{6}$$

with declining balance:

$$B_{DB} = \frac{t\delta}{k} P(d, -\delta/k, k) \tag{7}$$

and with Sum Of Years Digits:

$$B_{SOYD} = \frac{2t(1-\sigma)}{k(k+1)}\left[P(d,0,k) + \frac{k-1-P(d,0,k-1)}{d}\right]$$

where

k depreciation lifetime

δ declining balance multiplier

r_x annual fractional rate of increase in periodic expense of type x

The direct benefit B is the volume of fresh water supplied by the system

$$B = \sum_{i=1}^{n} Q_{a_i} L_{F_i} \tag{9}$$

where Q_{a_i} is the water production rate (say, m^3/year), and L_{F_i} the load factor, both in the i-th year.

The values of C/B are to be calculated from eqns. (1) and (9) for each water supply system being evaluated*. The one providing the smallest C/B ratio is the most desirable economically.

In the analysis of economic intangibles, typical items could be an increase in associated business activities, employment, tourism, improvement of tax base, etc.

To make a realistic and equitable comparison between different water supply systems, one must also realize that in many cases the prices of water or equipment for a particular system are biased due to different benefit-cost computation methods, special interest rates, federal/political subsidies, or manufacturer subsidies to develop markets. Generally speaking the bias is typically in favor of lower costs for conventional water supply schemes, to the detriment of desalination.

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*A system may actually be composed of a combination of a number of systems, such as desalination in conjunction with conventional water supply (cf. 3, 6).

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