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WATER SUPPLY FACILITIES COST EQUATIONS FOR APPLICATION TO ALTERNATIVE WATER SUPPLY PROJECTS INVESTIGATIONS AND REGIONAL WATER SUPPLY PLANNING

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

Water Supply Solutions, Inc.

Technical Memorandum

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From: Ronald L. Wycoff, P.E., D.WRE

Date: June 3, 2008

Re: Water Supply Facilities Cost Equations for Application to Alternative Water Supply Projects Investigations and Regional Water Supply Planning

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Background

The St. Johns River Water Management District (SJRWMD) develops and periodically updates the District Water Supply Plan (DWSP) as required by Chapter 373, Florida Statutes (F.S.). The current DWSP identifies portions of the District where projected water demands may exceed available traditional fresh groundwater supplies through 2025. The DWSP also identifies alternative sources and alternative water supply development projects sufficient to meet all projected water supply needs over the 20-year planning period. Water supply planning is a continuing process and the DWSP will be updated as needed, but no less than once every five years.

Further, Chapter 373, F.S., as amended by Senate Bill 444 in 2005, provides for State of Florida and water management district funds to be provided to water supply utilities to assist in the development of alternative water supplies and requires that certain factors, including construction cost, be considered in the selection and ranking of projects for funding.

As part of this effort, it is necessary to estimate construction, and operation and maintenance (O&M) costs of alternative water supply projects, which may include reclaimed water reuse, brackish groundwater, surface water or seawater demineralization, as well as appropriate transmission and storage systems.

As part of its water supply management responsibilities, SJRWMD estimates, at a conceptual planning level of accuracy, construction and O&M costs associated with alternative water supply projects. In order to provide an up to date and consistent basis for estimation of these costs SJRWMD contracted with Black and Veatch, Inc. to provide engineering assistance in updating information on water supply and reuse system component costs. The contract (SK30712) was initiated in December 2006 and the final report was completed in February 2008. The report has been published by SJRWMD as a Special Publication (SJ2008-SP10), and is available for download on the District WEB site. The final report is cited as follows:

> Black and Veatch, Inc. 2008. *Engineering Assistance in Updating Information on Water Supply and Reuse System Component Costs* Prepared for St. Johns River Water Management District, Palatka FL. Special Publication SJ2008-SP10.

The cost basis for the water supply systems included in the Black and Veatch report is third quarter 2007. At that time, the Engineering News Record Construction Cost Index (ENRCCI) was 8005.

Purpose

The purpose of this technical memorandum is to present construction and O&M cost equations and/or unit costs recommended for application to SJRWMD alternative water supply projects comparisons and to DWSP development. All equations presented herein are derived from cost data provided by Black and Veatch, Inc. The original data and resulting cost equations are accurate to the conceptual or order-of-magnitude level of accuracy and are suitable for conceptual level project comparisons and regional planning applications.

These equations supplement the Black and Veatch report and provide a basis for interpolation and extrapolation of the tabular cost data included in the report and supporting information. The user should be familiar with the content of the Black and Veatch report and fully understand underlying assumptions and conceptual design elements; before applying any of the equations presented herein.

Scope

Construction opinion of probable cost (OPC) and annual O&M equations, or unit costs, are developed for the following water supply facilities:

- Source water withdrawal facilities
    - Lower Floridan aquifer wellfield
    - Upper Floridan aquifer wellfield
    - Surface water intake
- Water treatment plants
    - Brackish groundwater treatment
    - Conventional (fresh) surface water treatment
    - Brackish surface water treatment for public supply
    - Brackish surface water treatment for reuse augmentation
    - Complete seawater desalination
- Water transmission and ground storage facilities
    - Booster pumping station
    - Residual disinfection
    - Ground storage tanks
- Transmission pipelines
    - Rural
    - Suburban
    - Urban

These water supply system components were selected for cost equation development because these facilities are often encountered by SJRWMD in alternative water supply project applications. However, cost information on additional water supply systems as well as individual components are included in the Black and Veatch report.

The development of the cost equations results in smoothing of the data and the equations will not exactly reproduce individual Black and Veatch report cost estimates. However, application results are within the order-of-magnitude level of accuracy of the original individual estimates. The cost equations are suitable for development of spreadsheet based cost estimating models for comparison of regional alternative water supply projects.

Construction OPC Equation Development

Construction OPC and facility design capacity data are taken from the Black and Veatch report. Appropriate mark ups were then applied to the construction OPC data, as per the report recommendations, as follows:

- For water supply facilities (other than transmission pipelines);
    - 15% for contractor overhead and profit (OH&P), mobilization and demobilization
    - 20% for construction contingency.
- For transmission pipelines;

- 10% for contractor OH&P, mobilization and demobilization
- 5% for construction contingency

All capacity related construction OPC equations with the exception of brackish groundwater treatment plants and ground storage tanks take the following general form:

$$\text{Construction OPC} = a + b(Qd)^{X}$$

where:

Construction OPC = Opinion of probable total construction cost including contractor mark ups and construction contingency, and

Qd = Design capacity, or maximum amount of treated water that can be produced or transported by the water supply facility, in million gallons per day (mgd).

For brackish groundwater treatment plants the design feed water concentration of total dissolved solids (TDS) is added as an independent variable resulting in the following general form:

$$\text{Construction OPC} = a(TDS)^{X}\ (Qd)^{Y}$$

where:

TDS = Design feed water TDS concentration, in milligrams per liter (mg/L)

All other terms are as previously defined.

For ground storage tanks, a linear model was developed with storage tank volume (V), expressed in million gallons, as the independent variable.

O&M Cost Equation Development

Estimated O&M costs for each facility were developed by Black and Veatch for a given set of operating conditions and a fixed unit energy cost. O&M cost equations are developed herein for these conditions. These O&M equations are termed the lumped parameter equations and they approximate the O&M cost estimates presented in the Black and Veatch report.

An additional and somewhat more general set of equations is also developed, allowing for variations in facility usage as well as variations in unit energy cost. These O&M equations are termed the distributed parameter equations.

Lumped Parameter O&M Equations

The lumped parameter O&M equations are developed for facility utilization factors as specified in the Black and Veatch report. The facility utilization factor is the ratio of average annual daily flow (Qadf) to facility design capacity as follows:

Utilization Factor (UF) = Qadf/Qd

Two utilization factors were applied in the Black and Veatch costing project depending upon the most likely general application for a given water supply facility. These were termed peaking facilities, with a UF = 0.67 and base load facilities with a UF = 0.95. Surface water treatment plants for public supply and seawater desalination plants are considered base load facilities (UF=0.95). All other facilities are considered peaking facilities (UF=0.67). In all cases, a unit energy cost of $0.08 per Kilowatt-hour (kWh) is used in the base O&M cost estimates prepared by Black and Veatch. The lumped parameter O&M equations reflect these facility utilization and unit energy cost assumptions.

All lumped parameter O&M equations, except for brackish groundwater, are expressed in the following general form:

$$O\&M = a + b(Qadf)^{X}$$

where:

O&M = Estimated annual operation and maintenance (O&M) cost, in $/yr

Qadf = Average annual facility production, in mgd

For brackish groundwater treatment plants, the design feed water TDS concentration is added as an independent variable resulting in the following general form:

$$O\&M = a(TDS)^{X} (Qadf)^{Y}$$

where all terms are as previously defined.

Distributed Parameter O&M Equations

The development of the distributed parameter O&M equations required consideration of individual O&M categories including fixed costs and variable costs. Fixed costs include routine maintenance and repair as well as labor. Fixed costs are generally a function of the total facilities design capacity (Qd) and are, for the most part, independent of facilities utilization or annual production rate (Qadf).

Variable costs include chemical and energy costs and are a function of facilities usage expressed as annual production. These costs depend upon operations and are largely independent of the facilities design capacity.

There is no single general form for the distributed parameter O&M equations. The O&M cost is expressed as the sum of the fixed and variable costs as follows:

O&M = fixed cost + variable costs

where:

fixed cost = routine maintenance and repair + labor = f(Qd), and

variable cost = chemicals + energy = f(Qadf).

In general, the distributed parameter O&M equations include Qd, Qadf and unit energy cost as independent variables. For brackish groundwater treatment, the independent variables also include the feed water TDS concentration.

The distributed parameter equations allow estimation of annual O&M costs for any combination of facility design capacity and annual production. These equations also allow for adjustment of unit energy cost independent of other annual O&M cost factors.

Transmission Pipeline Unit Cost Development

Black and Veatch reported estimated unit construction cost for transmission pipe of various standard diameters in dollars per liner foot (lf) for rural, suburban and urban alignments. Black and Veatch also reported the estimated construction costs of valves for each standard pipe size. These construction cost data were used to develop estimates of complete transmission pipeline systems for use in SJRWMD water supply planning applications.

For a complete transmission pipeline, a per linear foot valve allowance (one valve per mile) is added to the base pipeline unit costs. These costs are then adjusted for appropriate construction mark ups including contractor mark ups (10%) and construction contingency (5%). The resulting total unit construction OPC including the valve allowance, contractor mark ups and construction contingency are recommended for estimating total pipeline costs.

Pipeline O&M costs are considered negligible. For the purpose of regional water supply planning they are not estimated.

Results

The recommended planning level construction OPC and O&M cost equations for withdrawal, treatment, pumping and ground storage facilities are reported in Tables 1, 2 and 3. Table 1 presents cost equations for source water withdrawal facilities. Table 2 presents equations for water treatment plants. Table 3 presents equations for booster pumping stations, residual disinfection and storage facilities.

Table 4 presents transmission pipe unit construction OPC estimates including valves, contractor mark ups and construction contingency. Also reported is the recommended minimum construction right of way with for each pipe diameter.

Application and Adjustments

These water supply facilities cost equations and transmission pipe unit costs are directly applicable only to the conditions for which they were derived as fully documented in the Black and Veatch report. These equations and unit costs are representative of third quarter 2007 east-central Florida costs and are based on conceptual designs developed by Black and Veatch, Inc. for SJRWMD.

The cost estimates (or equation coefficients) can be adjusted for changed conditions including:

- Cost basis
- Revised contractor mark ups or contingency.

Future (post 2007) costs can be computed using an appropriate construction cost index such as the ENRCCI.

Adjustments can also be made for different construction contingencies or contractor mark ups by application of a direct ratio, if desired.

Different unit energy cost values can be applied directly in the distributed O&M equations to account for changes in energy costs independent of changes in other O&M cost components.

Table 1. Source Water Withdrawal Facilities

Water Supply System Component	Construction OPC	Estimated O&M Cost	
		Lumped Parameter Equation	Distributed Parameter Equation
Lower Floridan Aquifer Wellfield	OPC = 526,300 + 397,600*(Qd) [R^2 = 0.9994]	O&M = 7,790 + 15,530*(Qadf) (for UF = 0.67 and uec = $0.08/kWh) [$R^2$ = 0.9998]	O&M = 5,110 + 2,410*(Qd) + (uec)*150,750*(Qadf) [R^2 = 0.9998]
Upper Floridan Aquifer Wellfield	OPC = 384,800 + 290,700*(Qd) [R^2 = 0.9994]		
Surface Water Intake	OPC = 3,281,800*$(Qd)^{0.3585}$ [R^2 = 0.9675]	O&M = 10,200*$(Qadf)^{0.7337}$ (for UF = 0.67 and uec = $0.08/kWh) [$R^2$ = 0.9985]	O&M = 1,280 + 4,920*ln(Qd) + (uec)*45,750*(Qadf) [R^2 = 0.9978]

Table 2. Water Treatment Plants

Water Supply System Component	Construction OPC	Estimated O&M Cost	
		Lumped Parameter Equation	Distributed Parameter Equation
Brackish Groundwater TP	$OPC = 2,765,100*(TDS)^{0.1248}*(Qd)^{0.7031}$ [R^2 = 0.9884]	$O\&M = 175,700*(TDS)^{0.1975}*(Qadf)^{0.7357}$ (for UF = 0.67 and uec = $0.08/kWh) [$R^2$ = 0.9901]	$O\&M = 309,900*(TDS)^{0.0648}*(Qd)^{0.609} + 3,479*(TDS)^{0.2961}*(Qadf) + ((uec)*40,000*(TDS)^{0.4739}*(Qadf))$ [R^2 = 0.9942]
Conventional Surface Water TP	$OPC = 10,970,000 + 3,031,000*(Qd)^{0.824}$ [R^2 = 0.9960]	$O\&M = 434,000*(Qadf)^{0.7055}$ (for UF = 0.95 and uec = $0.08/kWh) [$R^2$ = 0.9993]	O&M = 247,600 + 360,100*ln(Qd) + (63,150 + (uec)*557,700)*(Qadf) [R^2 = 0.9990]
Brackish Surface Water TP -- Potable	OPC = 26,012,000 + 4,313,000*(Qd) [R^2 = 0.9950]	$O\&M = 823,400*(Qadf)^{0.8034}$ (for UF = 0.95 and uec = $0.08/kWh) [$R^2$ = 0.9986]	$O\&M = 598,300*(Qd)^{0.6704} + (114,700 + (uec)*1,333,800)*(Qadf)$ [R^2 = 0.9981]
Brackish Surface Water TP – Reuse Augmentation	OPC = 12,075,000 + 1,326,100*(Qd) [R^2 = 0.9900]	O&M = 432,400 + 121,700*(Qadf) (for UF = 0.67 and uec = $0.08/kWh) [$R^2$ = 0.9919]	O&M = 411,500 + 21,070*(Qd) + (49,160 + (uec)*527,600)*(Qadf) [R^2 = 0.9919]
Complete Seawater Desalination WTP (with intake and concentrate outfall)	$OPC = 38,720,000*(Qd)^{0.6559}$ (for Qd < 25 mgd) [R^2 = 0.9965] $OPC = 31,643,000*(Qd)^{0.7203}$ (for Qd > 25 mgd) [R^2 = 0.9992]	O&M = 1,416,000 + 883,100*(Qadf) (for UF = 0.95 and uec = $0.08/kWh) [$R^2$ = 0.9989]	O&M = 1,384,900 + 212,600*(Qd) + (127,200 + (uec)*6,665,000)*(Qadf) [R^2 = 0.9989]

Table 3. Water Transmission Pumping and Ground Storage Facilities

Water Supply System Component	Construction OPC	Estimated O&M Cost	
		Lumped Parameter Equation	Distributed Parameter Equation
Booster Pumping Station	OPC = 750,200 + 62,260*(Qd) [R^2 = 0.9918]	O&M = 24,820*(Qadf) (for UF = 0.67 and uec = $0.08/kWh) [$R^2$ = 1.000]	O&M = 2,700 + 420*(Qd) + (uec)*301,500*(Qadf) [R^2 = 1.000]
Residual Disinfection for Transmission System	OPC = 571,200 + 30,180*$(Qd)^{0.7932}$ [R^2 = 0.9885]	O&M = 5,035 + 947*(Qadf) (for UF = 0.67) [R^2 = 0.9980]	O&M = 4,380*$(Qd)^{0.116}$ + 897*(Qadf) [R^2 = 0.9972]
Ground Storage Tanks	OPC = 333,000 + 340,000(V) [R^2 = 0.9933]	NA	NA

Equation Parameters and Definitions

OPC = Opinion of probable construction cost, including contractor mark ups and construction contingency

Qd = Design (maximum daily) capacity of water supply system component, in mgd

O&M = Estimated annual operation and maintenance cost

Qadf = Average daily production or usage of water supply system component, in mgd

UF = Facilities utilization factor = Qadf/Qd

uec = unit energy cost, in $/kWh

TDS = Design feed water total dissolved solids concentration for brackish groundwater treatment plants, in mg/L

V = Ground storage tank volume, in million gallons

Cost Basis – The cost basis for all equations is third quarter 2007

Table 4. Transmission System Pipe Unit Construction Cost with Allowance for Valves and Mark Ups.

Nominal Pipe Diameter, in.	Total Pipe OPC -- $/lf			Construction Right-of-Way Width-- ft.
	Rural	Suburban	Urban	
10	$112	$125	$129	25
12	$122	$138	$141	25
`14	$126	$140	$143	30
16	$129	$144	$148	30
18	$183	$236	$277	30
20	$188	$240	$279	30
24	$209	$264	$305	30
30	$375	$452	$523	65
36	$425	$507	$586	65
42	$469	$559	$647	65
48	$519	$614	$711	65
54	$572	$674	$777	65
60	$735	$859	$992	65
66	$799	$929	$1,073	65
72	$989	$1,146	$1,324	65
78	$1,063	$1,228	$1,420	65
84	$1,136	$1,310	$1,514	65
90	$1,210	$1,395	$1,612	65
96	$1,284	$1,478	$1,705	65

Assumptions

One valve per mile

Mark Ups:

- Contingency = 5%
- Contractor OH&P and mobilization/demobilization = 10%