RECLAMATION

Managing Water in the West

Quantifying the Cost of Water Treatment

Research and Development Office
Science and Technology Program
Final Report ST-2017-1757-01

RO & NF OUTPUT

Estimating Construction Costs for NF90 Membrane Treatment Plant

Membranes	$ 10,069,500		@	$ 500	$/module	
RO Skids	$ 20,542,736	Steel	@	$ 5,000	$/Vessel	
Building	$ 17,124,107	Housing	@	$ 1,076	$/m^2	$1(
Electrical	$ 5,634,062	Manf & Elect	With Base of	$ 977	$/m^3	
Insturmentation & Controls	$ 4,843,764	Manf & Elect	add $300,000 for top of	$ 65,000		bas
High Pressure Pumps	$ 3,955,456	Piping		68,878,199	kWhr	
Energy Recovery for Seawater	$ -	Manf & Elect				
Transfer Pumps	$ 1,518,818	Piping		20,243,395	kWhr	
Product Water Pumps	$ 1,212,889	Piping		17,206,886	kWhr	
Odor Control	$ -	Piping		$ 50,000		bas
Process Piping	$ 76,888	Piping		$ 55,000		bas
Yard Piping	$ 67,117	Piping		$ 50,000		bas
Cartridge Filters	$ 20,465	Maint Materials		$ 15,000		bas
Membrane Cleaning Equip	$ 97,574	Manf & Elect		$ 67,000		Fro
Contractor Engineering & Training	$ 91,266	Labor		$ 100,000		bas
Concentrate Treatment & Piping	$ 806,912	Piping		$ 13	$/m^3	Co
Generators	$ 73,271	Electrical		0.7	MW	RO
Sitework	$ 7,144,179	Electrical		$ 14.53	$/m^3	

U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

December 30, 2017

Mission Statements

Protecting America's Great Outdoors and Powering Our Future

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

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BUREAU OF RECLAMATION

Research and Development Office
Science and Technology Program

Water Treatment, 86-68190

Final Report ST-2017-1757-01

Quantifying the Cost of Water Treatment

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Acronyms and Abbreviations

BWRO	Brackish water reverse osmosis
S&T	Reclamation Science and Technology program
DWPR	Reclamation Desalination and Water Purification Research
ED	Electrodialysis
EDR	Electrodialysis reversal
EPA	Environmental Protection Agency
gpd	Gallon per day
O&M	Operations and maintenance
MED	Multi-effect distillation
MF	Microfiltration
MSF	Multi-stage flash (distillation)
NF	Nanofiltration
RO	Reverse Osmosis
SWRO	Seawater reverse osmosis
UF	Ultrafiltration
VC	Vapor compression
WT	Water treatment
WTP	Water treatment plant

Executive Summary

Water treatment allows Reclamation to develop new water sources that would otherwise be considered impaired and unusable. Sound and efficient cost estimating techniques on water treatment projects helps ensure that Reclamation develops water treatment projects and performs water treatment research in an economically sound manner. Quantifying the cost of water treatment is an important component of water treatment research, planning, and design. Reclamation has well-developed cost estimating procedures and expertise providing ground-up "unit cost" estimates for a range of accuracies from Preliminary Level through Final Design; these are an integral part of Reclamation's design process. Cost estimating for Reclamation water treatment planning studies and research is less consistent with estimating needs and requirements that have not been fully defined. Some cost estimate consistency issues are due to funding and time limitations that do not allow for the development of "unit cost" cost estimates. This drives the question about the use of alternative cost estimating methods such as cost models.

This report provides a review of cost estimating options and makes recommendations on how to develop water treatment plant (WTP) costs for Reclamation with a look at broader use outside of Reclamation. An overall conclusion from this report is the need for more consistency and having a plan for cost estimating tailored to design, planning, and research. There is a particular report focus on evaluating cost model options and laying a foundation for possible water treatment cost model development and use. Cost model use has the potential to significantly reduce cost estimating costs, but there would be significant cost model development and maintenance costs that would offset some or all of these savings.

Key concerns for cost estimating and cost models in particular include:

- Time and cost to develop ground-up "unit cost" cost estimates.
- Quantifying cost estimate accuracy for estimates performed outside of our standard unit cost derived estimates.
- Ability to obtain usable and reliable cost data to build a cost model.
- Cost model development and maintenance costs.

Recommended next steps include:

- Develop standardized approach to WTP cost estimating.
- Develop WTP cost estimating guidelines for planning and research activities.
- Investigate demand for planning study cost estimates.
- Develop overall plan for planning, research, and design WTP cost estimates.
- Investigate cost estimates for research that will require more than a cost model.
- Develop specific plans for cost models if a decision is made to use cost models.
- Investigate cost estimate accuracy between similar type cost estimates.
- Update this report once general and specific plans are developed.

Contents

Tables

Figures

Background

Report Organization

The report begins with a discussion on all cost estimating types and options with details provided on existing cost models and cost databases. This is followed by a look into cost model development and related concerns. The report is then organized by application (design, planning, and research) with a focus on cost estimating needs and recommendations. This is followed by a section on cost reporting and a standardized approach. The report concludes with recommended next steps.

Research Questions

1) What water treatment (WT) cost models and cost databases exist?

2) What are the cost estimating needs for WTPs across design, planning, and research activities and how can those needs be best met?

3) What are the needs for WTP cost reporting standardization?

Cost Estimating Practices

Currently, there is no standardized approach for developing cost estimates for WTPs. An engineer needs to determine the cost estimate accuracy needed, determine the funds and time available to develop the costs, and use the tools available to develop an estimate on a case by case basis. In some cases, the desired accuracy cannot be achieved with available time and funds and adjustments need occur.

Reclamation has four levels (accuracies) of cost estimates that we produce (**Table 1**). These can be roughly correlated to the more widely used AACE International cost estimate classification system (**Table 2**).

Table 1. Cost estimate levels at Reclamation

Design Level	Approximate AACEI Estimate Class
Final	1 - 2
Feasibility	3 - 4
Appraisal	4 - 5
Preliminary	5 or lower accuracy

Table 2. AACEI cost estimate levels and corresponding accuracy

Estimate Class	Approximate Accuracy	
	Low	High
1	-3% to -10%	+3% to +15%
2	-5% to -15%	+5% to +20%
3	-10% to -20%	+10% to +30%
4	-15% to -30%	+20% to +50%
5	-20% to -50%	+30% to +100%

Table 3 provides a list of estimating types and estimating methodologies that can be used to develop cost estimates at the accuracy desired. Both the accuracy and level of detail of the unit quantities and the accuracy of the costs impact the resulting accuracy of the cost estimate.

Table 3. Estimating types and estimating methodologies

Accuracy	Estimate Type		Estimating Methodology			
			Unit cost based estimates		Cost Models	
	AACEI	General Description	Unit Cost Estimate Applicability	Approximate Reclamation Design Level	Parametric Model Applicability	Empirical Model Applicability
Highest	1	Detailed Estimate	✓	Final		
	2					
	3	Preliminary	✓	Feasibility		
	4		✓	Appraisal	✓	
	5					
Lowest	-	Order of Magnitude	✓	Preliminary	✓	✓

Unit Cost Estimates

Unit Cost Based Estimates are ground up cost estimates that use unit costs produced by treatment system designs:

- Design activity produces material quantities that are estimated on an individual basis.
- Percentages are included for design contingencies (items that have not been quantified in the design).
- Uses new or recent vendor quotes / bids, previous recent estimates, commercials cost databases (e.g. RS Means)

Accuracies of unit cost estimates are generally better than cost models, but may be comparable at lower estimate classes where quantities are only developed for major equipment and based on factors such as building area. The most accurate quantity take-off estimates require quotes and contractor bids, which sometimes can only be obtained if a design is moving into construction. Therefore a research project may not be able to achieve higher levels of cost estimate accuracy without special accommodations.

Cost Models

Cost models represent opportunities for significant cost and time savings, but require ongoing maintenance to ensure the accuracy is maintained. The concept is that the time it takes to develop a cost model will more than pay off after repeated use. A significant limitation of cost models is they may not capture local construction labor, material cost, permitting costs, etc. that could have major impacts on cost. These costs can be added to parametric type models or as an overall cost adder to an empirical model, but specialized cost estimating expertise is often needed to determine these values. Table 4 contains a list of various existing parametric and empirical models and the various WTP unit operation processes that each contains. A brief description of each model follows Table 4.

Table 4. Unit processes associated with each cost model and approximate AACEI level

Type	Models	Unit Processes																						
		Screening	Flash Mix	Flocculation	Sedimentation	Media Filtration	Microfiltration (MF) / Ultrafiltration (UF)	Nanofiltration (NF)	Reverse Osmosis (RO) - Brackish Water	Reverse Osmosis (RO) - Seawater	Distillation	Ion Exchange (IX)	Granular Activated Carbon (GAC)	Lime Softening	Activated Alumina	Electrodialysis	Diatomaceous Earth	Disinfection	Air Stripping	Oxidation (Ozone, KMnO4,Chlorine)	Greensand Filtration	Pipelines	Pumping	O&M Costs
Parametric	WaTER		x			x	x	x	x	x		x	x	x		x		x		x				x
	DEEP									x	x													
	WAVE						D		D			D												
	ROSA								D															
	A&E Example: CPES	4	4	4	4	4	4	4	4	4		4	4	4				4	4	4	4	4	4	4
	A&E Example: CCES	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		3	3	3	3	3	3	3
Empirical	Leitner database								x	x	x					x								
	GWI Desal Data									x	x													x
	Cost Est. Manual for WT Facilities		x	x	x	x	x	x		x	x		x	x				x		x			x	x
	UCM		x	x	x	x			x	x								x				x	x	x
	Wittholz Model									x	x													

x = Included, but AACEI level not determined.
D = Design only

Parametric Cost Models

A parametric (aka statistical) cost model uses formulas and regressions of past project equipment and materials costs with inputs for flow rate and other water treatment system parameters. Parametric cost models automate the design process to automatically generate unit quantities and O&M values. Typically, the more input parameters, the more detailed the design will be and the resulting accuracy will increase. As the number of inputs increases, so does the skill required by the model operator. Ongoing maintenance of parametric models includes updating cost indices, interest rates, energy and chemical costs at a minimum. More extensive periodic updates are needed to imbedded cost curves to capture recent vendor costs, specific material cost changes not adequately captured by cost indices, specific labor rates not adequately captured by cost indices, etc. Updates are also needed as designs are improved and technologies are modified or new technologies are developed. A number of software packages are publically available for cost estimating for water treatment processes. With parametric cost models, the accuracy of both the design and the cost estimate must be considered (**Figure 1**).

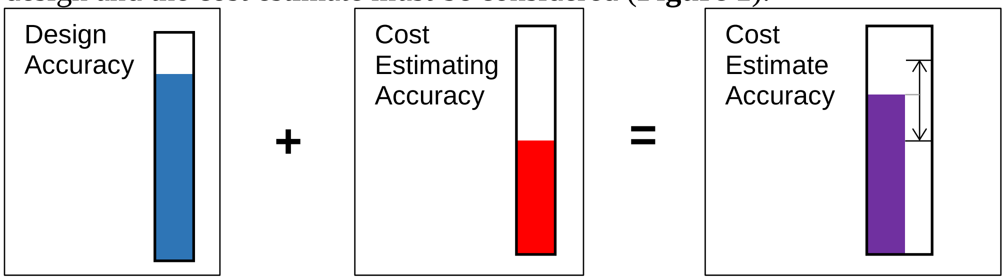

Figure 1: Cost estimate accuracy

WaTER
Owner: Bureau of Reclamation
Status: Incomplete
Last Update: 2017
Cost: Free by request
Cost Estimate Accuracy: Not determined
Information Date: Information about this model updated 12/2017

WaTER is a Microsoft Excel based program. The program has many unit processes with some processes such as RO that include multiple input parameters to size the unit to other unit processes such as microfiltration that are sized based solely on flow. Some of the cost curves used are the USEPA 1979 cost curves adjusted through construction cost indices.

WT Cost II
Owner: Irving Moch
Status: Commercial, but no longer available
Last Update: 2008
Cost: N/A
Cost Estimate Accuracy: Not stated (AACE 3 according to Huehmer et al. 2011)
Information Date: Information about this model updated 8/2017

This Visual Basic model was developed in part by Reclamation DWPR funding with detailed model information available in DWPR Report # 130 published in 2008. The model itself is a commercial product, but since it is no longer available, it is not detailed further.

Desalination Economic Evaluation Program (DEEP)
Owner: IAEA
https://www.iaea.org/NuclearPower/NEA_Desalination/index.html
Status: Public
Last Update: 2014 (DEEP 5.1)

Cost: Free
Cost Estimate Accuracy: Not determined
Information Date: Information about this model updated 12/2017

Desalination Economic Evaluation Program (DEEP) was developed by the International Atomic Energy Agency (IAEA) and first issued in 1989 with subsequent updates. DEEP is based on an empirical model developed by the IAEA in partnership with Kuwait University. The model used various cost data sources to calculate the unit product cost based on various economic parameters (Ettouney et al. 2002).

This program is used to conduct preliminary economic evaluations for desalination processes powered by either fossil fuel or nuclear power plants (International Atomic Energy Agency 2014). The following desalination technologies can be estimated using the program:

- Multi-stage flash distillation (MSF)
- Multi-effect distillation (MED)
- RO
    - Spiral wound
    - Hollow fiber
- Hybrid systems (MSF or MED followed by RO, RO feed typically taken from the condenser reject of the distillation process, salinity lower than RO alone, but higher than distillation)

Systems powered by either nuclear power or fossil fuels can be evaluated. The most suitable application of the IAEA methodology and of the DEEP program is for relative comparisons of design alternatives for water production in a given area or region, not for obtaining absolute numbers (International Atomic Energy Agency 2014). The tool is best suited for use in planning activities dealing with strategic water and energy issues.

Water Application Value Engine (WAVE)
Owner: Dow
https://www.dow.com/en-us/water-and-process-solutions/resources/design-software
Status: Commercial
Last Update: 10/2017
Cost: Free
Cost Estimate Accuracy: N/A. Model provides design parameters only.
Information Date: Information about this model updated 12/2017

WAVE combines other programs such as ROSA to provide designs for UF, RO, and IX. Output parameters include standard design parameters along with chemical and energy use.

Reverse Osmosis System Analysis (ROSA)
Owner: Dow
https://www.dow.com/en-us/water-and-process-solutions/resources/design-software
Status: Commercial
Last Update: 9/2013 (Version 9.1)
Cost: Free

Cost Estimate Accuracy: N/A. Model provides design parameters only.
Information Date: Information about this model updated 12/2017

ROSA is used to model membrane product performance for a user-defined feed water and system configuration. The program is typically used to determine operating pressure and product water quality for different membrane products.

The Element Value Analysis (EVA) tool is a feature in the ROSA software program that allows users to compare the impact of membrane product selection (i.e. low pressure RO vs traditional RO) on the cost of desalination systems. The EVA tool uses results from the ROSA performance modeling (for pumping power, permeate production, feed pressure, concentrate pressure, membrane type, number of membrane elements, and system recovery) along with user defined inputs (project life, interest rate, power costs, energy recovery efficiency. This software could be useful for evaluating different membrane alternatives, but would need to be coupled with a different model for developing preliminary level cost estimates.

A&E Firm Example: CH2M Parametric Design & Cost Estimating System (CPES)
Owner: CH2M (Jacobs Engineering)
Status: Private. Use only by CH2M through contract with CH2M
Last Update: Continuous
Cost: Determined by scope of work and A&E cost proposal
Accuracy: AACEI Class 4
Information Date: Information about this model updated 11/2017

The Microsoft Excel based model provides facility design, construction cost estimating, and lifecycle cost estimating as well as links to a conceptual facility 3D visualization tool (**Figure 2**) and carbon footprint calculator. The bottom up type design provided by the model allows for checking of many key treatment process assumptions. The model is continuously updated based on projects designed and constructed by CH2M.

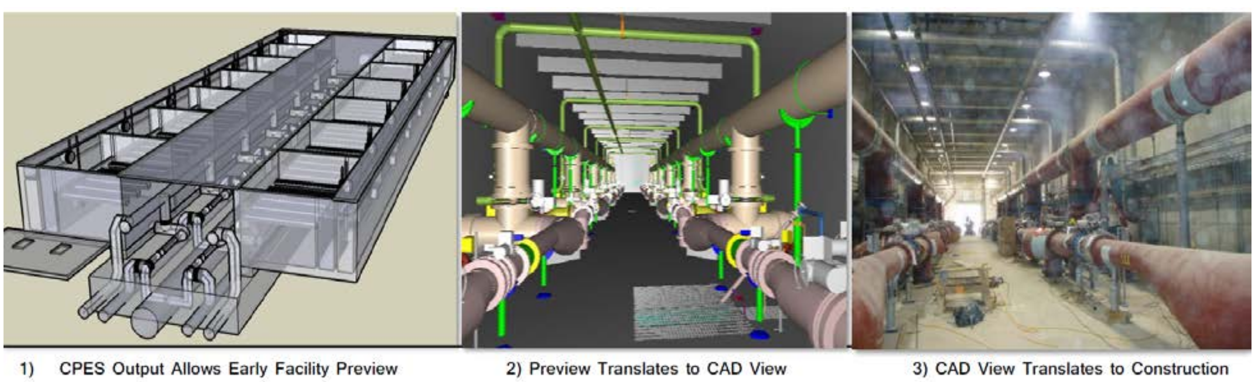

Figure 2: CPES 3D visualization output (left), courtesy of CH2M

A&E Firm Example: Carollo Cost Estimating System (CCES)
Owner: Carollo Engineers
Status: Private, Use only by Carollo through a contract with Carollo
Last Update: Continuous

Cost: Determined by scope of work and A&E cost proposal
Accuracy: AACEI Class 3
Information Date: Information about this model updated 12/2017

The Carollo Cost Estimating System (CCES) is supported by a compilation continuously updated cost databases that includes information from: RS Means, Harrison Publishing House, Richardson's Construction Estimating Standards, Rental Rate Blue Book, Trade Services, National Electrical Contractor's Association, quotations from major equipment and material suppliers, and historical bid tabulations within the company. Unit costs are developed using a Materials, Labor, Equipment and Subcontractor (MLES) approach. The CCES system base template uses cost divisions corresponding to the basic Construction Specifications Institute (CSI) breakdown. AACEI Class 2 level estimates are also possible through the existing database and associated supporting structure.

Empirical Cost Models

An empirical cost model employs curve fitting of past water treatment project costs. The primary input is typically flow rate, but additional inputs can be used if more delineated historic data exists. Empirical models are those that employ curve fitting of data entries from a database. Cost databases can be developed from existing and planned WTP cost data. Empirical cost correlations can provide an order of magnitude estimate to determine the likely cost of water produced at a WTP. This class of models is best used for general planning projects where different water treatment and water supply options are being compared. Empirical models do not have the sensitivity to compare different process configurations, materials, or many site-specific conditions.

Highlighted Empirical Cost Models

A number of cost databases and models have been compiled in the last 20 years. The more comprehensive databases and models with usable results are shown below:

Leitner database

Owner/Author: Leitner
Last Update: 1997
Cost: Free
Cost Estimate Accuracy: Not determined
Information Date: Information about this model updated 9/2017

Leitner published a cost database including 180 desalination plants in the United States, Canada, and the Virgin Islands (Leitner 1997). Leitner's database includes WTPs that utilize the following technologies: SWRO, MED, MSF, EDR, and membrane softening, and brackish RO.

GWI Desal Data Cost Estimator

Owner/Author: GWI
https://www.desaldata.com/cost_estimator
Last Update: continuous
Cost: $4,000 per year subscription

Cost Estimate Accuracy: Not determined
Information Date: Information about this model updated 12/2017

Global Water Intelligence (GWI) publishes the largest collection of desalination WTP information, called Desal Data (Global Water Intelligence 2016). Desal Data's cost estimator uses the database of desalination WTP cost to generate capital and operating costs for SWRO, MED, and MSF. In order to generate capital costs, user are asked to input a number of quantitative and qualitative design parameters, include treatment technology, capacity, salinity, feedwater temperature, location, and complexity of pretreatment, intake, and permitting. Capital cost outputs are grouped into thirteen categories, which include items such as design costs, civil work, pretreatment, pumps, membranes, etc. Finished water storage and distribution is not included in the cost estimates. Inputs used to estimating operating costs include capacity, location, utilization rate, energy consumption, and electricity prices. Operating cost outputs include parts, chemicals, labor, replacement membranes, and energy. Estimates for wells are not included, and instead assumes open intakes and outfalls (Huehmer et al. 2011). Model calculations are not shown to users; therefore model is considered a black-box.

Cost Estimating Manual for Water Treatment Facilities
Owner/Author: Susumu Kawamura, William T. McGivney
https://www.wiley.com/en-us/Cost+Estimating+Manual+for+Water+Treatment+Facilities-p-9780471729976
Last Update: 2008
Cost: $135 (book)
Cost Estimate Accuracy: Not determined
Information Date: Information about this model updated 12/2017

The Cost Estimating Manual for Water Treatment Facilities book provides both construction and operations and maintenance costs estimates for the preliminary design of WTPs. The costs are based on a database (not provided) of actual construction costs, and include capital cost equations for 43 processes of facilities that could be included in a WTP. Cost estimates are presented as both an equation and in graphical form, along with the range over which each equation is considered valid. Equations and cost curves are also provided for operations and maintenance costs for 14 different types of WTPs (conventional, membrane filtration, RO, etc.). These values are presented as lump sum costs and include items such as labor, chemicals, power, repairs, and replacement.

Unified Costing Model (UCM)
Owner/Author: Texas Water Development Board
http://www.twdb.texas.gov/waterplanning/rwp/planningdocu/2016/doc/current_docs/project_docs/20130530_UnifiedCostingModel_UsersGuide.pdf
Last Update: 2013
Cost: Free
Cost Estimate Accuracy: Not determined
Information Date: Information about this model updated 12/2017

The Unified Costing Model is an Excel-based cost estimating program prepared by HDR Engineering, Inc. and Freese and Nichols, Inc. for the Texas Water Development Board. The goal of this program is to help standardize cost estimates across the 16 Regional Water Planning Groups in Texas, which then roll up to form the Texas State Water Plan. The program contains modules for estimating the costs of pipelines, well fields, embankments, land acquisition, and water treatment. The water treatment component of this program provides a lump sum estimate based on capacity and types of treatment. An exact treatment process is not specified in the program, but rather six general levels of treatment (disinfection only, iron and manganese removal, direct filtration, conventional treatment, brackish groundwater desalination, and seawater desalination) are provided as user-selected options. The lump sum cost estimate includes site work, buildings, storage tanks, sludge handling, clearwell, pumps, process equipment, and finished water pumping. The Unified Costing Model (UCM) comes with statement that it is "…not intended to be used in lieu of professional engineering design or cos estimation procedures for water supply facilities. Results of all applications of the UCM, including those for technical evaluation of water management strategies in the regional water planning process, should be carefully reviewed by professional engineers and other knowledgeable professionals prior to use and publication. This tool was developed for the purpose of preparing regional water planning level cost estimates only. …"

Wittholz Model

Owner/Author: Wittholz, M.K.
Last Update: 2008
Cost: Free
Cost Estimate Accuracy: Not determined
Information Date: Information about this model updated 8/2017

Wittholz developed a cost correlation from exiting cost data from 331 desalination plants utilizing ED, MED, MSF, brackish water RO (BWRO), seawater RO (SWRO), and vapor compression (VC) (Wittholz et al. 2008). Cost data was captured for desalination plants with a capacity greater than 300 m^3/d. The data collected includes information about the plants including location, desalination technology used, plant capacity, plant lifespan, availability and type of water being treated. Cost data collected included capital cost, fixed cost, operating cost per year per cubic meter and unit cost.

The capital cost included the plant and land costs, civil works, and amortization. All costs were indexed to 2005 dollars and foreign costs were converted to US dollars using the weighted average exchange price for 2005 published by the US Federal Reserve Bank. A power law model was developed for each desalination technology using simple linear regression using least squares. The model is described in **Equation 1**.

$$\ln(Capital\ Cost) = m \cdot \ln(Capacity) + c \qquad \text{Equation 1}$$

The unit price cost (UPC) was calculated by **Equation 2**.

$$UPC = \frac{\left(\frac{Capital\ Cost}{Plant\ Life}\right) + Annual\ Operating\ Cost}{Plant\ Capacity \cdot Plant\ Availability} \qquad \text{Equation 2}$$

The results of the regression are summarized in **Table 5**.

Table 5. Regression coefficients for desalination costs (Wittholz et al. 2008)

Technology	Exponent (m)	Constant (c)	R^2
ED	0.75	3.88	0.66
SWRO	0.81	4.07	0.91
BWRO	0.74	3.95	0.81
MSF	0.70	4.86	0.72
MED	0.83	4.13	0.88

The operating cost included the cost of chemicals, for pre and post treatment, energy (electrical and steam), spares and maintenance, and labor. Wittholz was not able to develop correlations for UPC as a function of capacity due to the large variation in UPC at a given capacity. An analysis of fixed costs, operating costs, and the energy contribution to the operating cost was conducted. These results are shown in **Table 6**.

Table 6. Fixed cost and operating cost percentages and contribution of energy cost to operating cost for desalination technologies.

Technology	Fixed cost contribution	Operating cost contribution	Energy cost contribution	E/Op. cost
SWRO	0.35	0.65	0.35	0.54
BWRO	0.35	0.65	0.3	0.46
MSF	0.4	0.6	0.45	0.75
MED	0.4	0.6	0.45	0.75

Additional Empirical Cost Models

Empirical cost models and databases that are less comprehensive or have less usable results are shown below for completeness.

Watson Model

Owner/Author: Watson, et al.
Last Update: 2003

Watson et al. provided cost curves for various desalination processes in Reclamation's Desalting Handbook for Planners. The cost curves were developed from bid data, vendor quotes, personal cost data files, and experience, and the implied level of accuracy is approximately +/- 30%. Cost are presented for desalination processes (MSF, MED, MVC, SWRO, BWRO, NF, and EDR) along with concentrate disposal options, intakes, pretreatment, post-treatment, auxiliary equipment, buildings, etc. Curves for O&M costs (including labor, chemicals, energy, etc.) are also presented.

Zhou and Tol Model

Owner/Author: Zhou, Y. and Tol, R.S.J
Last Update: 2002

Zhou and Tol developed an empirical model using the 2002 IDA Desalination Plant Inventory (Wangnick 2002) using data for plants greater than 600 m^3/d and includes plants delivered or under construction as of 2001 (Zhou & Tol 2005). Regression coefficients were identified for both log-log and semi-log models for seawater desalination by both MSF and RO. The log-log models showed a higher R^2 value.

Lamei Model
Owner/Author: Lamei, et al.
Last Update: 2008

Lamei et al. compiled data from 21 WTPs (Lamei et al. 2008) in the Middle East (Egypt, Cypress, Libya, Tunis, and Saudi Arabia). Lamei et al observed that for the WTPs considered in this study; there was not cost difference for different locations; cost was independent of location. However, because this work only utilized WTP costs from the Middle East where thermal desalination processes are favored, the corresponding cost curves may not accurately represent costs for desalination in the United States where the predominant technology used is RO.

Cost Model Development Evaluation

Subsequent sections in this report discuss cost estimating needs including potential cost model development and use. Therefore, a discussion on cost model development is provided here to provide context later.

WaTER was Reclamation's first water treatment cost model development activity. It has undergone varying degrees of development within each unit process, but Reclamation standard cost estimating techniques have not been incorporated. If a new comprehensive cost estimating model is developed, WaTER would be a good starting point, but the cost estimating methodology needs to be standardized and automated.

The development and maintenance of a parametric cost model is a significant undertaking. If higher accuracies are needed, the one time and ongoing costs could be very high at hundreds of thousands to millions of dollars for an initial model. Not having a cost model requires contracting estimating services with A&E firms that have a cost model or the ground-up development unit cost method each time a cost estimate is needed. There is no clear or inexpensive option to solve this issue. The development of an empirical cost model represents an opportunity for lower development and maintenance costs, but it also has more limited use.

Model development and maintenance costs need to be balanced against Reclamation's total cost estimating needs which range from an estimated 6 to 19 WTP cost estimates per year. If a ballpark contracted rate of $9,000 per cost estimate using an A&E cost model were used, this equates to $40,000 to $190,000 per year plus contract development costs. TSC use of an internally developed cost model might cost $25,000 to $120,000 per year.

A key question when considering developing a cost model is the accuracy needed for individual processes and process component (from a research perspective) and the entire water treatment process (from all perspectives). An ideal cost model considers the accuracy of the cost estimate needed, then looks at the accuracy needed for the design and cost estimating portions. For the design portion, the cost impact of each design parameter must be considered; then an optimized set of design parameters must be developed to ensure the accuracy is met without over or under designing the WTP. The accuracy needed will directly impact the time to develop the cost model and maintain it.

The following represent challenges and concerns with developing an in-house water treatment cost model, with higher accuracies driving some of these concerns more than others.

- **Development Cost**: The potential cost of developing a comprehensive/complex model that captures capital and O&M costs for all possible treatment processes/trains will be very high and could outweigh the benefit.
- **Bid Data**: The difficulty of finding "meaningful" actual bid data that forms the basis of costs in the model will be difficult to obtain and normalize. Reclamation and the federal government are not actively involved with designing and building WTPs at a frequency that lends itself well to obtaining sufficient timely bid data to populate a water treatment

cost database. Therefore, bid data would need to be obtained by contacting individual municipalities that may or may not be willing to provide sufficient cost data.

- **Site Impacts**: When upstream processes impact downstream processes that change the elevation of the entire system and resulting excavation/fill, these impacts are complicated and time consuming to model on the design and cost side.
- **Site Specific**: If a site specific cost is desired, it may be difficult to normalize data, incorporate location factors, and incorporate specific site conditions without getting into more detailed design and cost estimating. These factors can be very high (e.g. doubling or more the cost of the WTP).
- **Maintenance**: The cost model/database will need to be updated periodically with current costs to ensure accuracy. Construction cost indices can sometimes be used, but material and labor costs do not all trend the same direction over time and the model eventually needs to be re-calibrated with new cost data and cost curves.
- **Broad Applicability**: A single model that is useful and technically operable to designers, planners, and researchers is a particular challenge.
- **Non-Federal Use**: The cost model data derived from public utilities (not Reclamation data) may be hard to defend and represents a potential liability for users relying on this model.
- **Proprietary Treatment**:
    - **Obtaining Data**: There are concerns regarding developing accurate unbiased capital and O&M costs for proprietary treatment processes and how those types of treatment technologies will be referenced.
    - **Conflict of Interest**: If Reclamation obtains cost data from proprietary manufactures and/or vendors to develop this cost model; a potential conflict of interest may be perceived. For example; a manufacturer could claim that Reclamation cost data and cost model results are biased in favor of competitors that provided data inputs.
- **Research Sensitivity**: Developing a cost model that is comprehensive enough to vary a component within one unit process and have that change the cost with sufficient accuracy is a particular challenge. There may be lingering questions on whether the proposed process change is indeed too insignificant or if it’s the cost model not accurately capturing the cost impact.
- **New Technologies**: A method for adding new technologies would need to be determined to ensure they are capturing all significant costs, making them comparable to existing unit processes.
- **Cost Estimating Professionals**: Cost estimating professionals have unique skill sets and insight into cost estimating, but their involvement when actually using the model would increase costs and have practicality limitations. The role of cost estimating professionals in running the cost model and making updates (e.g. new technologies) needs to be determined.

If a new cost model is to be distributed outside Reclamation, a robust user manual or help menus will be needed. The current 65 page WaTER user manual that includes assumptions, required inputs, output information, and model limitations, etc. provides a good basis for future user manuals. A comprehensive user manual will help ensure the model is used correctly and will minimize Reclamation time answering questions.

Design Application

Cost Estimate Needs

The vast majority of Reclamation's cost estimates for WTP design projects occur in the TSC with Water Treatment and many other design groups performing the design and Cost Estimating Services performing the Cost Estimating. Designs include all levels of cost estimating from Preliminary Level Design through Final Design and all WTP sizes from 500 gallons per day (gpd) to 50 million gpd. Designs can be for Reclamation facilities or for our customers such as Native Americans that we support. The number of design cost estimates per year is small, typically 5 or less. The goal for all these estimates is to obtain the accuracy desired within the design budget and schedule.

Table 7 details typical cost related design questions and the anticipated minimum level of design and cost estimating needed to effectively answer the questions. The questions and solutions demonstrate the need for costs that are for an entire water treatment system and for individual processes.

Table 7. Level of design and estimating required to answer typical design cost questions

Design Question	Cost Estimate	
	Design	**Estimating**
What is the "rough cost" of the WTP?	Preliminary Level or Appraisal Level	Same as design
What should the expected cost of the WTP be for this design-build contract?	Appraisal Level or Feasibility Level	
What is the cost of one treatment option vs a different treatment option?	Appraisal Level or Feasibility Level	
What is the cost of the WTP so we can obtain congressional funding?	Feasibility Level	
What is the final cost of the WTP for construction?	Final Design	

The use of a WTP cost model could greatly reduce the time required to produce Preliminary and Appraisal Level cost estimates used in the initial stages of design. The process currently involves producing a custom WTP layout for each design and contacting vendors for all WTP equipment. This is a time intensive process that can cost $30,000 to $60,000 per project for design and cost estimating. Assuming a $45,000 cost per cost estimate and 2 Preliminary Level or Appraisal Level cost estimates per year, this equals a cost of $900,000 over 10 years.

Recommendations

- **Cost Model**: It will be difficult to have a cost model that will capture the range of flows that we work with on design projects, so the applicable flow range would likely have to be more limited. The "Preliminary Level" is the likely target design/cost estimate level for this cost program from a design standpoint. However, as seen in the design questions, its use is limited at a Preliminary Level. An Appraisal Level cost model is possible for a cost model and would have much broader use for design projects. However, the cost to develop and maintain an Appraisal Level model is a concern. Given the low number of design estimates performed per year, research and planning level studies would likely be needed to justify the development of a cost model.

Planning Application

Water supply planning is used to identify areas with water supply/demand imbalances and identifying alternatives for meeting future water supply needs. Treatment of non-traditional water supplies is a critical water supply category that is sometimes not considered in water supply planning activities.

Cost Estimate Needs

Reclamation programs fund planning projects that evaluate water supply options, some or all of the options may require water treatment. WTP sizes for planning studies are typically from 100,000 gpd to 20 million gpd. Currently, there is no prescribed level of accuracy for planning activities (such as basin studies). These cost estimates are generally developed using the best available data; therefore, the level of detail and accuracy in the cost estimates may be different for different alternatives. The accuracy level of cost estimates is often contingent upon the budget available for the planning study, the number of alternatives considered, the amount of cost share from non-federal partners, and the schedule or time available to develop the estimates. The development of these cost estimates may be performed by the TSC or by regional staff. The TSC performs water treatment design and cost estimating for about 2 planning studies a year. There is an unknown number of planning studies involving w performed by the regions without TSC involvement.

While planning studies do not always have a prescribed accuracy level, the default procedure would be to rely on our established cost estimate levels to guarantee some level of accuracy (e.g. Preliminary Level and Appraisal Level cost estimates). Otherwise, decisions could be based on data that is so far off that decisions would change if there was more accurate data. However, there is no tool/model readily available to help with these studies. Therefore, regions either need to go through standard cost estimating methods which often cost $30,000 to $60,000+ for ground up cost estimates or rely on publically available tools or data with unknown accuracy which also leads to inconsistent cost estimate accuracies across Reclamation.

Table 8 details typical cost related planning study questions and the anticipated minimum level of design and cost estimating needed to effectively answer the questions. The questions and solutions demonstrate the need for costs that are for an entire water treatment system.

Table 8. Level of design and estimating required to answer typical planning study cost questions

	Cost Estimate	
Design Question	**Design**	**Estimating**
What is the “rough cost” of treatment for a source water?	Preliminary Level or Appraisal Level	Same as design
What is the cost of this treating a source water vs no treatment for a different source water?	Preliminary Level or Appraisal Level	
What is the cost of this treating a source water that requires standard WT vs a	Preliminary Level or Appraisal Level	

Design Question	Cost Estimate	
	Design	Estimating
different source water that also requires desalination?		

The use of a WTP cost model could greatly reduce the time required to produce Preliminary and Appraisal Level cost estimates used in planning stages. A cost model that would be simple enough for region engineers without a water treatment background to operate would be ideal. Such a model may have inputs such as:

- Water source and depth to groundwater
- Feed water salinity
- Geographic location
- Product flow
- Concentrate disposal options based on location (deep well injection, surface discharge, evaporation ponds)

Recommendations

- **Demand for Cost Estimating**: The number of planning studies taking place in the regions with water treatment being considered is unknown. This should be ascertained to determine the demand for cost estimating services and tools.
- **Cost Model**: The "Preliminary Level" is the likely target design/cost estimate level for this cost program from a planning study standpoint. An Appraisal Level cost model is possible for a cost model and would have much broader use for design projects. However, the cost to develop and maintain an Appraisal Level model is a concern. There may be sufficient data (from the input list above) that could be gathered in a database to create an empirical model. If not, a parametric model or hybrid empirical/parametric model would be needed.
- **Consistency**: If a model or cost database is used for estimating water treatment costs in planning studies, there should be some consistency in its use and agreement on the accuracy.

Research Application

Cost Estimate Needs

Reclamation Research

Reclamation's Advanced Water Treatment research programs include internal research funded by the Science and Technology (S&T) program (2 to 6 projects per year in water treatment) and external research funded by the Desalination and Water Purification Research (DWPR) program (~8 projects per year on average). These programs for water treatment have an overarching goal to reduce or remove barriers to the wide-spread use of treatment technologies for non-traditional water sources to increase water supplies in the Western US. One of largest barriers to the use of non-traditional supplies is the higher capital and/or operating cost associated with treatment. The National Academies 2008 report on Desalination recognized that the cost of current technologies are cost prohibitive and recommended "[Developing] approaches to lower the costs of desalination to make it an attractive alternative to water importation or transfer in locations where traditional sources of water are inadequate."

Most of the research projects funded have a goal of reducing costs and/or energy use. Reclamation research efforts aimed at reducing treatment costs include: the development of new materials, processes, process efficiency improvements, and the treatment and disposal of concentrate. Improved cost estimating would help Reclamation's R&D Office quantify the outcomes of research and development efforts and plan for future research, identifying technology areas that have the highest potential for improvements including cost reductions. This planning could drill down to the level of identifying water treatment process components and sub-components that need additional research to improve economics.

Non-Reclamation Research

While non-Reclamation funded research is inherently not part of our mission, there exists a widespread need across the many federal and non-federal (e.g. universities) entities for cost models and standardized approaches to cost estimating. Therefore, any cost model development done by Reclamation will have much larger benefits to the American tax payer through other federal and non-federal uses. Use of cost models outside of Reclamation has inherent risk to Reclamation if cost results are used outside their intended purpose, are misrepresented, or are just incorrectly developed.

Research Questions Related to Cost

Table 9 details typical cost related research questions and the anticipated minimum level of design and cost estimating needed to effectively answer the questions. The questions and solutions demonstrate the need for costs that are for an entire water treatment system and for individual processes and process components.

Table 9. Level of design and estimating required to answer typical research cost questions

Research Question	Cost Estimate	
	Design	Estimating
What is the cost/benefit of an improvement to a component (e.g. membrane) within an individual treatment process (membrane skid) relative to the entire WTP cost?	**Component Improvement** Feasibility Level or Final Design Level **Entire WTP** Preliminary Level	**Component Improvement** Appraisal Level **Entire WTP** Preliminary Level
What is the cost/benefit of a new individual treatment process compared to similar individual treatment processes (e.g. comparing types of desalination process costs and energy use)?	Feasibility Level or Final Design Level	Preliminary Level or Appraisal Level
What are the major cost drivers for desalination that may make good areas for focusing future research efforts?	Feasibility Level	Preliminary Level or Appraisal Level

Standardized Approach

No matter how the costs are developed, a standardized cost estimating approach is a critical item. This is due to the need to compare costs across technologies and over time to identify and show capital and O&M cost improvements when and where they occur. Therefore ensuring cost estimates are comparable is an important component that will be greatly improved by developing a standardized approach. If a cost model were used, the standardized approach for costs and cost reporting would be mostly imbedded. If costs are developed on a unit cost methodology, the standardized approach can be described to help ensure estimates from inside and outside Reclamation are reasonably comparable. A standardized approach is described in the "Cost Reporting" section of this report.

Estimate Accuracy

Cost estimates have an absolute cost value with the accuracy presented as a +/- cost range. The cost ranges are fairly similar across similar levels of cost estimates. However, in research the relative cost value is often more important than the absolute value. Within Reclamation's cost estimating practices, the accuracy of one cost estimate relative to another is not well defined, and is certainly significantly more accurate than the absolute values.

Recommendations

- **Cost Model**: The design and estimating levels needed to answer the research questions provide a good overview of the cost estimating needs. A parametric cost model could provide the design and estimating solutions to answer these questions. An empirical cost model could provide a reference point for total WTP costs and possibly some processes. Considering the cost and the design and planning applications, and initial plan for cost estimates is shown in **Table 10**.

  A development plan is needed for a limited parametric model and an empirical model. The WaTER model will be a useful starting point. Some cost equations that have been published in peer reviewed literature should be investigated. With continued development of free design tools such as Dow's WAVE, the suitability of Reclamation developed design for UF and RO should be evaluated against these other tools to determine the best path forward.

Access to existing cost databases should be further investigated to help jumpstart the development of an empirical model. Both models would need ongoing funding for maintenance to periodically add updated cost data, estimated at $10,000 - $15,000 per year with the parametric model requiring more maintenance time than the empirical model.

- **Unit Costs**: Methods for using TSC or contracting A&E cost estimating services should be developed to support DWPR projects.
- **Standardized Approach**: A standardized approach to cost estimating should be developed as described above. This approach should be conveyed to all S&T projects and all new DWPR projects.
- **Estimate Accuracy**: Relative accuracy of similar cost estimates should be investigated as described above.

Table 10. Initial plan for Research application cost estimating.

<table>
<tr><th rowspan="3">Accuracy</th><th colspan="2" rowspan="2">Estimate Type</th><th rowspan="3">Approximate Reclamation Design Level</th><th colspan="5">WT Process</th></tr>
<tr><th colspan="3">Reclamation Only</th><th colspan="2">Other Federal and Non-Federal Use</th></tr>
<tr><th>AACEI</th><th>General Description</th><th>• Coag / Sed / Media Filtration, Cl_2
• Coag/ Sed, MF/UF, RO, Cl_2
• Option: UV</th><th>All other established WT processes</th><th>New WT processes</th><th>All established WT processes</th><th>New WT processes</th></tr>
<tr><td rowspan="6">Highest</td><td>1</td><td>Detailed Estimate</td><td rowspan="2">Final</td><td rowspan="5">Unit Costs</td><td rowspan="5">Unit Costs</td><td rowspan="5">Unit costs</td><td rowspan="6">Unit Costs [1]</td><td rowspan="6">Unit costs [1]</td></tr>
<tr><td>2</td><td></td></tr>
<tr><td>3</td><td>Preliminary</td><td rowspan="2">Feasibility</td></tr>
<tr><td>4</td><td></td></tr>
<tr><td rowspan="2">5</td><td></td><td>Appraisal</td></tr>
<tr><td rowspan="2">Order of Magnitude</td><td rowspan="2">Preliminary</td><td>Parametric Model</td><td>Unit Costs [2]</td><td rowspan="2">Unit Costs [2]</td></tr>
<tr><td>Lowest</td><td>-</td><td colspan="2">Empirical Model</td><td colspan="2">Empirical Model</td></tr>
</table>

1 For Reclamation funded research, plan would be for Reclamation to develop the cost estimate or pay an A&E contractor under a contract established each year after DWPR proposals are awarded. Some cost estimating performed by outside entities may be included in each proposal, but will need to be compliant with Reclamation cost estimating guidelines to be developed.

2 The default is unit costs, but additional parametric model modules may be developed for certain treatment processes allowing for expanded parametric model capabilities and use.

Cost Reporting

There is no current federal or non-federal agreed upon approach on what costs to include or exclude when reporting water treatment capital and O&M costs. When cost are developed for a specific municipality, this issue of not having a standardized approach is not a particular concern. However, if a municipality, state, or federal agency, consulting engineer, or researcher is trying to compare technologies in general, this issue is significant.

The desire is for an apples to apples comparison, but without a standardized approach cost reported on one project or by one equipment vendor may be very different than another. In some cases this may be for political or cost competition reasons, or for others it may just be because there is no standardized approach. **Table 11** shows how complex this issue is. The table includes some of the many costs that need to be considered for both a cost model and a standardized approach to water treatment cost reporting.

Table 11. Water treatment costs components

Unit Product Cost	Direct Capital	Operating Costs	Indirect Capital
• Daily flow production • Instantaneous flow production • Raw Water Quality • Site conditions • Building climate control • Operator certification requirements • Electricity • Fossil Fuels • Finished water quality (operating at or below regulatory limits) • Primary and secondary WQ standards • State and Federal regulations • Building codes • Permitting • Plant life • Equipment life • Waste disposal in landfill • Waste discharged to water bodies and different discharge regulations • Salvage value	• Intake structure / well • Land • Redundancy • Process equipment • Instrumentation • Labs • Process buildings • Maintenance buildings • Sustainable design features • Office space • Storage rooms • Fire protection • Pumps • Tanks • Backup power (what systems included and how long can a WTP operate?) • Intake pipelines • Clearwell or pipeline used for disinfection CT • Vehicles used for maintenance • Vehicles used for process operation and inspections	• Electricity • Labor (direct costs, retirement, union costs, insurance) • Membrane replacement • Maintenance and spare parts • Insurance • Chemicals • Chemical delivery • Municipal overhead	• Freight and insurance • Construction overhead • Owner's costs • Contingency costs • Design stage • Planning stage • Accelerated design and/or construction time • Design-Build vs Design-Bid-Build • Financing (interest rates)

Note: Developed using cost factors by Ettouney et al. 2002, but expanded to be more comprehensive.

These many cost factors shed light on both the issue of cost reporting and the complexity of adding a cost to a cost curve in a cost model. There are even further nuances such as how a cost for an operator is reported if an operator has joint responsibilities for WTP and distribution system operation? Some of these cost can have dramatic impacts with small vs large WTPs, remote locations, or in states with more regulations.

Conclusions and Next Steps

An overall conclusion from this report is the need for more consistency and having a plan for cost estimating tailored to design, planning, and research. There are unique cost estimating needs within design, planning, and research, but there are also overlapping needs as well. The development of a cost model capable of providing Preliminary Level cost estimates or even Appraisal Level cost estimates could be the most cost effective long term approach. Over a 10 year period, design work is estimated to require roughly $900,000 in estimating costs. A similar effort by the TSC using a cost model is estimated to cost $100,000 over 10 years, representing a net $800,000 in potential cost savings over 10 years. There would be some potential savings from planning and research studies as well, but more information is needed on planning study cost estimating activities. These savings would have to be offset against cost model development costs which need to be determined and cost model maintenance costs which could be roughly $10,000 to $15,000 per year, on the higher side for a parametric model and on the lower side for an empirical model. Besides possible cost savings, there are other concerns and risks detailed in the report associated with developing and maintaining a cost model.

The following are recommended next steps:

- **Standardized Approach to WTP Cost Estimating**: Investigate the development of a standardized approach to reporting water treatment costs. This topic is large and complicated enough to be its own effort. This affects Reclamation cost estimates, but requires much broader national consensus to ensure the approach proposed is valid long term. It may be worthwhile to try to quantify the relative cost impact of each cost component in **Table 11** to determine how much consensus is needed and the time required for this effort.
- **Guidelines**: For Planning and Research activities, provide cost estimating guidelines for the recommended cost estimate accuracy and cost estimating details such as the “Standard Approach to WTP Cost Reporting” described above.
- **Demand for Planning Study Cost Estimates**: The number of planning studies taking place in the regions with water treatment being considered is unknown. This should be ascertained to determine the demand for cost estimating services and tools.
- **Overall Plan**: Determine a cost estimating path forward for planning, research, and design. The approach of using unverified cost estimating tools and databases when no standard cost estimating techniques are available or are within budget and/or schedule is not a sound basis for consistent and accurate cost estimating. In these cases, it would be more appropriate to not provide costs. **Table 10** provides an example plan within the Research application. This can be combined with a plan on how to answer each type of common cost question with a certain level of cost estimate.
- **Cost Estimates for Research**: It is likely that some cost estimates needed for research will be go beyond the capabilities of a cost model. This should be specifically investigated including contracting options and costs.
- **Specific Plans for Cost Models**: If we develop empirical and/or parametric cost models, develop specific plans for each with clear requirements, goals, tasks, development costs, maintenance requirements, and schedules for each. The list of concerns in the “Cost Model Development Evaluation” section should be addressed specifically.

- **Estimate Accuracy**: Investigate the accuracy of the difference when comparing similar type cost estimates to determine if lower level cost estimates will still be useful when only making comparative evaluations.
- **Report Update**: Once the general and specific plans are developed, this report should be updated to reflect those changes.

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Data Sets that Support the Final Report

- Q:\Civil Engineering\8190\Cost Estimating Resources (-)\Cost Estimating Scoping FY17
- Point of Contact: Steve Dundorf, sdundorf@usbr.gov, (303)445-2263
- Data: Excel file with cost data to support estimated costs
- Keywords: cost estimate
- Size: <1 MB