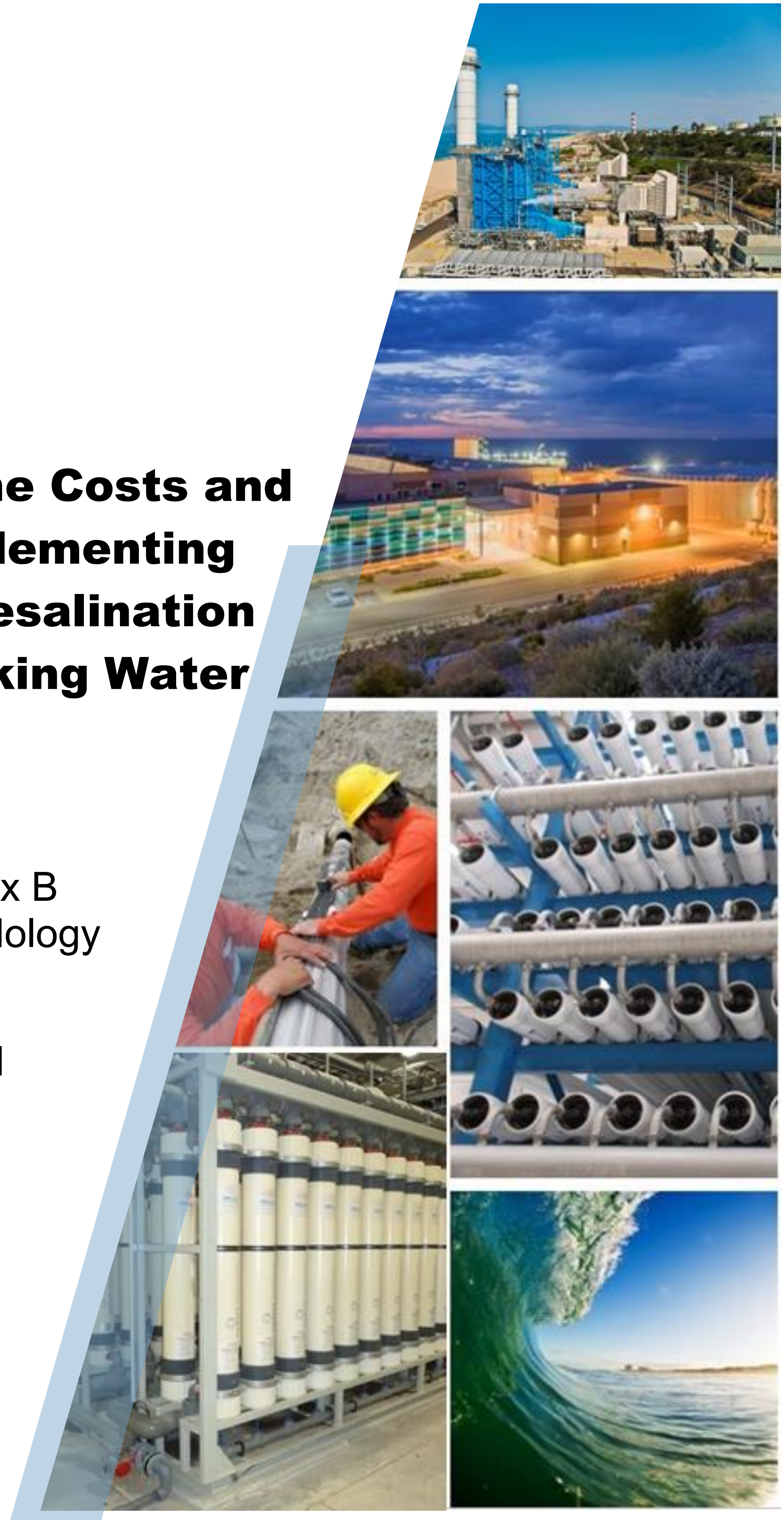
Evaluation of the Costs and Benefits of Implementing Ocean Water Desalination as a Local Drinking Water Supply



Chapter III - Appendix B
Risk Analysis Methodology

West Basin Municipal
Water District

Final Report
July 30, 2021

Submitted by

GHD

in association with
RAFTELIS

Appendix B – Risk Analysis Methodology

B1 – Overview

This appendix provides some further detail on the probabilistic modelling approach used to estimate the risk-adjusted cash flows for the OWDP. This Appendix should be read in conjunction with the main report body.

B2 - Inherent Risks

Inherent risks affect parameters that are defined inputs to the OWDP cash flow model. These risks were incorporated into the risk analysis using a direct methodology whereby the parameters are redefined as probability distributions and fed directly into the cash-flow calculations.

Note that risk distributions are defined from the perspective of the District – i.e. where risks are transferred to the private sector, the deterministic 'base estimate' value was used (i.e. removing the uncertainty).

The parameters subject to inherent risk are: i) capital cost line items; ii) operating cost line items and external parameters.

Capital Cost Items

To incorporate inherent risk into the capital cost estimates for Current Project Design and Subsurface Intake Design, the following steps were taken:

1. Removing the contingency allowance from the capital cost estimates;
2. Classifying each CAPEX line item as low (L), medium (M), or high (H) uncertainty depending on level of confidence in base estimate; and
3. Defining a probability distribution function to apply to the CAPEX line item for each of low, medium and high uncertainty. The probability distribution was applied as a multiple of the base estimate.

With respect to steps 1 and 2 above, the base estimate and uncertainty classification of each CAPEX line item is shown in Table B1 below.

Table III-B1 Inherent Risk Assessment - CAPEX

Capital Cost Components	Current Project Design		Subsurface Intake Design	
	Uncertainty	Base Estimate ($ mil)	Uncertainty	Base Estimate ($ mil)
Construction Costs – Direct				
Site Civil Works + Land Acquisition Cost	M	$13.64	M	$13.64
Electrical Substation, Transformers, etc.	M	$5.10	M	$5.10
Intake: Offshore Seawater Intake Piping and Screens (Current Project Design) *or* Subsurface Infiltration Gallery (Subsurface Intake Design)	H	$10.54	H	$155.72
Onshore Intake Pump Station	M	$12.92	M	$12.92
Pretreatment System	M	$33.20	M	$26.56
Reverse Osmosis System (SWRO and Partial 2nd Pass)	M	$83.90	M	$83.90
Post Treatment	L	$6.98	L	$6.98
Chemical Storage and Handling	L	$1.80	L	$1.80
Product Water Storage Tank	L	$1.40	L	$1.40
Backwash Water Treatment and Solids Handling	M	$25.00	M	$25.00
Brine Discharge Tank	L	$0.75	L	$0.75
Offshore Brine Diffuser System	M	$10.94	M	$11.76
Operations/Admin Building	M	$15.00	M	$15.00
Product Water Pump Station	M	$6.80	M	$6.80
Product Water Conveyance Pipeline	M	$38.50	M	$38.50
Concrete Plug Demolition / Site Improvements	M	$5.00	M	$5.00
Interconnecting Pipe, Valves, & Auxiliary Systems	M	$26.55	M	$26.55
Control & Instrumentation	M	$6.45	M	$6.45
Construction Costs – Indirect				
Mitigation Monitoring	M	$2.28	M	$3.33
Spare Parts	L	$1.50	L	$1.50
Engineering & Other Consulting	M	$24.48	M	$35.50
Overhead & Fee	M	$66.09	M	$96.16
Contingency	***N/A - REMOVED***			
Biological Mitigation	M	$10.96	M	$11.33
Permitting costs	H	$5.50	H	$4.30
TOTAL CAPITAL COSTS (excl. contingency)		**$399**		**$580**

With respect to step 3, the following probability distributions were defined for the low, medium and high uncertainty capital cost items. The figure below shows the probability distributions in terms of both cumulative probability distribution (left) and probability density (right). All probability distributions were modelled as lognormal distributions with a finite, defined lower bound and infinite, undefined upper bound.

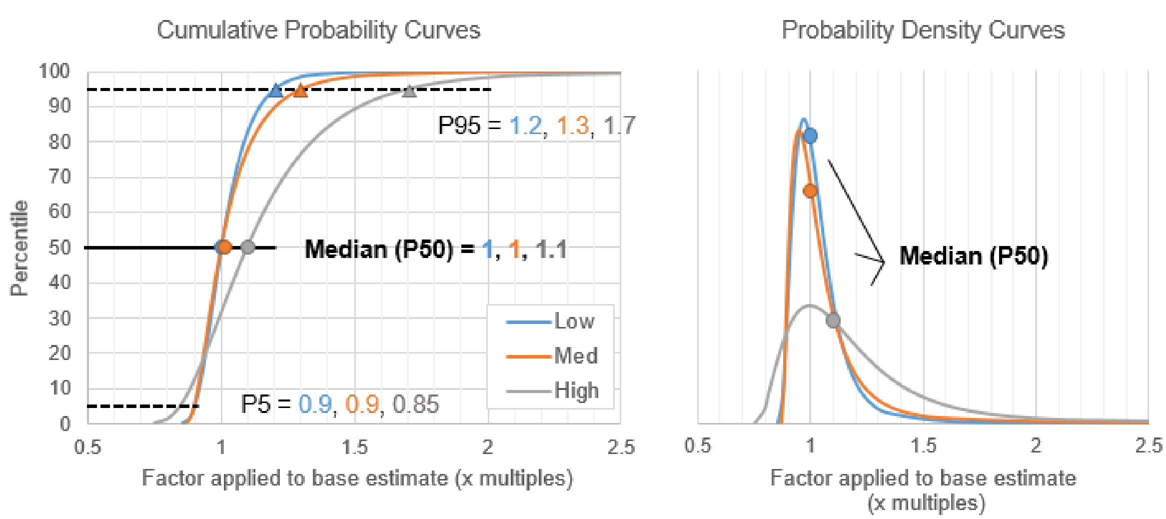


Figure III-B1 Inherent risk distributions, capital cost line items

Operating Cost and External Items

The line items comprising the operating cost estimate are also subject to uncertainty. Furthermore, macroeconomic and external items will also impact on the project costs (e.g. cost of power, capital cost escalation, carbon price etc.). Similar steps were taken to model the inherent risk of these items, namely:

1. Classifying each OPEX line item and external parameter as low (L), medium (M), or high (H) uncertainty depending on level of confidence in base estimate.
2. Defining a probability distribution function to apply to the OPEX line item for each of low, medium and high uncertainty. The probability distribution was applied as a multiple of the base estimate.

With respect to step 1, the base estimate and uncertainty classification of each parameter is shown in Table B2 below.

Table III-B2 Inherent Risk Assessment – OPEX and external parameters

Operating Cost Components	Unit	Current Project Design		Subsurface Intake Design	
		Uncertainty	Base Estimate	Uncertainty	Base Estimate
Project OPEX components					
Annual Power Consumption	kWh/1000 gal	L	13.0	L	13.2
Sludge Disposal	$ mil/yr	M	$0.21	M	$0.21
Chemicals	$ mil/yr	L	$0.75	L	$0.75
Maintenance	$ mil/yr	H	$1.11	H	$1.11
Membrane & Cartridge Replacement	$ mil/yr	M	$0.80	M	$0.80
Labor	$ mil/yr	M	$1.67	M	$1.67
Other/ Misc.	$ mil/yr	H	$0.42	M	$0.42
NPDES Required Monitoring	$ mil/yr	M	$0.10	H	$0.10
State Lands Lease	$ mil/yr	M	$0.20	H	$0.50
Biological Mitigation	$ mil/yr	M	$0.72	H	$0.74
External Parameters					
Power cost in 2023	$/kWh	M	$0.12	Same as Current Project Design	
Carbon Price in 2023	$/kWh	L	$20.00		
Power escalation	% per year, real	H	1.5%		
CAPEX escalation	% per year, real	M	0.5%		
Carbon price escalation	% per year, real	H	1.5%		

With respect to step 2, the following probability distributions were defined for the low, medium and high uncertainty operating cost items. Again, they are shown as probability distributions in terms of both cumulative probability distribution (left) and probability density (right). In this case high uncertainty variables were modelled as lognormal distributions which a finite, defined lower bound and infinite, undefined upper bound. Low and medium uncertainty items were modelled as PERT curves (essentially adjusted normal distributions) which have defined, finite upper and lower bounds.

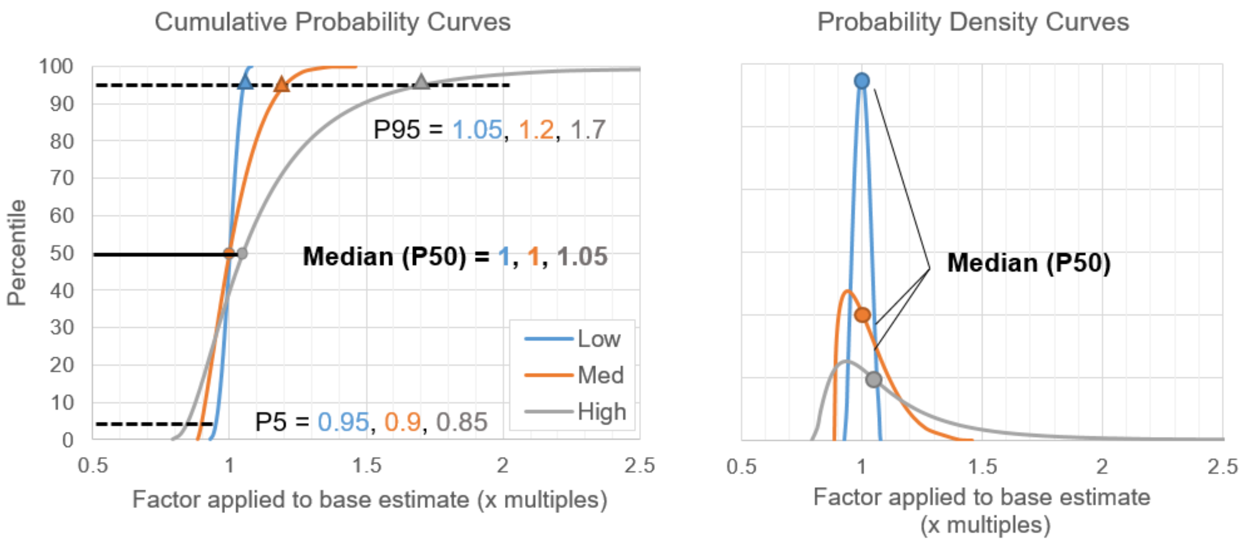


Figure III-B2 Inherent risk distributions, operating cost and external items

B3 – Contingent Risks

Contingent risks for the project were identified and developed by the project team in a risk register. The risk register can be found below, as Appendix B1.

Contingent risks were identified based on specifics of the proposed OWDP at the ESGS site, as well as GHD's experience in the delivery of large international public infrastructure projects, including extensive involvement with desalination facilities in North America, Australia and the Middle East.

Identified risks were then quantitatively defined for the risk-adjusted cash flow model using the following parameters:

- **Design** – does the risk impact both Current Project Design and Subsurface Intake Design?
  Most risks are relevant to both Current Project Design and Subsurface Intake Design, however a small number were specific to only one. These were flagged as such. The risk-adjusted cash flow model only incorporated the impacts of the risk to the relevant design.

- **Likelihood** – what is the probability of the risk eventuating?
  The likelihood of each risk was modelled as a Bernoulli function (i.e. a certain probability between 0 and 1 that it occurs, otherwise it does not occur).

- **Consequence –** what will the cost impact be if the risk eventuates?
  Risks were modelled as lognormal distributions and were defined based on estimates for the P5, P50 and P95 cost impacts. If the cost impact is expected to be different between Current Project Design and 2, this was also defined.

- **Allocation** – does the risk sit with the District, is it transferred to the private sector, or is it shared?
  Refer to Section 6.2.3 of the main report for discussion on risk allocation.

Contingent Risk Modelling Example

The following example for the ***'Design Errors'*** risk illustrates the contingent risk modelling approach. The steps below correspond to the ordering of information in the risk register.

Risk Description – that the project design issued-for-construction is not suitable leading to additional construction costs or delays.

Risk Allocation – this risk is transferrable to the private sector in situations where the design and construction stages are performed by the same entity. That is, the private sector is likely to accept this risk when it is responsible for design and construction, and is empowered to seamlessly incorporate construction considerations during the design process. Therefore, this risk was classified as risk Group B, which as the following risk allocation:

Table III-B3 – Risk allocation example for 'Design Errors' Risk

Risk Category	Risk allocation under different delivery methods					
	DBB	DBOM	DBFOM - 10%	DBFOM - 50%	DBFOM - 100%	PPP
B						

Designs – This risk affects both Current Project Design and Subsurface Intake Design so is included in the risk-adjusted cash flow modelling for both.

Likelihood – the assessment by the project team was to allocate this risk a likelihood probability of 20%. In other words, there is a 1 in 5 chance that a material design error is made that would result in a material impact to construction costs. A Bernoulli function with probability 10% is included in the @Risk model to capture this. Figure B3 is a graphical representation of this likelihood function.

Consequence – a consequence distribution was created to model the potential construction cost impacts of the risk, if it eventuates. The distribution was modelled as lognormal distribution with the following three-point inputs used for Current Project Design, developed based on project team experience:

- P95 estimate- $20 million
- P50 estimate - $5 million
- P5 estimate - $2 million

Due to the larger construction cost and increased complexity of Subsurface Intake Design, a multiplier of 1.25x was applied to the inputs for Subsurface Intake Design. Graphically, the consequence distribution for Current Project Design is shown on Figure B4.

The inputs and distribution for Current Project Design can be interpreted as saying the most likely impact of the risk is $5 million if it eventuates, and there is a less than 5% chance the cost impact is over $20 million, and less than 5% chance the cost impact is less than $2 million. A similar narrative applies for Subsurface Intake Design.

It should be noted that the consequence inputs used in the risk register are not based on a detailed cost estimation process for the additional works that would be required in case the risk eventuates. Rather they rely on judgement of the project team based on experience at knowledge of the OWDP project. This is appropriate at this stage of the project development. More detailed risk analysis with more accurate and data-driven likelihood and consequence estimate are typically performed after further design work.

Risk output – using the risk inputs described above, Monte Carlo modelling is used to quantify the risk impact. To do this, the @Risk model randomly selects values for likelihood and consequence based on the inputs. It does this over many iterations, and records the risk cost impact, where:

$$Risk\ cost\ impact\ (\$\ million) = likelihood\ (\%) \times consequence\ (\$\ million\ )$$

The output graph shown in Figure B5 below shows the distribution produced for 500 iterations for this 'Design Errors' risk.

Incorporation into the risk-adjusted cash flow model – the risk cost impact is added to the construction cost of the project each iteration completed by the @Risk software. (Operating risks would have the impact added to the yearly operating cost).

This is the process used for all contingent risks.

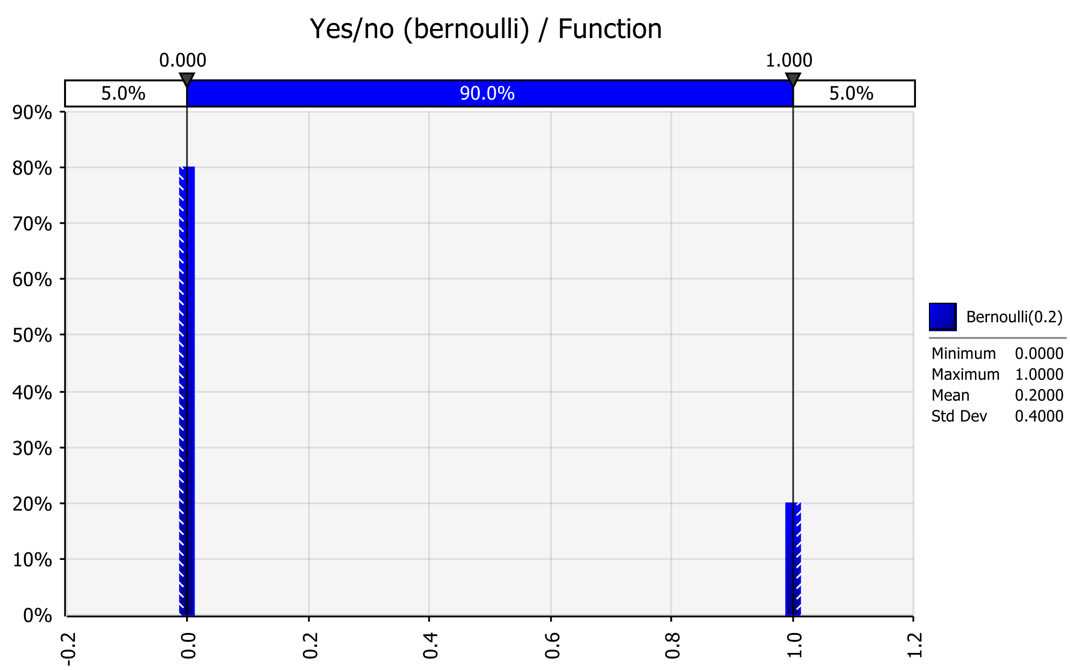


Figure III-B3 – Contingent Risk example – likelihood distribution with p=0.2

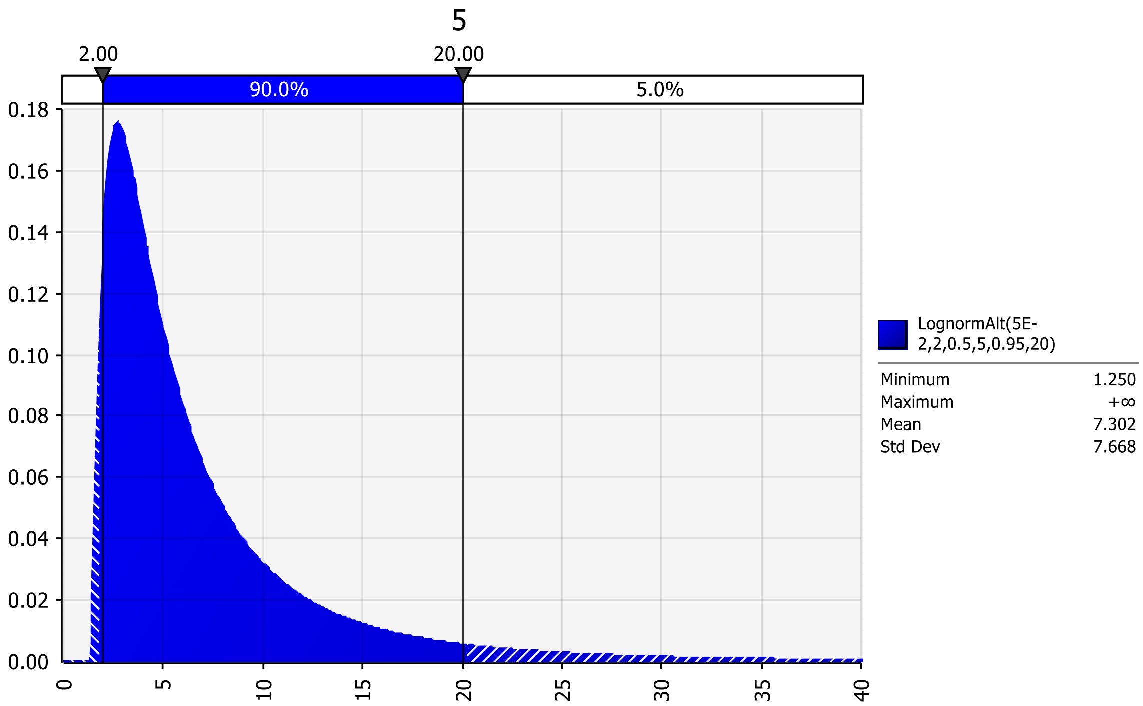


Figure III-B4 – Contingent Risk example – consequence distribution with P50 = $ mil and P90 = $20 mil

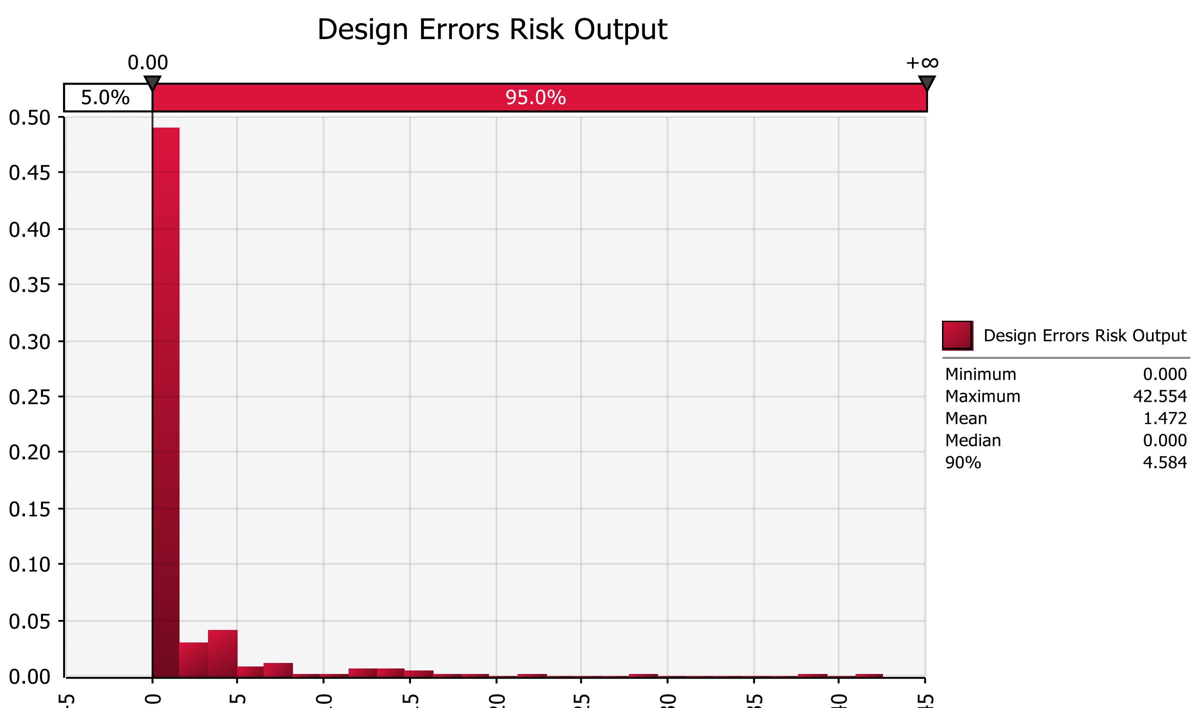


Figure III-B5 – Contingent Risk example – risk output results based on Figures B3 and B4

Appendix B1 – OWDP Preliminary Risk Register

GHD Advisory

Revision 1

Cost Benefit Analysis - Ocean Water Desalination Project

Current Project Design = CPD
Subsurface Intake Design = SID

Risk Allocation Legend:
- Risk transferred to private sector entities
- Risk shared with private sector entities (50-50 split assumed)
- Risk retained by District / cannot be transferred to private sector entities

Current Project Design = CPD
Subsurface Intake Design = SID

	CONTINGENT RISKS			Risk Allocation								Likelihood			Consequence	CPD ($ millions)			SID
ID	Risk Name	Risk Description	Risk Category	DBB	DBFOM - 10%	DBFOM - 50%	DBFOM - 100%	PPP	DBOM w. 50% SRF funding	DBOM	Both Designs	Type	Probability of occurrence (p)	Input 2 (n)	Type	P5	P50	P95	Conseq. Multiplier
1	Onshore geotechnical risk	Onshore geotechnical conditions at ESGS site, seawater pipeline and/or conveyance pipeline alignments are significantly different to design-level geotechnical evaluations completed during design stage, leading to additional costs during construction.	A								Both	Yes/no (bernoulli)	0.2		Unbounded (lognormal)	$2	$5	$10	1.25
2	Construction delays/errors (General Design and Construction Risk)	Contractor errors lead to delays and/or additional costs to rectify, during construction phase	A								Both	Yes/no (bernoulli)	0.5		Unbounded (lognormal)	$2	$5	$10	1.1
3	Major exchange rate fluctuations (General Design and Construction Risk)	Fluctuations in prices of imported materials & equipment lead to additional costs	A								Both	Yes/no (bernoulli)	0.1		Unbounded (lognormal)	$2	$5	$10	1
4	Major tariff impacts (General Design and Construction Risk)	Changing tariffs result in higher prices of imported materials & equipment.	A								Both	Yes/no (bernoulli)	0.1		Unbounded (lognormal)	$2	$5	$10	1
5	Design errors (General Design and Construction Risk)	Design issued for construction is not suitable leading to additional construction costs or delays.	B								Both	Yes/no (bernoulli)	0.2		Unbounded (lognormal)	$2	$5	$20	1.25
6	Offshore geotechnical risk	Geotechnical conditions at location of open intake (CPD) or subsurface intake (SID) are different to expected adding costs / delays	A								Both	Yes/no (bernoulli)	0.2		Unbounded (lognormal)	$5	$15	$50	1.5
7	Site access	Complexities of managing construction on the ESGS site which requires access in busy area, leading to extra construction costs	C1								Both	Yes/no (bernoulli)	0.4		Unbounded (lognormal)	$2	$15	$30	1
8	Regulatory, permitting or community opposition during construction	Regulatory changes (e.g. zoning, permitting, community, environmental impacts) lead to change in scope/costs/timing of project AFTER contract signed	C2								Both	Yes/no (bernoulli)	0.2		Unbounded (lognormal)	$5	$30	$70	1
9	OPPORTUNITY - Private sector construction cost savings for construction	Opportunity that private sector design & build involvement leads to CAPEX savings due to improved technology choice and/or purchasing power	H								Both	Yes/no (bernoulli)	0.6		Unbounded (lognormal)	$2	$5	$10	1
10	OPPORTUNITY - Private sector O&M cost savings	Opportunity that private sector design & operations involvement leads to OPEX savings due to improved technology choice and/or maintenance regime.	H								Both	Yes/no (bernoulli)	0.6		Unbounded (lognormal)	$0.2	$0.5	$1.0	1
11	Power consumption risk	Power usage (kWh per gallon) increases during operation due to poor equipment performance or other causes	E								Both	Risk transfer captured in inherent modelling elsewhere in cash flow model							
12	Power cost escalation	Power prices increase significantly during plant lifetime	G								Both	Risk transfer captured in inherent modelling elsewhere in cash flow model							
13	Seawater quality	Long-term changes in ambient seawater composition or physical properties occurs, resulting in additional chemical or other costs during operation	F								Both	Yes/no (bernoulli)	0.1		Unbounded (lognormal)	$0.2	$0.5	$1.0	1.1
14	Regulatory & permitting changes during operation	Regulatory changes affect the operating mode of the plant (e.g. brine discharge, beach nourishment or waste disposal routes) and lead to higher OPEX	G								Both	Yes/no (bernoulli)	0.3		Unbounded (lognormal)	$0.2	$0.5	$1.0	1
15	Labor and consumable cost risk	Operator labour and/or consumables prices increase significantly during plant lifetime due to unforeseen circumstances.	E								Both	Risk transfer captured in inherent modelling elsewhere in cash flow model							
16	Financing risk (REMOVED)																		
17	Demand risk (REMOVED)																		
18	Sea Level Rise	Seawater rise occurs quickly during plant lifetime requiring additional works to protect the plant	D								Both	Yes/no (bernoulli)	0.75		Unbounded (lognormal)	$2.0	$5.0	$10.0	1
19	Force majeure (REMOVED)	Not able to distinguish between delivery options in a meaningful way.																	
20	Integration with existing outfall (SID only)	Brine co-discharge strategy in SID is to comingle at existing treated wastewater outfall for Hyperion plant. Risk that comingling changes buoyancy or other properties of outfall stream sufficiently that diffusers need to be redesigned and replaced to meet environmental standards.	D								SID only	Yes/no (bernoulli)	0.3		Unbounded (lognormal)	$5.0	$20.0	$50.0	1
21	Site contamination	Additional contamination remediation works are needed and costs to complete will be incurred by the OWDP rather than site owner (NRG).	C3								Both	Yes/no (bernoulli)	0.3		Unbounded (lognormal)	$5.0	$20.0	$50.0	1
22	Demolition costs	Risk that additional demolition costs will be needed and incurred by the OWDP rather than the site owner (NRG).	C3								Both	Yes/no (bernoulli)	0.3		Unbounded (lognormal)	$5.0	$20.0	$50.0	1
23	Reuse of existing intake infrastructure (CPD only)	Condition of existing ocean water intake to ESGS (which is reused in CPD) requires additional works to render it usable, leading to extra costs during construction.	C3								CPD only	Yes/no (bernoulli)	0.2		Unbounded (lognormal)	$5.0	$30.0	$100.0	1
24	Algae blooms (CPD only)	Short term algae blooms (e.g. red tide) in seawater feed result in additional treatment costs . This does not impact SID as seabed infiltration gallery (SIG) would remove algae particles entering the plant.	F								CPD only	Multiple bounded (binomial)	0.25	30	Unbounded (lognormal)	$1.0	$5.0	$10.0	1
25	Industrial Action (General Design & Construction Risk)	Industrial labor disputes during construction period result in additional construction costs.	A								Both	Yes/no (bernoulli)	0.1		Unbounded (lognormal)	$1.0	$5.0	$10.0	1
26	Offshore intake performance risk (SID only)	Submerged seawater intake used in SID experiences significant clogging, resulting in additional maintenance costs to maintain intake volumes.	F								SID only	Yes/no (bernoulli)	0.3		Unbounded (lognormal)	$2.0	$5.0	$10.0	1
27	Design-related Maintenance Risks	Design of the facility results in higher than expected maintenance costs – e.g. additional equipment failures, downtime or additional refurbishments	E								Both	Yes/no (bernoulli)	0.5		Unbounded (lognormal)	$1.0	$2.0	$5.0	1

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https://projects-northamerica.ghd.com/sites/uswest1/wbmwddesalcostbenefi/ProjectDocs/FINAL DELIVERABLES/Chapter III - Proj Delivery Method and Incentive Eval - Evaluation of Costs and Benefits of OWDP.docx

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about GHD

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