INL/MIS-21-61716-Revision-0

Integrated Nuclear-Driven Water Desalination: Providing Regional Potable Water in Arizona

February 2021

Changing the World's Energy Future

Aaron S Epiney, James D Richards, Jason K Hansen, Paul W Talbot, Pralhad Hanumant Burli, Cristian Rabiti, Shannon M Bragg-Sitton

Idaho National Laboratory

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Integrated Nuclear-Driven Water Desalination

Providing Regional Potable Water in Arizona

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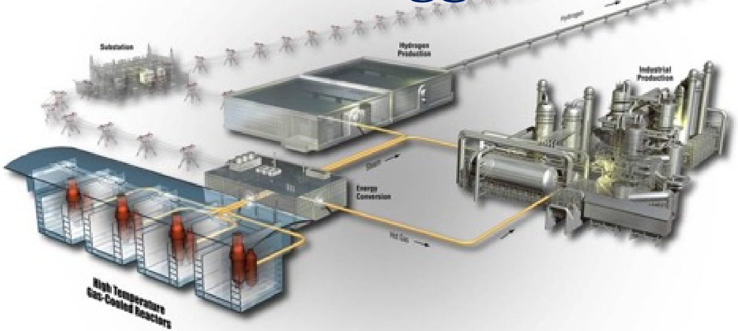

Integrated Energy Systems Kickoff Meeting 2020
February 18, 2020, INL, Idaho Falls, ID

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Outline

- Introduction
- Economic Framework
- Case Description
- Modeling Framework
- Results
- Approximations Made
- Future Work
- Conclusions

Introduction: Motivation

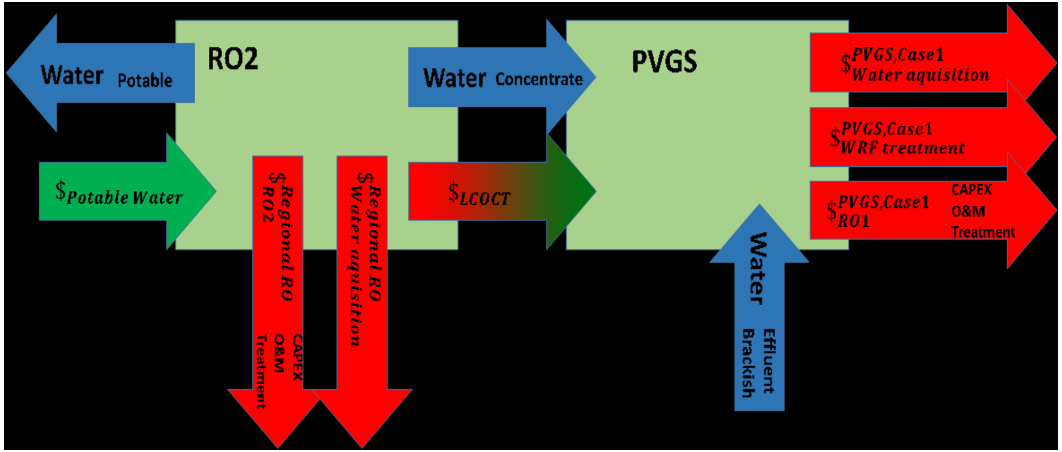
Symbiosis: Concentrate treatment at PVGS

Introduction: Economic Optimization

- **Investors**
  - What is the optimum size for regional RO?
    - Max IRR, or NPV
    - LCOPW as function of size

- **APS/PVGS**
  - What should be the price for treating RO concentrate at PV?

Economic Framework



- APS and regional RO2 one entity (but still two separate business units)
- How to establish the levelized cost of concentrate treatment (LCOCT)?
- Which FOM to optimize regional RO2?

Economic Framework
Cost Transfer Strategies

- Case I
  - Profit is made at the regional RO2 while APS concentrate treatment service is transferred at economical cost ($LCOCT_1$)
  - APS economical cost is determined with respect to the least water acquisition cost strategy
- Case II
  - Profit is made at the regional RO2 while APS concentrate treatment service is transferred at economical cost ($LCOCT_2$)
  - APS economical cost is determined only with respect to the cost of water treatment (not the saving in water acquisition!!!)

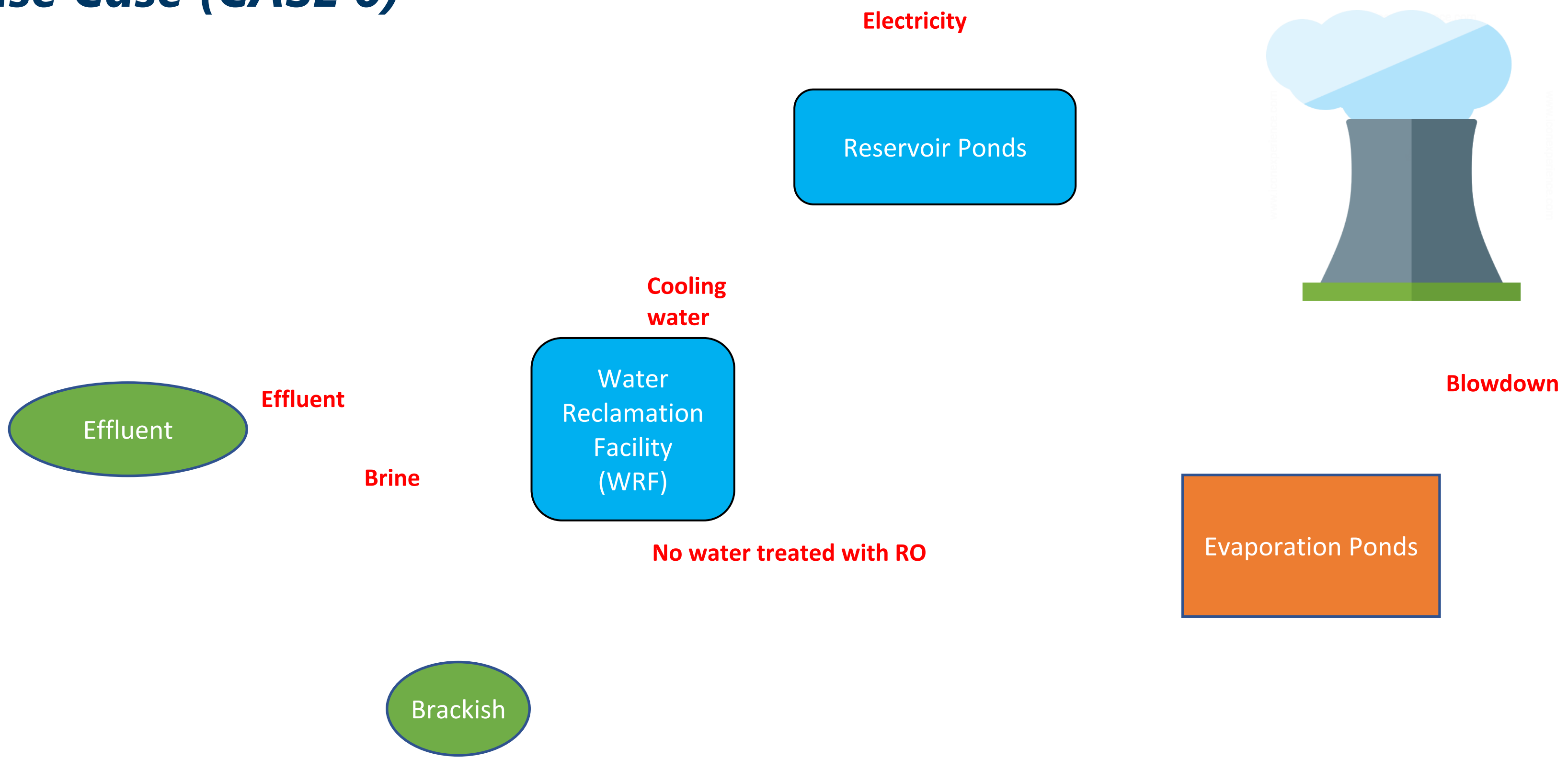
Economic Framework
Regional RO2 Financial Optimization

- If potable water market unknown
  – Minimize LCOPW (Levelized Cost of Potable Water)

- If potable water market known:
  – Maximize NPV (if no competing investment)
  – Maximize IRR (if capital is in competition)

Case Description

Base Case (CASE 0)

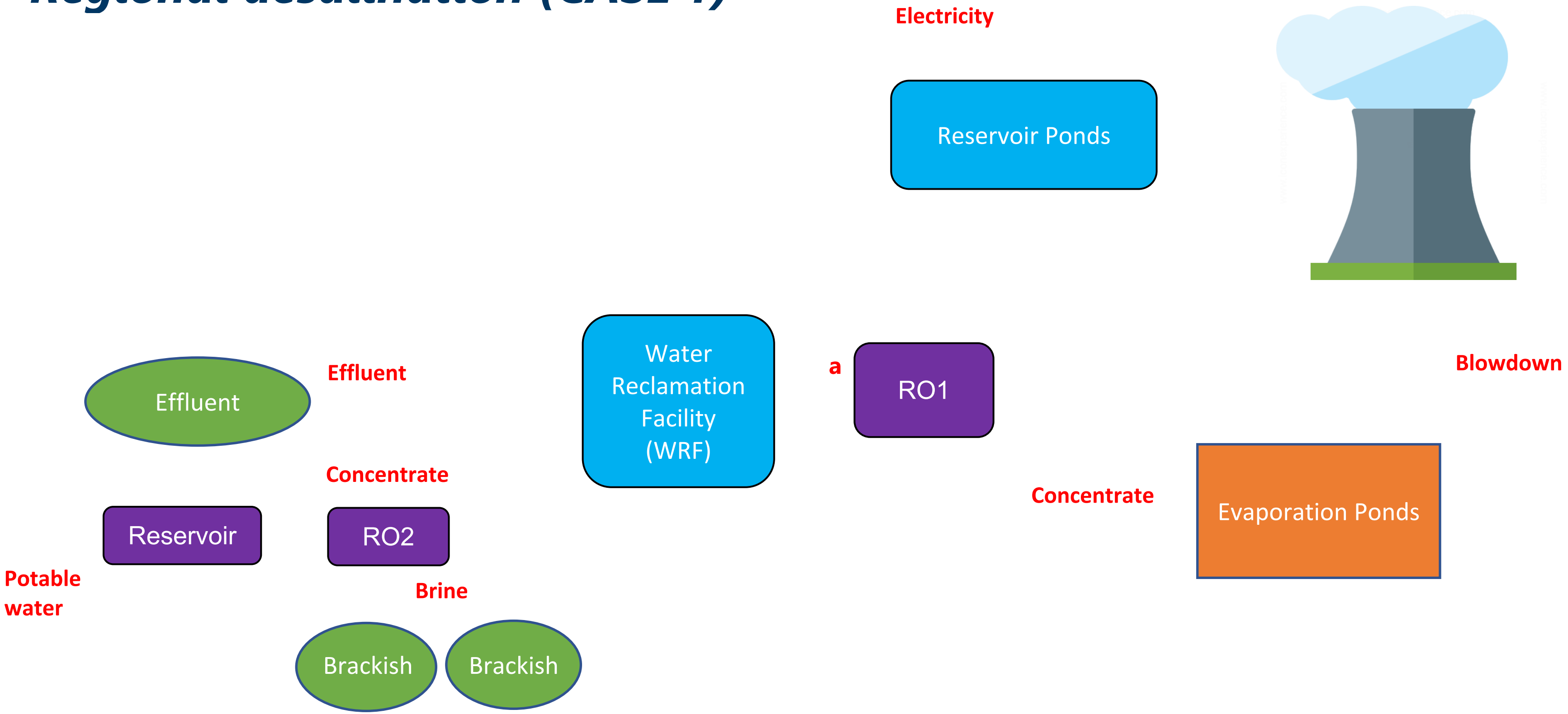


Case Description

CASE 0: Most Cost Effective Water Acquisition Strategy

- Represent the reference water acquisition strategy
- Is the cheapest possible (FY18 analysis)
- No RO is built
- No flexing WRF
- No reservoir as buffer
- Maximization of brackish water intake without additional treatment

Case Description
Regional desalination (CASE 1)



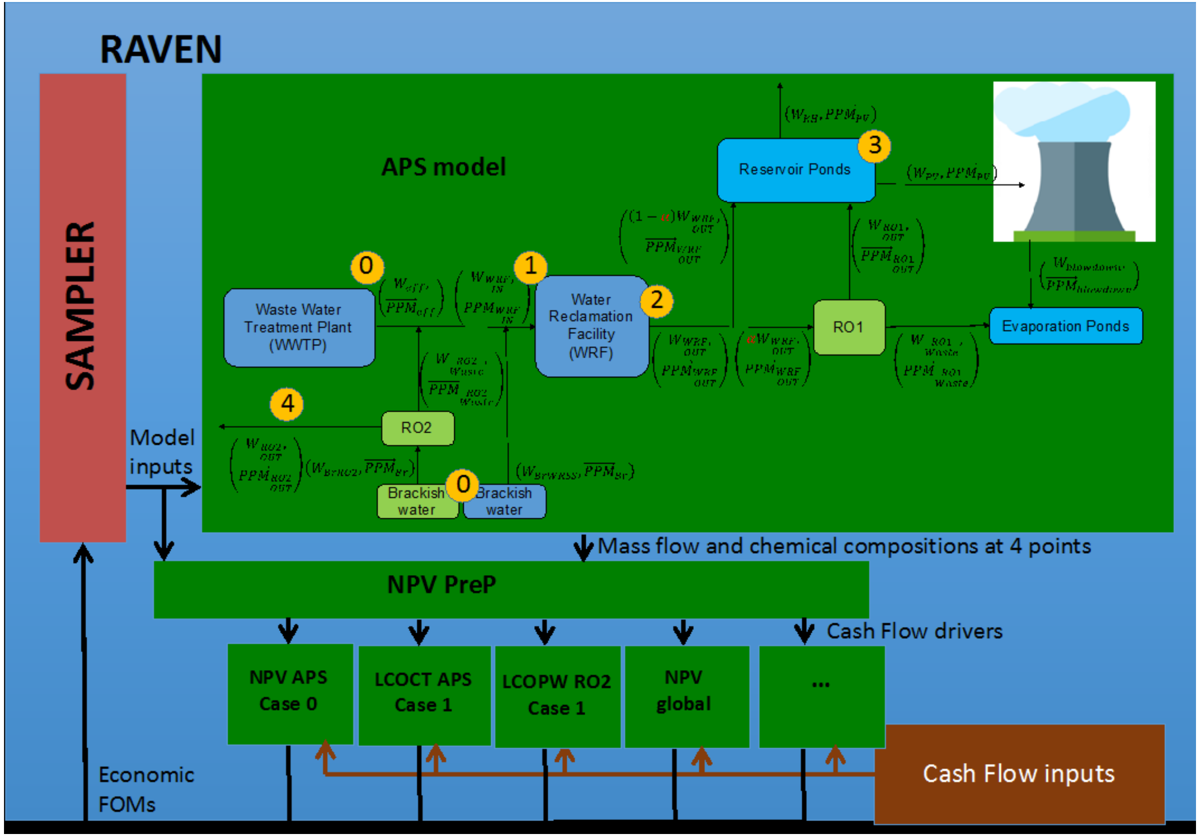
Case Description
CASE 1: Regional RO

- Consistent with base case
  - Monthly time discretization
  - No flexing WRF and RO
  - No use of reservoir

- RO1 downstream of WRF instead of downstream of circ. water (blowdown)
  - No option to mix treated water from blowdown back into reservoir
  - RO downstream of WRF allows operational chloride limits respected in reservoir

Modeling Framework

- RAVEN as driver
- CahFlow plugin for economics



Modeling Framework
APS model considerations

- 6 chemicals explicitly tracked (Calcium, Magnesium, Sodium, Alkalinity, Chloride, Sulfate)
  - All reported concentrations are yearly time averages
  - Silica are assumed to be maintained within limits providing magnesium and calcium are maintained in the tertiary treatment process
  - Chlorides are considered limiting in this study. All other chemicals are non limiting or assumed to be treated with WRF (accounted in the economics of the model)

- Magnitude of electricity demand volatility absorption benefit is small
  - Finding form 2018 study
  - Volatility absorption not considered in this study
  - Analysis was not performed with the new APS supplied data

Modeling Framework

Economic model considerations

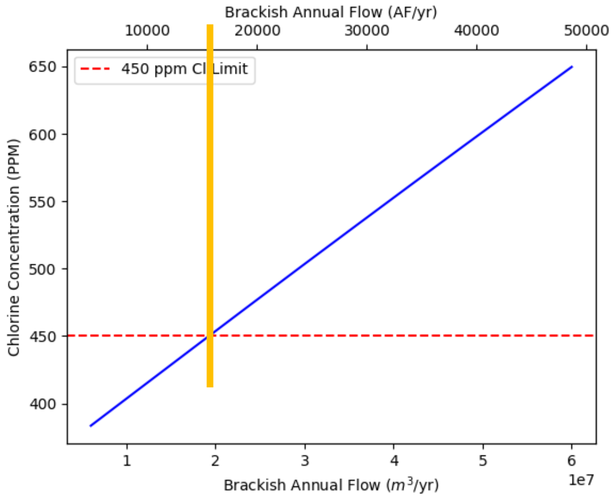
- Relevant cash Flows:
  - WRF treatment costs (chemicals/electricity) -APS-
  - Total annual costs from effluent water acquisition (tiered structure and non-usage fee) –APS-
  - Cost (potential) of brackish water (assumed $25/AF) -APS, RO2-
  - Brackish water pump costs (CAPEX/fixed/variable/electricity) -APS, RO2-
  - ROs (CAPEX/ fixed/variable/electricity) -APS, RO2-
  - Revenue from potable water sales –RO2-
- Internal cash Flows:
  - LCOCT revenue for APS ($$ RO2→APS)
  - LCOCT cost to RO2 ($$ APS→RO2)
- Irrelevant cash flows in differential analysis:
  - WRF (CAPEX/fixed)
  - NPP (fixed/variable)

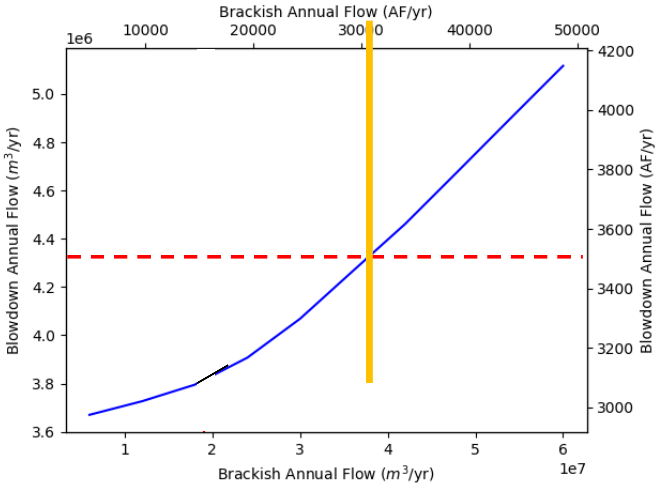
Results: CASE 0

- Least cooling water acquisition and treatment cost
  - Maximum brackish water without supplemental RO treatment

- Two constraints considered
  - Circulation water system blowdown (2200 gpm)
    - Evaporation pond capacity
  - Chloride concentration operational target in reservoir (450 ppm)
    - Assures Red Hawk water quality within limits
- Optimal solution is at the constraints

Results: CASE 0





- Chlorine reservoir concentration is more limiting
- Maximum brackish to exceed 450 ppm is 1.9e7 m^3/yr (15500 AF/yr)
- Minimum cooling water cost (discounted cash flow) is ~ $94 million

APS economics for CASE 1 scenarios are always compared to this

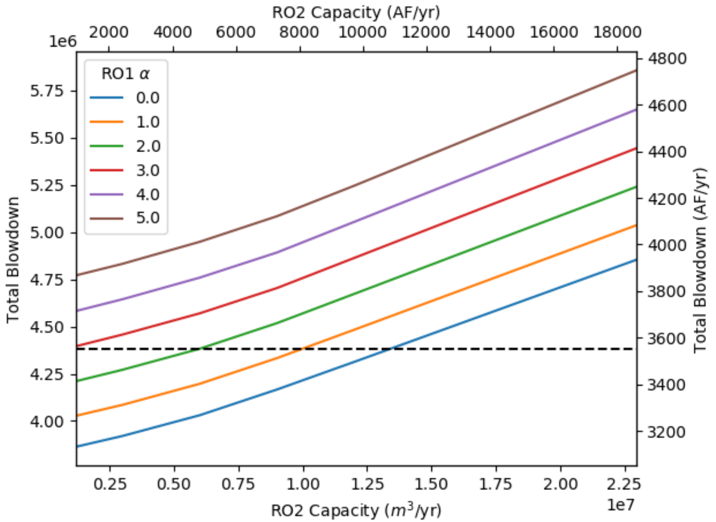
Results: CASE 1

- Optimization variables (degrees of freedom)

  - **Capacity of RO1**: Only a slipstream out of the WRF needs to be treated to maintain salinity in the reservoirs (RPS operational requirement)
  - **Capacity of RO2**
  - **Amount of brackish water to WRF**: This is the amount of brackish water blended with effluent

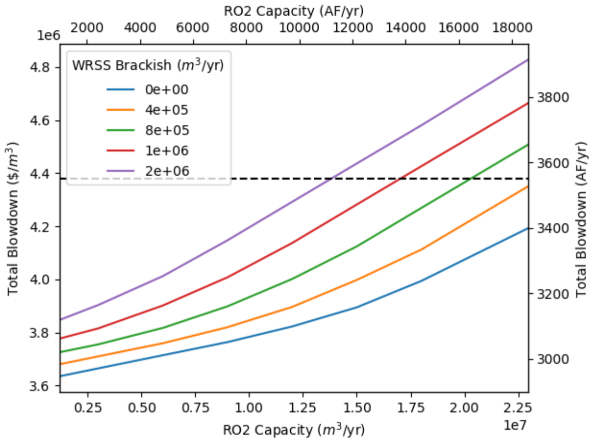
Results: CASE 1 Physics

- Blowdown constraint only, no economics!

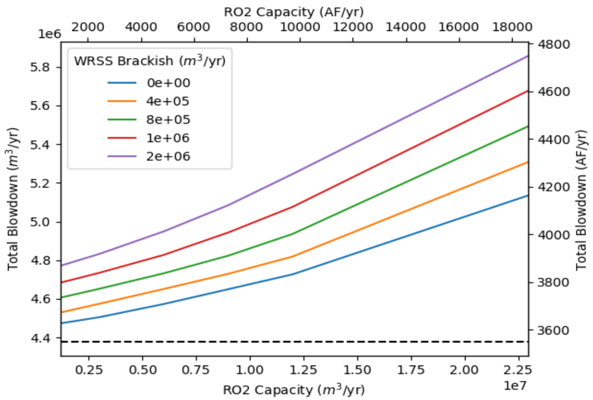


Brackish water 1.9e7 m^3/yr (15500 AF/yr).

No RO1

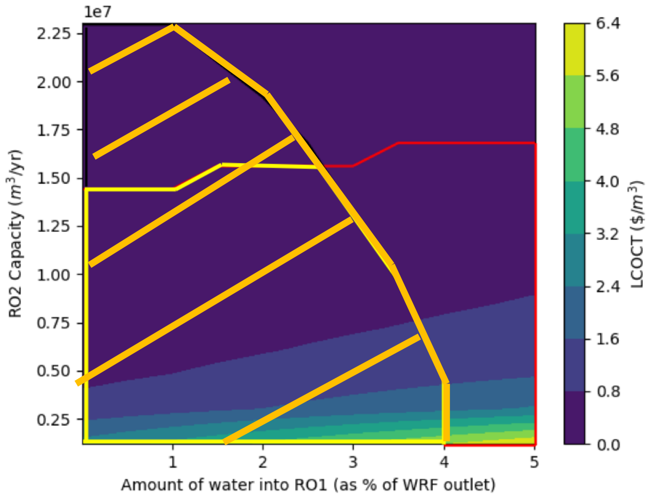


5% RO1

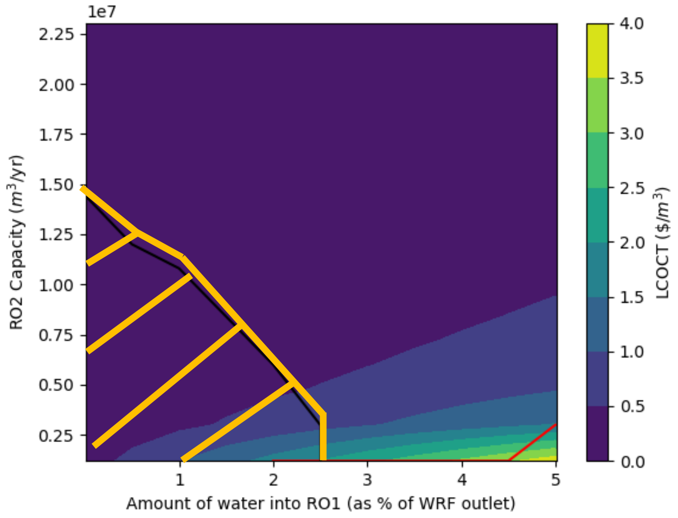


Results: CASE 1 Physics

- The largest feasible RO2 size is achievable when no RO1 is built.
- RO1 concentrate is less concentrated than NPP blowdown
- The PV RO1 works around 80% efficiency, while the blowdown in the PV circulating water system is ~4%; i.e., an equivalent efficiency of removing chlorides of ~96%.



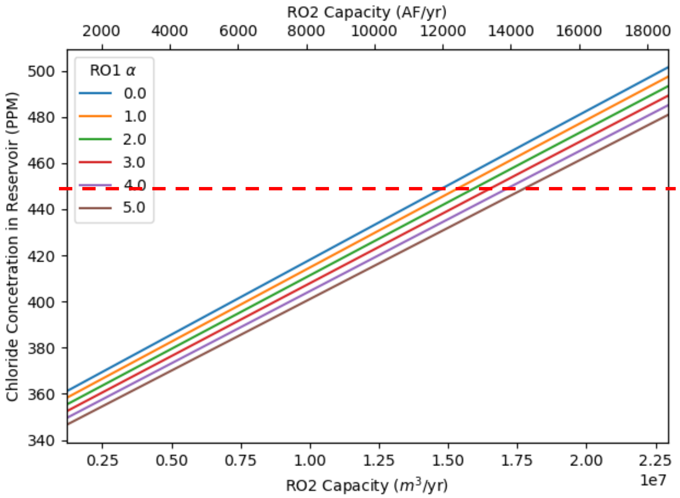
Brackish water 0.0 m³/yr (0 AF/yr).



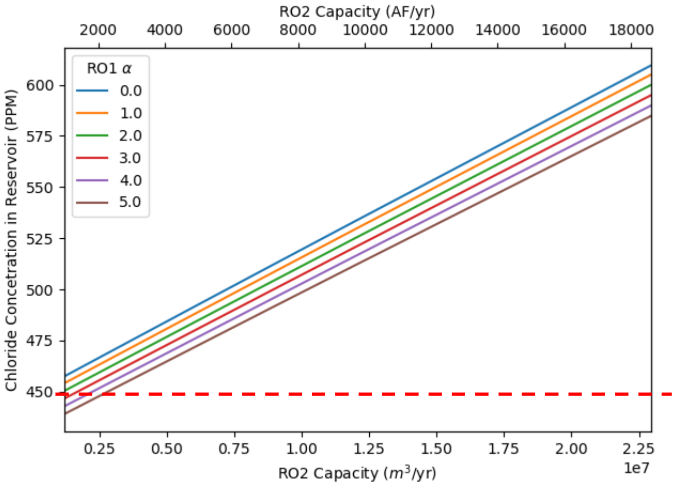
Brackish water 1.9e7 m³/yr (15500 AF/yr).

Results: CASE 1 Physics

- Time-averaged reservoir pond salinity constraint only, no economics!
  - Chloride concentration in the reservoirs is allowed to exceed the operational target
  - Circulating water chemistry operational limit (12000 ppm chlorides) is respected at all times by adjusting the blowdown



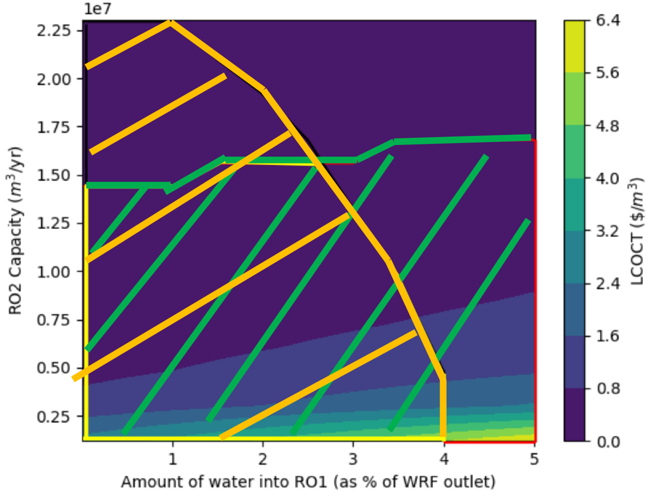
Brackish water 0.0 m^3/yr (0 AF/yr).



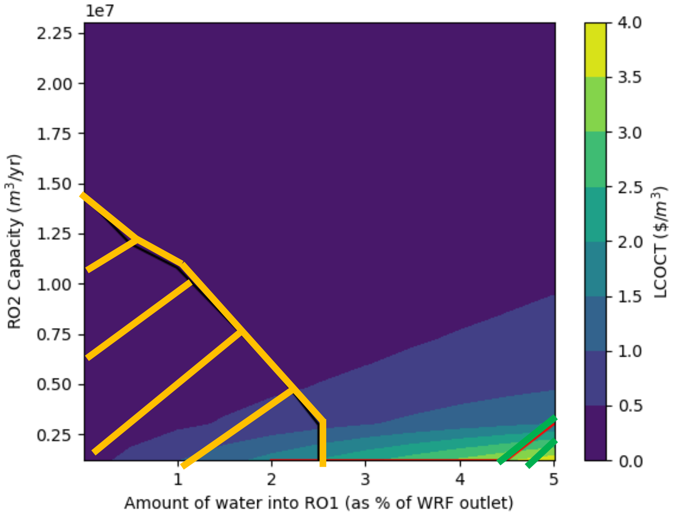
Brackish water 1.9e7 m^3/yr (15500 AF/yr).

Results: CASE 1 Physics

- **Operational chloride concentration in the reservoir more restrictive than blowdown for RO2 size.**
  - Considering both limits simultaneously, the maximum size RO2 can be build when no additional brackish water is injected



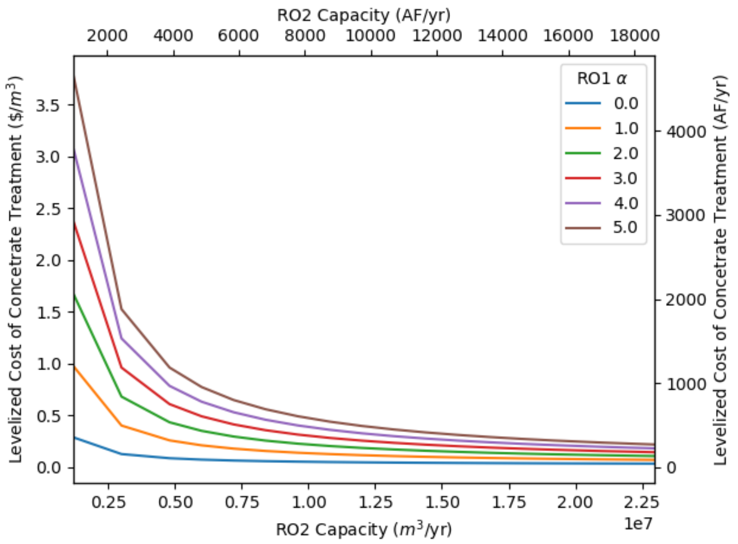
Brackish water 0.0 m³/yr (0 AF/yr).

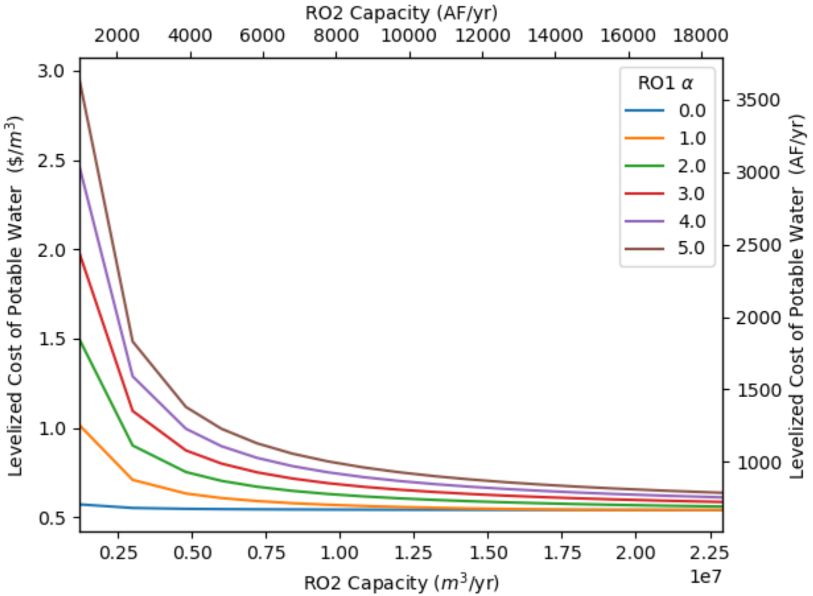


Brackish water 1.9e7 m³/yr (15500 AF/yr).

Results: CASE 1 Economics

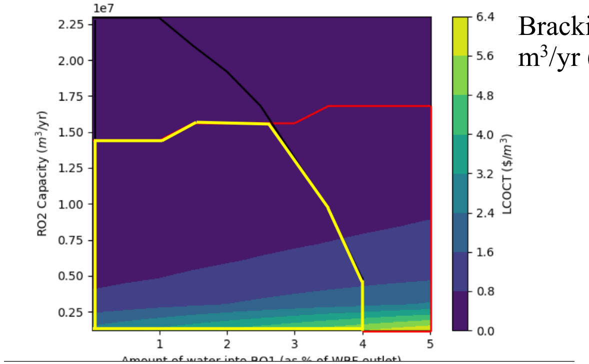
- LCOCT offsets the water treatment cost and effluent water cost savings





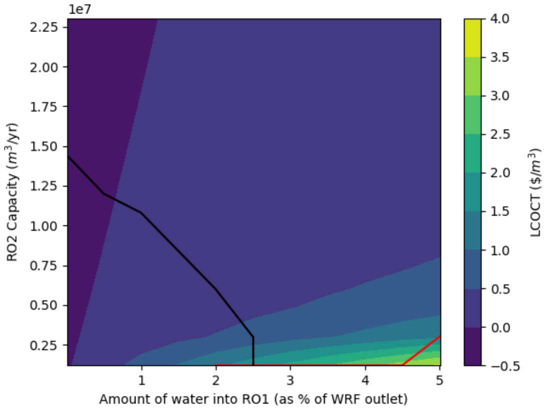
Brackish water 1.9e7 m^3/yr (15500 AF/yr).

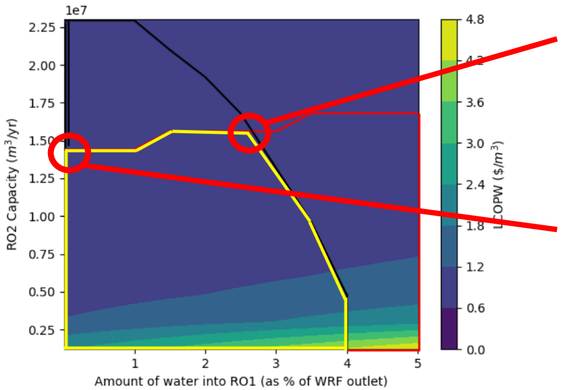
Results: CASE 1 Economics



Brackish water 0.0 m^3/yr (0 AF/yr).

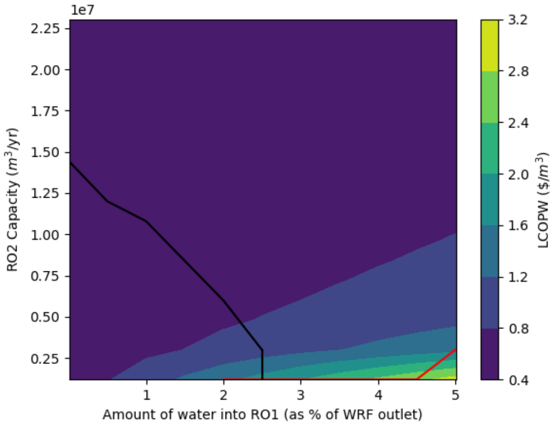
Brackish water 1.9e7 m3/yr (15500 AF/yr).





RO2: 12600 AF/yr
LCOPW: 0.74 $/$m^3$

RO2: 11700 AF/yr
LCOPW: 0.65 $/$m^3$



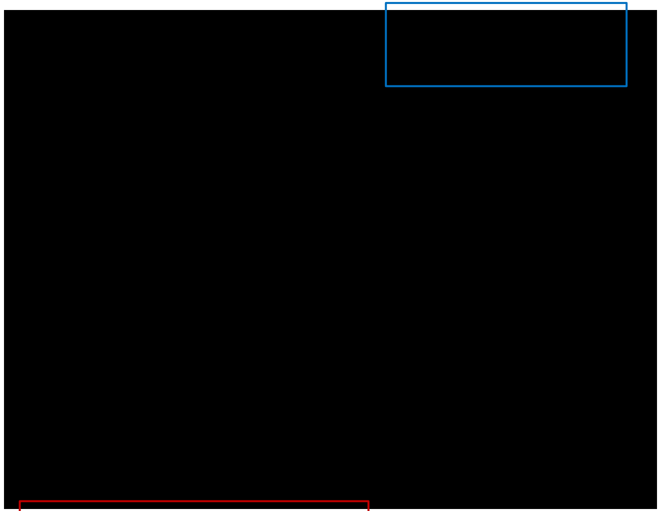
Results: CASE 1 Economics

- Building the reginal RO2 of 11700 AF/yr (with lower LCOPW) or 12600 AF/yr (with higher LCOPW) depends on the water price.
  - Selling price >1.82 $/m^3$ ⇨ build the larger one
  - Selling price <1.82 $/m^3$ ⇨ build the smaller one

- Value of the concentrate as cooling water to APS (LCOCT offsets only cost of water treatment not the saving in water acquisition)
  - If APS takes in concentrate, must maintain pond salinity
    - Increase effluent (%) – expensive
    - Reduce brackish water (%) – cheap

Estimating Water Demand

- What does water demand in the Phoenix west valley cities look like today and in the future? Answering requires two relationships: price-quantity and demand growth.



price-quantity: movement along the demand curve

- Econometric analysis enables estimating these relationships
  - use local data
  - estimate parameters

[redacted]

Buckeye	consumption	51491	103050	72587	10877	thousand gallons
	water rate	2.02	4.37	3.11	0.86	dollars per thousand gallons
	Population	50396	76815	60279	7361	people

[redacted]

Tolleson	consumption	7107	21304	12067	2883	thousand gallons
	water rate	1.12	3.04	2.34	0.45	dollars per thousand gallons
	Population	6524	7319	6958	266	people

[redacted]

- Demand equation and parameter, A, and elasticities for price and population

[redacted]

Forecasting Water Demand

- In terms of quantity and price: [redacted]

- With initial parameters by city and month:

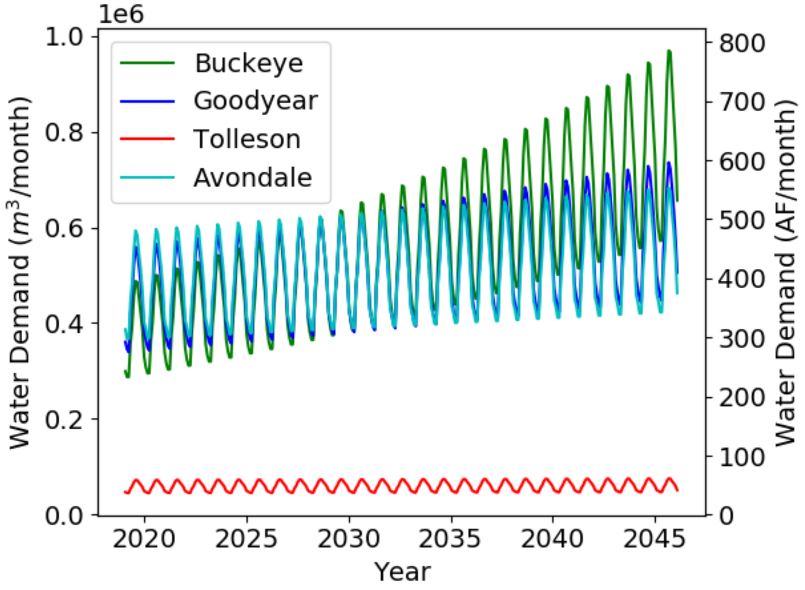
[redacted]	Buckeye		[redacted]	Tolleson		[redacted]
	P_{m0}	N_{m0}		P_{m0}	N_{m0}	
[redacted]	4.13	71461	[redacted]	2.31	7276	[redacted]
[redacted]	4.13	71945	[redacted]	2.16	7280	[redacted]
[redacted]	4.14	72429	[redacted]	2.17	7284	[redacted]
[redacted]	4.14	72913	[redacted]	2.67	7288	[redacted]
[redacted]	4.25	73397	[redacted]	2.78	7292	[redacted]
[redacted]	4.31	73881	[redacted]	3.04	7296	[redacted]
[redacted]	4.19	74370	[redacted]	2.94	7299	[redacted]
[redacted]	4.24	74859	[redacted]	2.88	7303	[redacted]
[redacted]	4.37	75348	[redacted]	3.01	7307	[redacted]
[redacted]	4.19	75837	[redacted]	2.51	7311	[redacted]
[redacted]	4.26	76326	[redacted]	2.48	7315	[redacted]
[redacted]	4.19	76815	[redacted]	2.30	7319	[redacted]

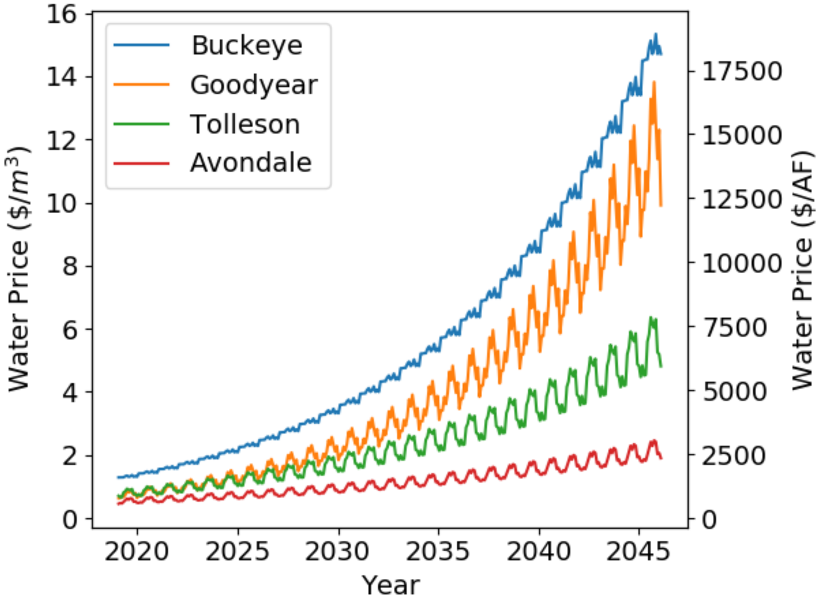
- And water price and population growth rates (r, n) and elasticities (α, □), respectively

[redacted]

Results: CASE 1 Economics (Water Market)

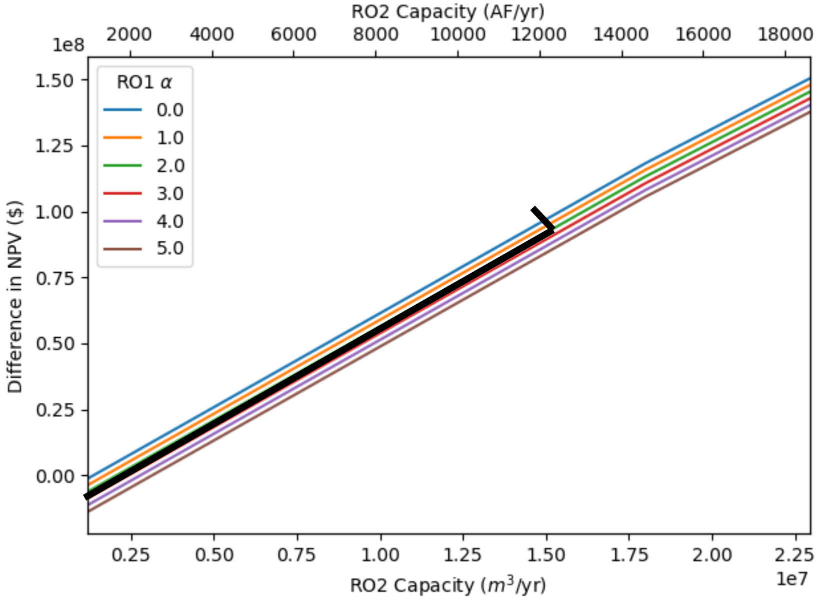
- Estimated water demand and price development

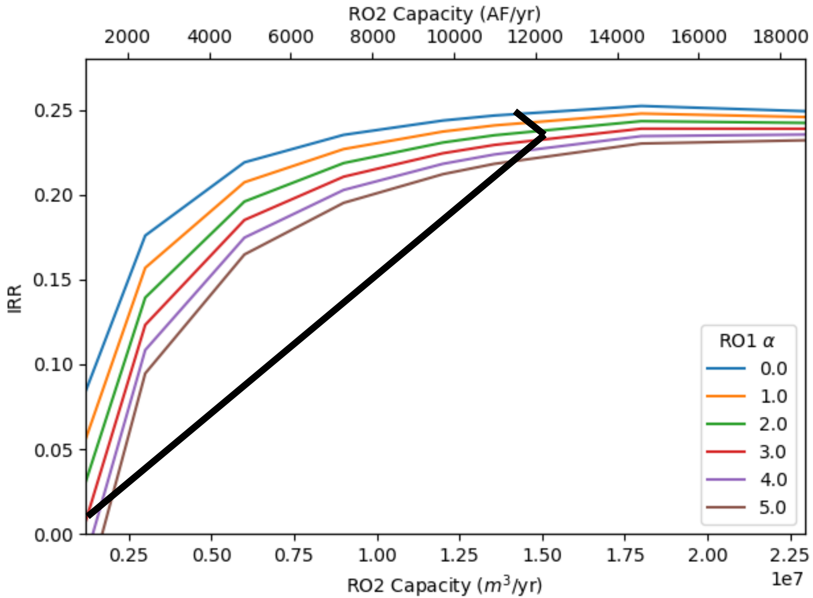




Results: CASE 1 Economics (Water Market)

- NPV and IRR

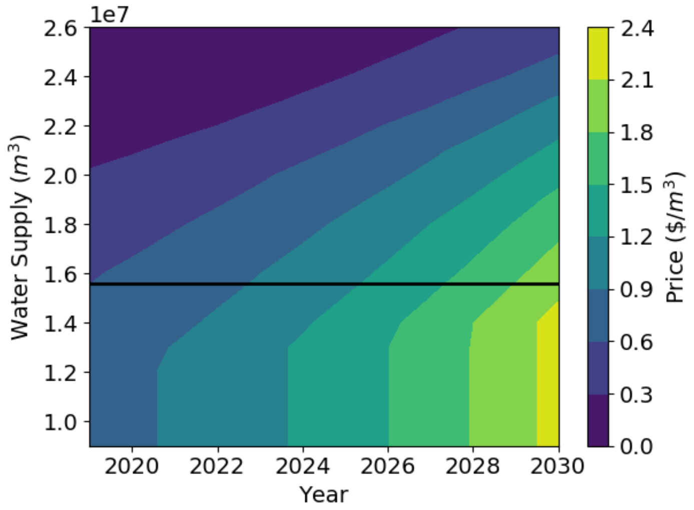


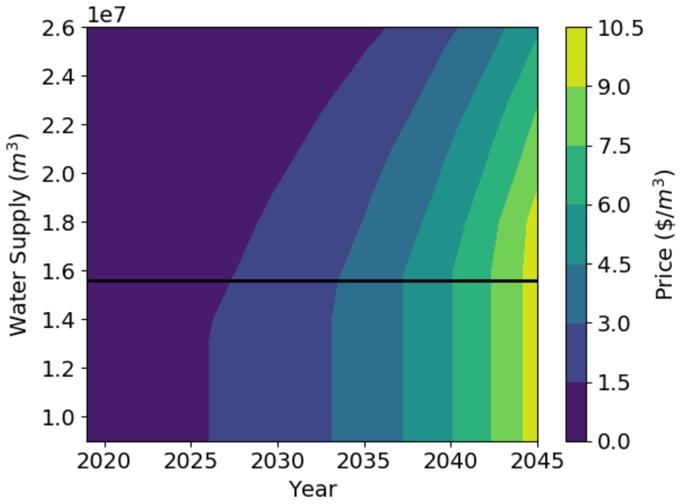


Brackish water 0 m^3/yr (0 AF/yr).

Results: CASE 1 Economics (Water Market)

- Water prices





Approximation Pros and Cons

- Brackish water acquisition cost $ 25/AF is not currently in the market
  - Removal will lead to increase in LCOCT, likely decrease of LCOPW
- APS vs. RO2 discount rate
  - Discount rate in RO2 should probably by higher TBD, will increase LCOPW
- Grid benefit
  - No benefit from baseload increase are captured
  - No benefit from increase in population are considered

Conclusions

LCOPW (Potable water price unknown)	- Price > 1.82 \$/m^3
	  - Minimum LCOPW (0.65 \$/m^3) within constraints
	    - no RO1
	    - 11700 AF/yr RO2 (7000 AF/yr potable)
	    - no brackish
	- Price > 1.82 \$/m^3
	  - Biggest RO2 (12600 AF/yr) within constraints
	    - ~2.7% RO1
	    - no brackish
	    - LCOPW (0.74 \$/m^3)

NPV/IRR (Potable water	- Within constraints Maximum NPV (~ 100 million) and IRR (~23%) coincide: