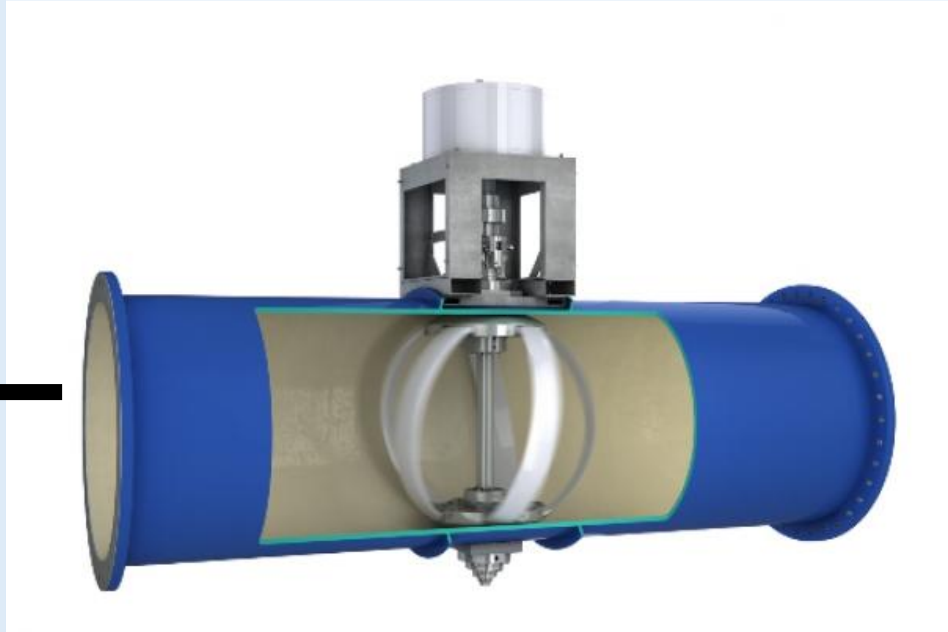
IS THE INSTALLATION OF MINI HYDROPOWER TURBINES IN WATER TRANSMISSION SYSTEM PIPELINES COST EFFECTIVE?

Supervisors: Professor Angus Simpson and Jinzhe Gong

Who is responsible with preventing this?

- Australia one of the largest CO_2 emitters per capita.
- 85% of our emissions from energy generation.

Mini Hydropower - Dreams into Reality?



The Hahndorf Dissipator

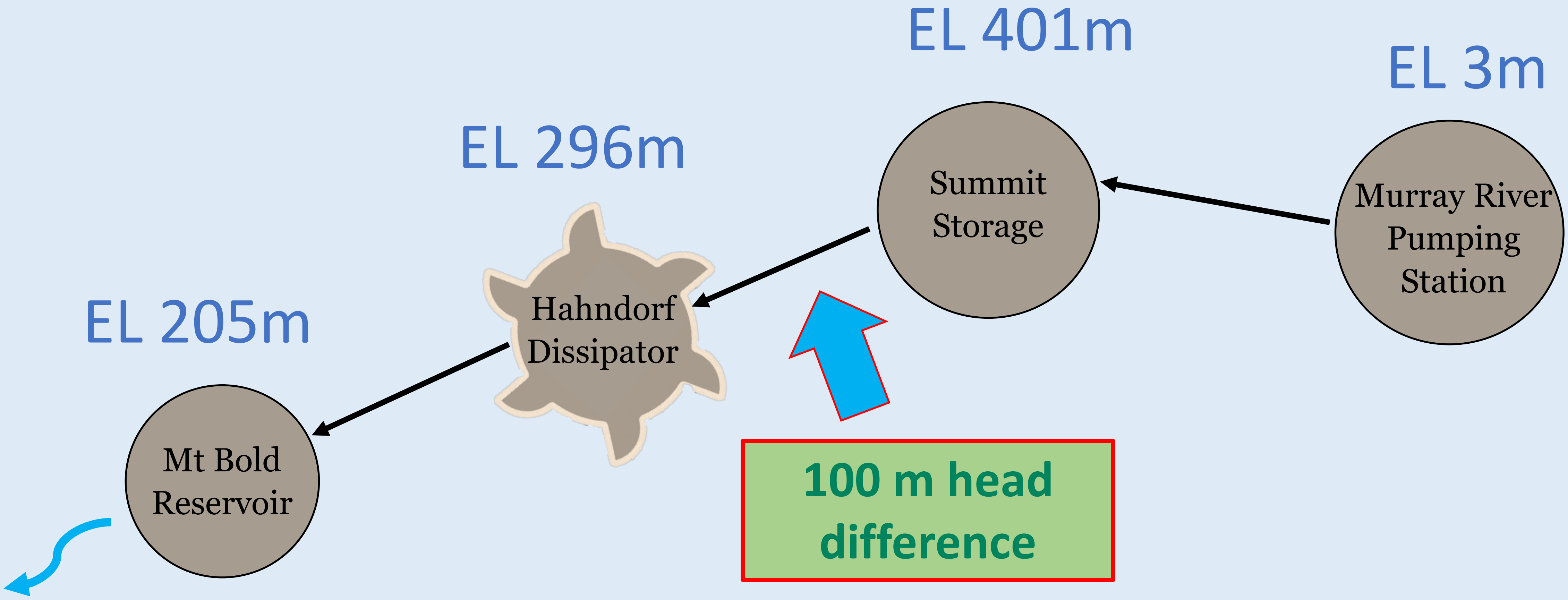
- Murray Bridge to Onkaparinga (MBO) Pipeline
- Pumped at **Murray Bridge**
- Rising main to **Summit Storage**
- Released through **Hahndorf Dissipator**
- Into **Onkaparinga River**
- Water supply for **Southern Adelaide**

50 km long

1.4 - 1.7 Diameter


Hahndorf Dissipator

Hydraulics at the Dissipator



EL 401m
EL 3m
EL 296m
EL 205m
Summit Storage
Murray River Pumping Station
Hahndorf Dissipator
Mt Bold Reservoir
100 m head difference

Turbine Flow

- Traditionally flows varied from 1-4 m^3/s at through the Dissipator.
- EPANET Modelling
- As turbine flow increases, so does the head losses.

Q (m^3/s)	Δh_T (m)
1.0	108.30
1.5	105.57
2.0	101.92
2.5	97.40
3.0	92.04
3.5	85.86
4.0	78.88

Turbine Power Output

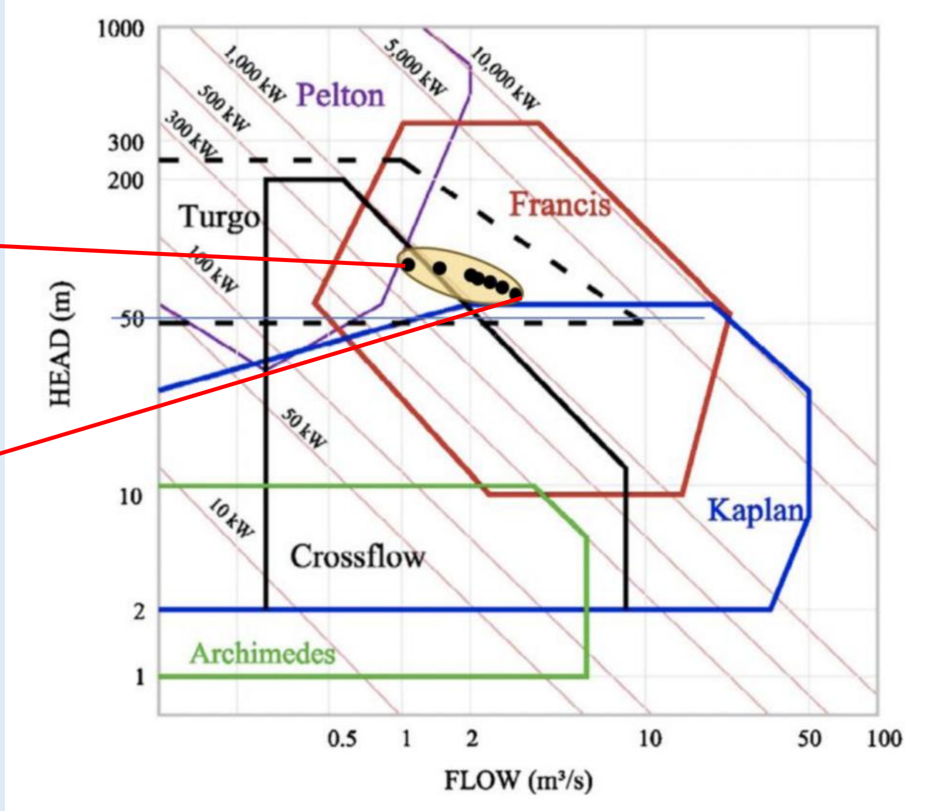
- The bigger the turbine, greater power output
- Power range from 0.9-2.63 MW
- 1 MW = can power 1000 homes!!

Flow Rate (m^3/s)	Flow Rate (L/s)	Turbine Head (m)	Turbine Power (MW)
1.0	1000	108.30	0.90
1.5	1500	105.57	1.32
2.0	2000	101.92	1.70
2.5	2500	97.40	2.03
3.0	3000	92.04	2.30
3.5	3500	85.86	2.51
4.0	4000	78.88	2.63

Turbine Selection

- EPANET computations and (Benzon et al. 2016) to find a range of turbine types.

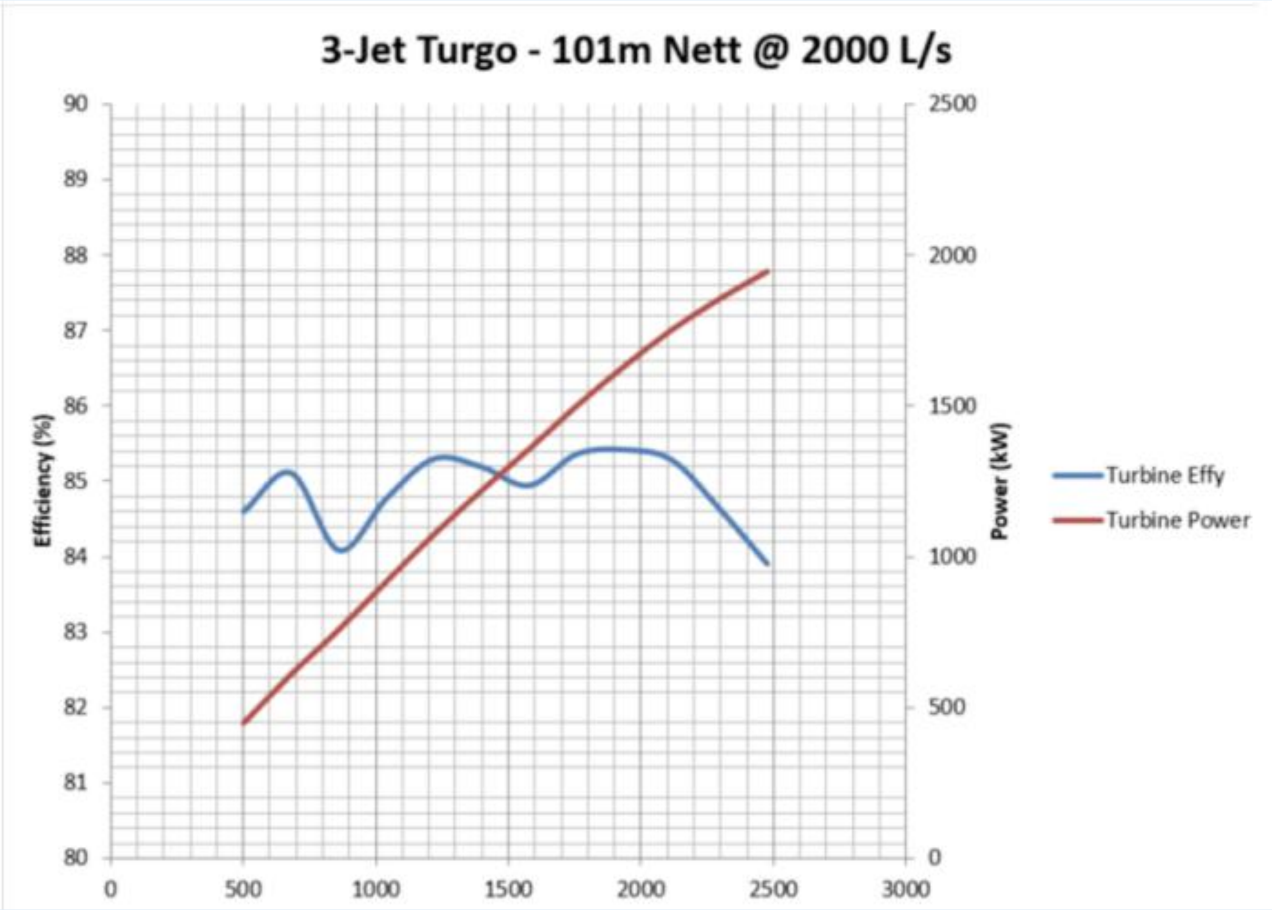
Q (m^3/s)	Δh_T (m)	V (m/s)	H_L (m)
1.0	108.30	0.79	1.44
1.5	105.57	1.18	3.03
2.0	101.92	1.58	5.14
2.5	97.40	1.97	7.75
3.0	92.04	2.37	10.84
3.5	85.86	2.77	14.40
4.0	78.88	3.16	18.43



Selection of Turbine Type

- Research indicated Turgo most suitable due to constant efficiency across varying flows.

- Tamar Hydro deemed 3-jet Turgo most appropriate.



But what size is optimal?

AEMO Electrical Energy Prices

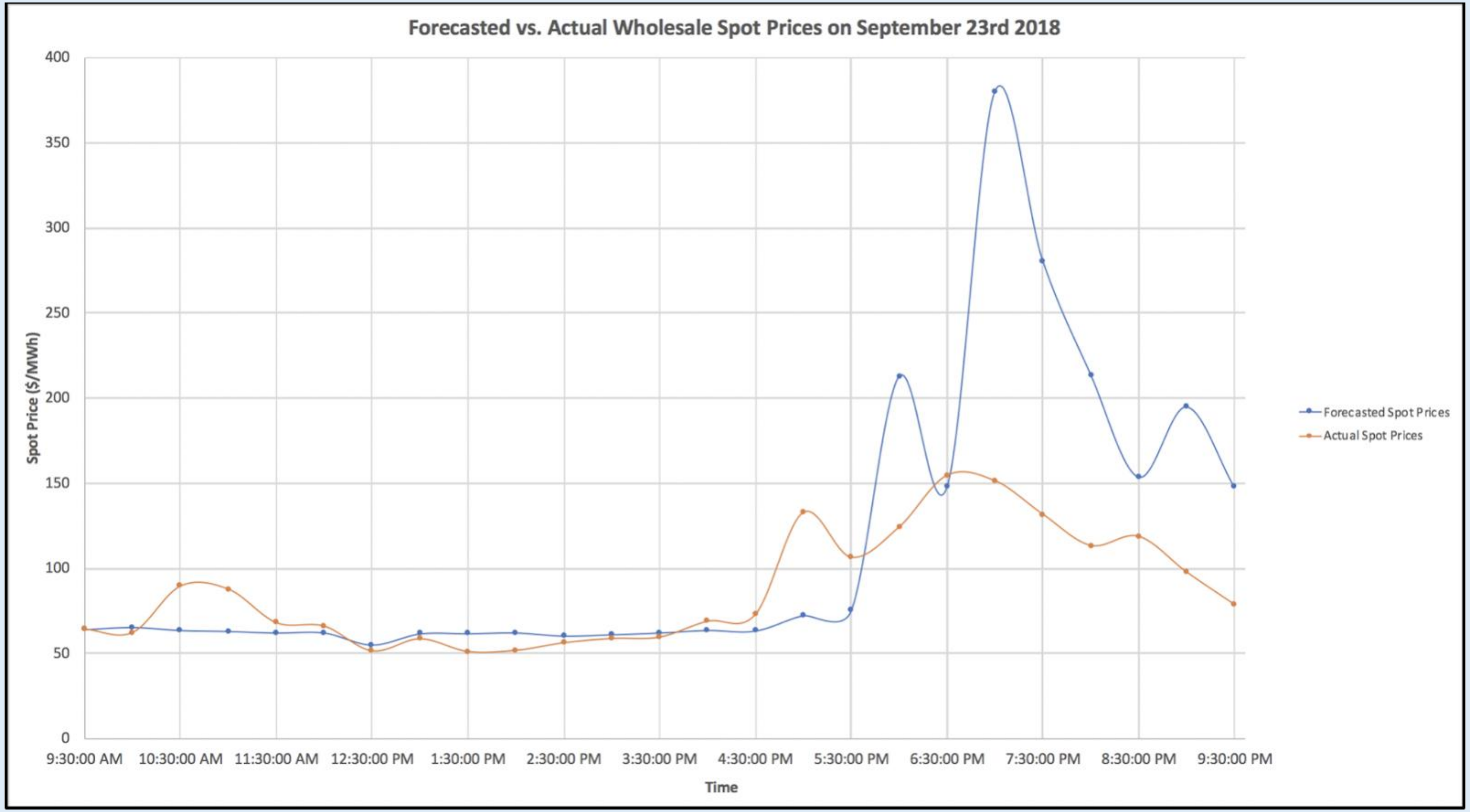
- Provides wholesale price of energy every 30 minutes.
- Prices are capped between -$1000 and $14,000 per MWh.

Energy Consumption Error 2016/17

State	MPE	Comment
New South Wales	1.1%	Good alignment with forecast
Queensland	-0.7%	Good alignment with forecast
South Australia	-1.1%	Good alignment with forecast
Tasmania	-2.5%	Difference driven by lower industrial consumption than forecast
Victoria	-5.0%	Difference explained by Portland smelter load reduction

Down from 2.2% in 2015/16

AEMO Price Prediction Accuracy



- Created 12 hours in advance.
- Shows accuracy decreases with time.
- Energy price order of magnitude is almost **equivalent**.

The Feasibility Scenarios

Scenario 1: The Idealised Returns

- Data - 8 years of historic data utilised (ignoring Millennium Drought years of 2001-2009). (used 2010-2017)
- Assumes operator monitors spot prices throughout the day every 30 minutes.
- Ranks historic daily spot prices from **highest to lowest** and transfers flow.
- Turbine can turn on/off every 10 mins.
- Purpose to use scenarios for NPV analysis.

Fortran Model

Scenario 2: Practical Operations

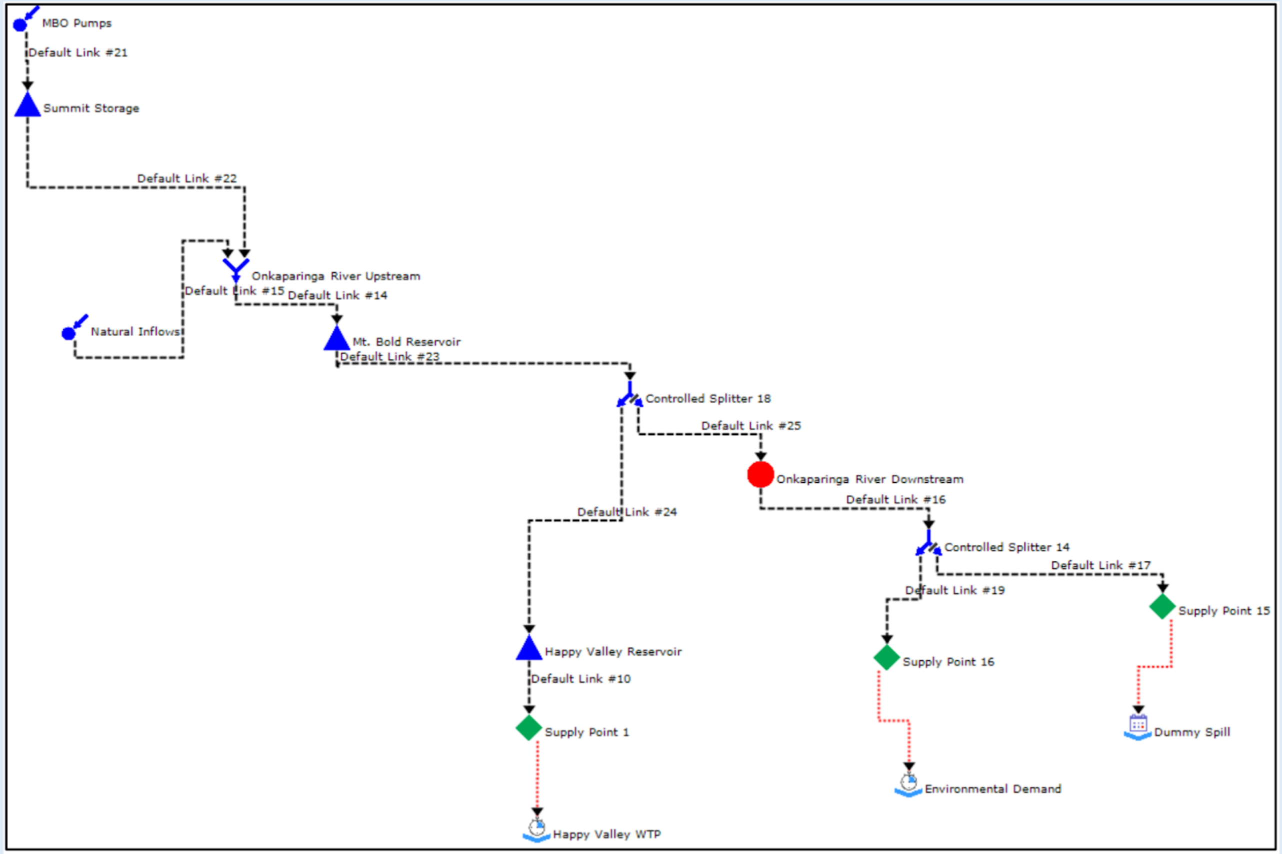
- Frequency analysis over 8 years to find average monthly spot price peaks.
- Assumes that the operator will transfer flow volume in historically known **high priced times.**
- Outside these times, spot prices are ranked (as per scenario 1).
- Water demands aren't realistically known on daily time scale.

Highest AEMO Energy Priced Times						
Period	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
AM	-	-	9:00-10:00	9:00-10:00	-	8:30-10:30
PM	1:00-6:00	1:00-5:30	2:00-5:00	5:30-8:00	6:00-7:30	5:30-9:00
Period	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
AM	8:00-10:30	7:00-9:00	-	-	-	-
PM	6:00-9:00	6:00-8:00	6:00-9:00	4:00-9:00	-	3:00-5:30

Fortran Model

Scenario 3: Maximising Profits

- Is the system optimised for hydropower generation?
- Can flow regulation be altered to earn additional profits subject to environmental and reservoir regulations?
- How will the system cope with an increase in future demand?



Fortran & SOURCE Model

Thinking to the Future

Introduction to Multiple Plausible Future Scenarios

What will most likely affect the feasibility of Mini Hydropower in the near future?

1. An increase in residential rooftop solar power and eventual battery storage installation.

2. An increase in market competition due to public educational programs.

3. Victoria closing baseload power concurrently with South Australia's investment of renewable energy sources.

4. The increase in export rates of natural gas.

5. Instantaneous fluxes in oil trading in the Middle East and Asia.

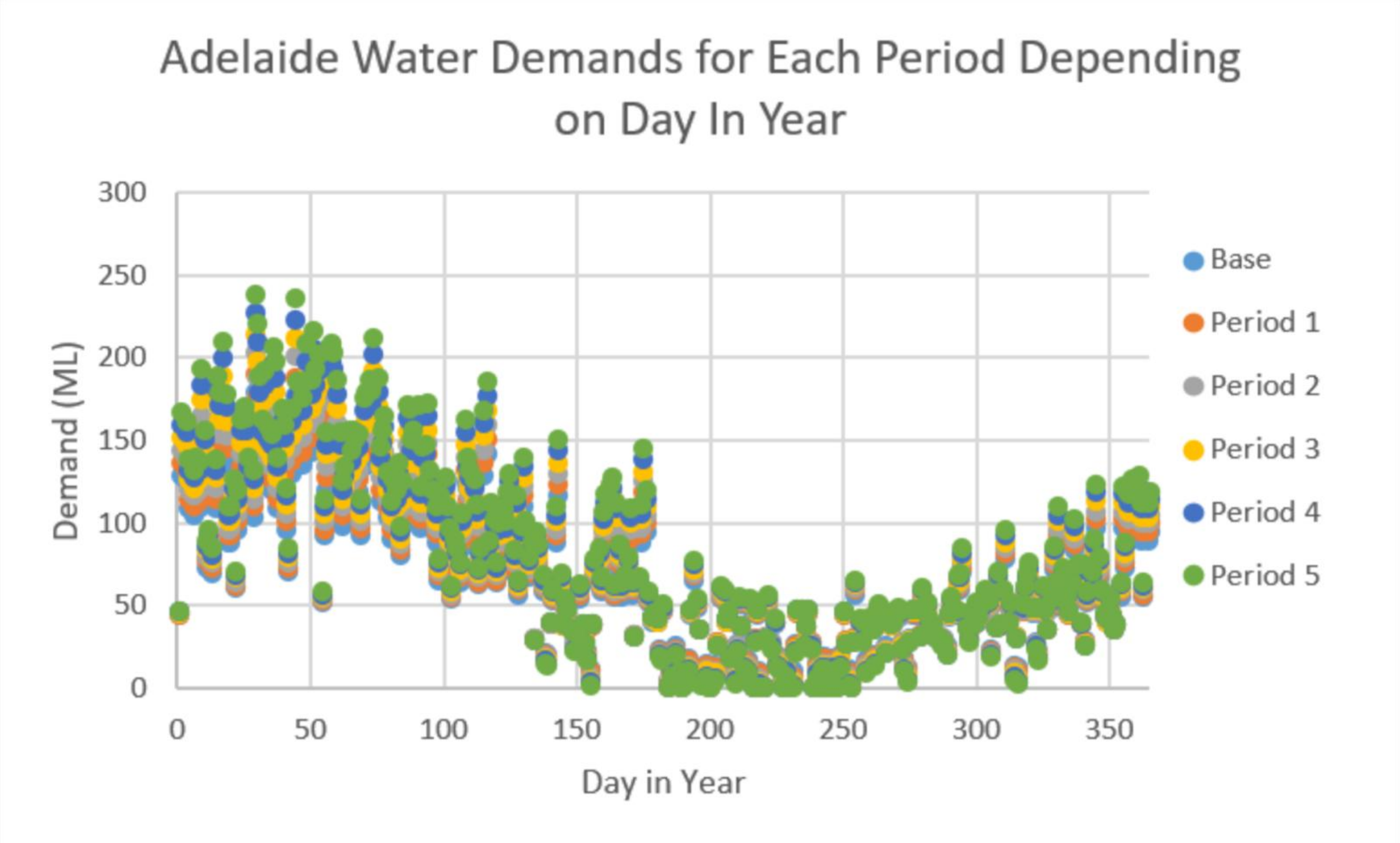
6. Taxes and incentive programs aimed at emissions abatement and renewable investment.

7. Buy back of base load power stations (electricity prices reduce as South Australia becomes less dependent on the Heywood Interconnector with Victoria).

Multiple Plausible Future Scenarios - Demands

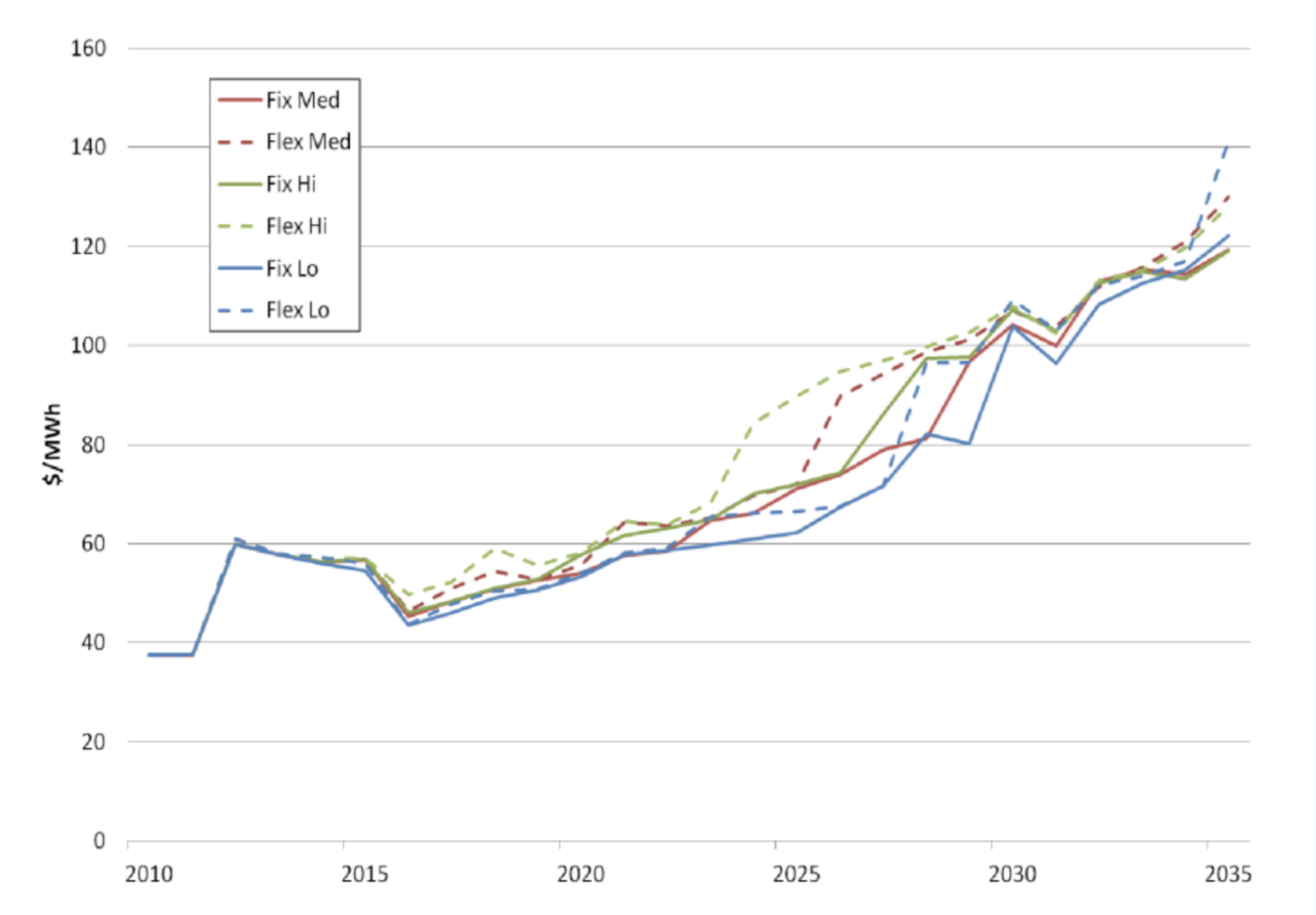
- Changes in Southern Adelaide Water Demands
- Dependent on:
  - Population Change
  - SRES Scenario A2 and B2
  - Water reduction strategies

- Magnitude changes found every 5 years



Multiple Plausible Future Scenarios – AEMO Spot Prices

- Likely changes in spot prices over next 25 years (ARENA)
- Renewable Energy Targets (RETs) expected
- 3 electricity demand cases (Low, medium, high)
- Fixed vs. flexible RETs
- Magnitude changes found every 5 years



Economic Analysis

NPV formula

$$PV = C\sum_{n=1}^{t}\left[\frac{1}{(1+i)^n}\right]$$

Discount Rate (%)	Present Value Factor
0	1
1.4	0.71
2	0.61
4.63	0.32
6	0.23
8	0.15

- 25 year design life of turbine.
- Range of discount rates explored for decision maker.

Turbine Capital Costs

- Maintenance cost = 4% of turbine capital (IRENA 2012)

Maximum Turbine Flow Capacity (m3/s)	Turbine Capital ($)	Annual Operation & Maintenance Cost ($)
1	1,600,000	64,000
1.5	1,900,000	76,000
2	2,200,000	88,000
2.5	2,500,000	100,000
3	2,850,000	114,000
3.5	3,250,000	130,000
4	3,600,000	144,000

Site Capital Costs

- 4.7 million to set up Hahndorf Dissipator site.

SITE CAPITAL COSTS ($)	
Project Construction Costs	
Preliminaries	359,170
Civil Works	492,850
Total	**852,020**
Fees & Allowances	
Construction Industry Training Board Levy	13,664
SAPN Cost	1,690,000
Total	**1,703,664**
Project Delivery Costs	
SAW Internal Direct Costs	98,000
CBD Overheads	150,000
SAW Engineering Direct Costs	61,600
CBD Engineering Overheads	72,000
Procurement	21,863
Operational Support	27,328
Environmental Management Unit	10,931
Total	**441,722**
Design Costs	
Design Review	54,657
Contractor Design	273,285
Engineering Support – Quality & Construction	81,985
Total	**409,927**
Miscellaneous	
Opportunity/Risk Contingency	1,280,602
PCI Insurance	23,279
Total	**1,303,881**
TOTAL SITE CAPITAL	**4,711,214**

Let’s see some results!

Final Results - Scenario 1

Turbine Maximum. Flow Capacity (L/s)								
SCENARIO	**Discount Rate (%)**	1000	1500	2000	2500	3000	3500	4000
Scenario 1	0	**$1,209,263**	**$3,620,258**	**$5,167,345**	**$5,978,736**	**$6,056,951**	**$5,511,385**	**$4,495,804**
	1.4	**-$2,624**	**$1,971,508**	**$3,220,947**	**$3,853,243**	**$3,862,454**	**$3,340,345**	**$2,432,019**
	2	**-$438,186**	**$1,378,934**	**$2,521,395**	**$3,089,322**	**$3,073,732**	**$2,560,054**	**$1,690,277**
	4.63	**-$1,909,692**	**-$623,023**	**$158,025**	**$508,490**	**$409,113**	**-$76,083**	**-$815,629**
	6	**-$2,465,737**	**-$1,379,512**	**-$735,033**	**-$466,741**	**-$597,780**	**-$1,072,213**	**-$1,762,547**
	8	**-$3,100,038**	**-$2,242,467**	**-$1,753,777**	**-$1,579,224**	**-$1,746,379**	**-$2,208,535**	**-$2,842,732**

Final Results - Scenario 2

Turbine Maximum. Flow Capacity (L/s)								
SCENARIO	**Discount Rate (%)**	1000	1500	2000	2500	3000	3500	4000
Scenario 2	0	**$806,486**	**$2,949,962**	**$4,232,236**	**$4,792,959**	**$4,601,589**	**$3,839,776**	**$2,626,548**
	1.4	**-$340,495**	**$1,409,227**	**$2,436,526**	**$2,858,548**	**$2,641,615**	**$1,938,107**	**$863,984**
	2	**-$752,730**	**$855,474**	**$1,791,132**	**$2,163,304**	**$1,937,184**	**$1,254,631**	**$230,503**
	4.63	**-$2,145,426**	**-$1,015,328**	**-$389,268**	**-$185,511**	**-$442,670**	**-$1,054,428**	**-$1,909,651**
	6	**-$2,671,690**	**-$1,722,257**	**-$1,213,187**	**-$1,073,069**	**-$1,341,956**	**-$1,926,963**	**-$2,718,362**
	8	**-$3,272,020**	**-$2,528,677**	**-$2,153,061**	**-$2,085,540**	**-$2,367,806**	**-$2,922,297**	**-$3,640,887**

Final Results - Scenario 3

Turbine Maximum. Flow Capacity (L/s)								
SCENARIO	**Discount Rate (%)**	1000	1500	2000	2500	3000	3500	4000
Scenario 3	0	**$14,247,456**	**-$20,909,060**	**-$65,913,395**	**-$133,677,874**	**-$208,897,694**	**-$317,257,383**	**-$509,169,443**
	1.4	**$10,934,531**	**-$18,605,035**	**-$56,405,496**	**-$113,298,420**	**-$176,453,351**	**-$267,415,890**	**-$428,458,706**
	2	**$9,743,838**	**-$17,776,949**	**-$52,988,274**	**-$105,973,867**	**-$164,792,574**	**-$249,502,426**	**-$399,450,568**
	4.63	**$5,721,193**	**-$14,979,338**	**-$41,443,520**	**-$81,228,571**	**-$125,397,757**	**-$188,983,508**	**-$301,449,360**
	6	**$4,201,138**	**-$13,922,192**	**-$37,081,050**	**-$71,877,948**	**-$110,511,451**	**-$166,114,937**	**-$264,417,179**
	8	**$2,467,154**	**-$12,716,266**	**-$32,104,617**	**-$61,211,346**	**-$93,530,088**	**-$140,027,909**	**-$222,173,193**

Perfect Forecasting Scenarios – Payback Period

Capital Recovery (Years)	
Scenario 1	11.48
Scenario 2	12.43
Scenario 3	7.12 (NA)

Final Results - Future Scenarios

		Turbine Maximum. Flow Capacity (L/s)						
SCENARIO	**Discount Rate (%)**	1000	1500	2000	2500	3000	3500	4000
A2 Low	1.4	$14,996,833	$20,381,480	$23,326,494	$24,445,565	$24,264,165	$23,152,897	$21,392,423
	4.63	$7,936,483	$11,386,574	$13,193,714	$13,793,723	$13,541,961	$12,653,975	$11,355,283
	8	$3,698,377	$5,997,179	$7,134,242	$7,433,701	$7,142,994	$6,392,112	$5,370,418
A2 Medium	1.4	$15,181,299	$20,612,112	$23,582,675	$24,712,252	$24,534,614	$23,420,228	$21,652,674
	4.63	$8,081,720	$11,568,638	$13,396,543	$14,005,484	$13,756,642	$12,866,206	$11,561,660
	8	$3,807,679	$6,134,382	$7,287,331	$7,593,789	$7,305,250	$6,552,523	$5,526,304
A2 High	1.4	$16,057,972	$21,715,397	$24,817,103	$26,006,416	$25,846,145	$24,717,047	$22,911,693
	4.63	$8,698,175	$12,344,223	$14,264,151	$14,915,096	$14,678,278	$13,777,445	$12,446,312
	8	$4,242,363	$6,681,091	$7,898,752	$8,234,797	$7,954,599	$7,194,501	$6,149,538
B2 Low	1.4	$14,484,135	$19,544,256	$22,199,228	$23,124,211	$22,898,443	$21,754,117	$20,075,224
	4.63	$7,626,520	$10,877,773	$12,509,809	$12,991,682	$12,713,346	$11,804,401	$10,562,616
	8	$3,503,395	$5,675,314	$6,702,387	$6,926,188	$6,619,330	$5,854,357	$4,875,648
B2 Medium	1.4	$14,665,974	$19,770,316	$22,449,379	$23,384,715	$23,161,996	$22,014,537	$20,327,809
	4.63	$7,769,338	$11,055,746	$12,707,203	$13,197,567	$12,921,698	$12,010,257	$10,762,217
	8	$3,610,739	$5,809,248	$6,851,119	$7,081,446	$6,776,469	$6,009,600	$5,026,154
B2 High	1.4	$15,524,909	$20,844,490	$23,644,815	$24,634,459	$24,427,252	$23,264,494	$21,539,227
	4.63	$8,373,440	$11,811,072	$13,547,684	$14,076,133	$13,811,122	$12,888,865	$11,613,813
	8	$4,036,820	$6,341,850	$7,443,661	$7,700,753	$7,403,389	$6,628,850	$5,626,425

Final Results - Payback Period (Future Scenarios)

Scenario 1 A2 LOW			
Turbine Size (L/s)	Capital Cost ($)	Annual Revenue ($)	Capital Recovery (Years)
1000	$ 6,311,214.00	$ 1,100,368.32	5.74
1500	$ 6,611,214.00	$ 1,390,444.07	4.75
2000	$ 6,911,214.00	$ 1,562,251.32	4.42
2500	**$ 7,211,214.00**	**$ 1,644,846.51**	**4.38**
3000	$ 7,561,214.00	$ 1,667,508.83	4.53
3500	$ 7,961,214.00	$ 1,649,320.51	4.83
4000	$ 8,311,214.00	$ 1,594,851.74	5.21

Scenario 1 A2 MED			
Turbine Size (L/s)	Capital Cost ($)	Annual Revenue ($)	Capital Recovery (Years)
1000	$ 6,311,214.00	$ 1,108,384.35	5.69
1500	$ 6,611,214.00	$ 1,400,446.77	4.72
2000	$ 6,911,214.00	$ 1,573,338.14	4.39
2500	**$ 7,211,214.00**	**$ 1,656,363.89**	**4.35**
3000	$ 7,561,214.00	$ 1,679,190.79	4.50
3500	$ 7,961,214.00	$ 1,660,866.63	4.79
4000	$ 8,311,214.00	$ 1,606,101.19	5.17

Scenario 1 A2 HIGH			
Turbine Size (L/s)	Capital Cost ($)	Annual Revenue ($)	Capital Recovery (Years)
1000	$ 6,311,214.00	$ 1,149,449.21	5.49
1500	$ 6,611,214.00	$ 1,452,131.84	4.55
2000	$ 6,911,214.00	$ 1,631,170.44	4.24
2500	**$ 7,211,214.00**	**$ 1,716,992.99**	**4.20**
3000	$ 7,561,214.00	$ 1,740,638.87	4.34
3500	$ 7,961,214.00	$ 1,721,627.01	4.62
4000	$ 8,311,214.00	$ 1,665,091.58	4.99

Scenario 1 B2 LOW			
Turbine Size (L/s)	Capital Cost ($)	Annual Revenue ($)	Capital Recovery (Years)
1000	$ 6,311,214.00	$ 1,074,397.03	5.87
1500	$ 6,611,214.00	$ 1,348,125.37	4.90
2000	$ 6,911,214.00	$ 1,505,231.85	4.59
2500	**$ 7,211,214.00**	**$ 1,577,992.35**	**4.57**
3000	$ 7,561,214.00	$ 1,598,415.53	4.73
3500	$ 7,961,214.00	$ 1,578,578.27	5.04
4000	$ 8,311,214.00	$ 1,528,047.59	5.44

Scenario 1 B2 MED			
Turbine Size (L/s)	Capital Cost ($)	Annual Revenue ($)	Capital Recovery (Years)
1000	$ 6,311,214.00	$ 1,082,312.99	5.83
1500	$ 6,611,214.00	$ 1,357,949.27	4.87
2000	$ 6,911,214.00	$ 1,516,084.50	4.56
2500	**$ 7,211,214.00**	**$ 1,589,281.26**	**4.54**
3000	$ 7,561,214.00	$ 1,609,834.11	4.70
3500	$ 7,961,214.00	$ 1,589,861.80	5.01
4000	$ 8,311,214.00	$ 1,538,994.17	5.40

Scenario 1 B2 HIGH			
Turbine Size (L/s)	Capital Cost ($)	Annual Revenue ($)	Capital Recovery (Years)
1000	$ 6,311,214.00	$ 1,122,544.23	5.62
1500	$ 6,611,214.00	$ 1,408,265.68	4.69
2000	$ 6,911,214.00	$ 1,572,083.32	4.40
2500	**$ 7,211,214.00**	**$ 1,647,826.31**	**4.38**
3000	$ 7,561,214.00	$ 1,669,107.06	4.53
3500	$ 7,961,214.00	$ 1,648,419.71	4.83
4000	$ 8,311,214.00	$ 1,595,744.56	5.21

Conclusions…