Australian National University

Development of a Cost Model for Pumped Hydro Energy Storage

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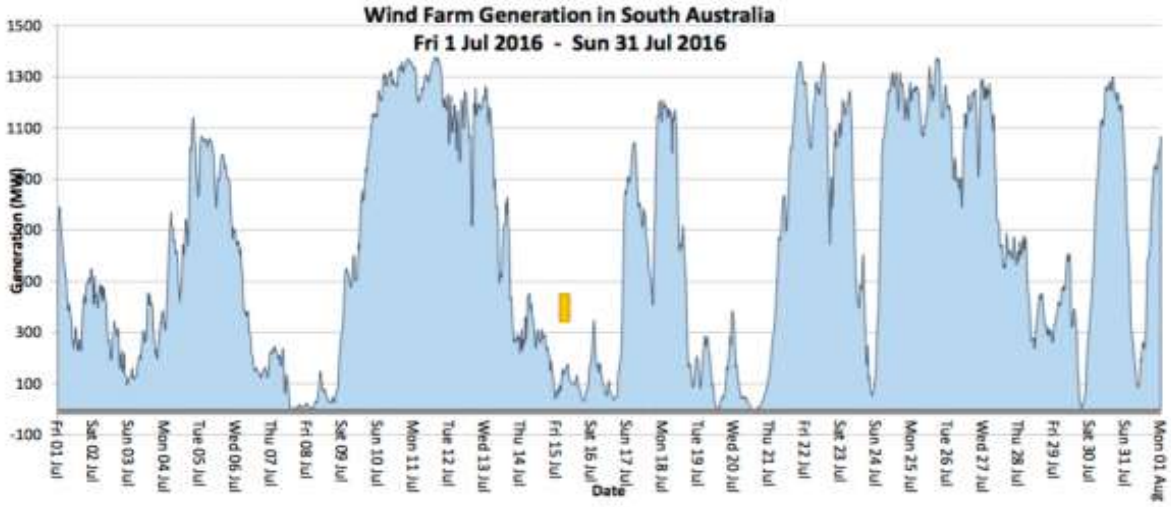
https://re100.eng.anu.edu.au

Intermittent Renewables



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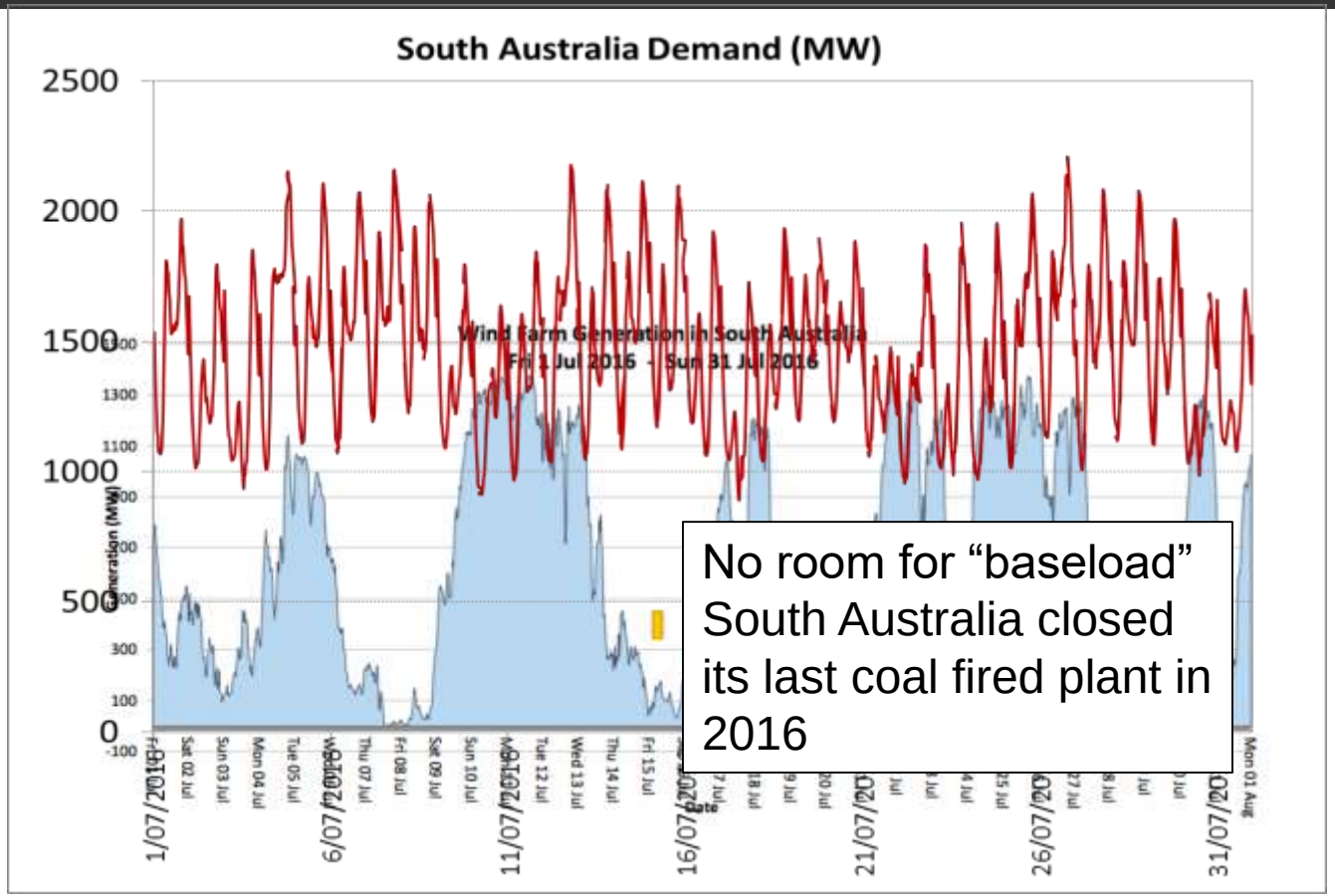
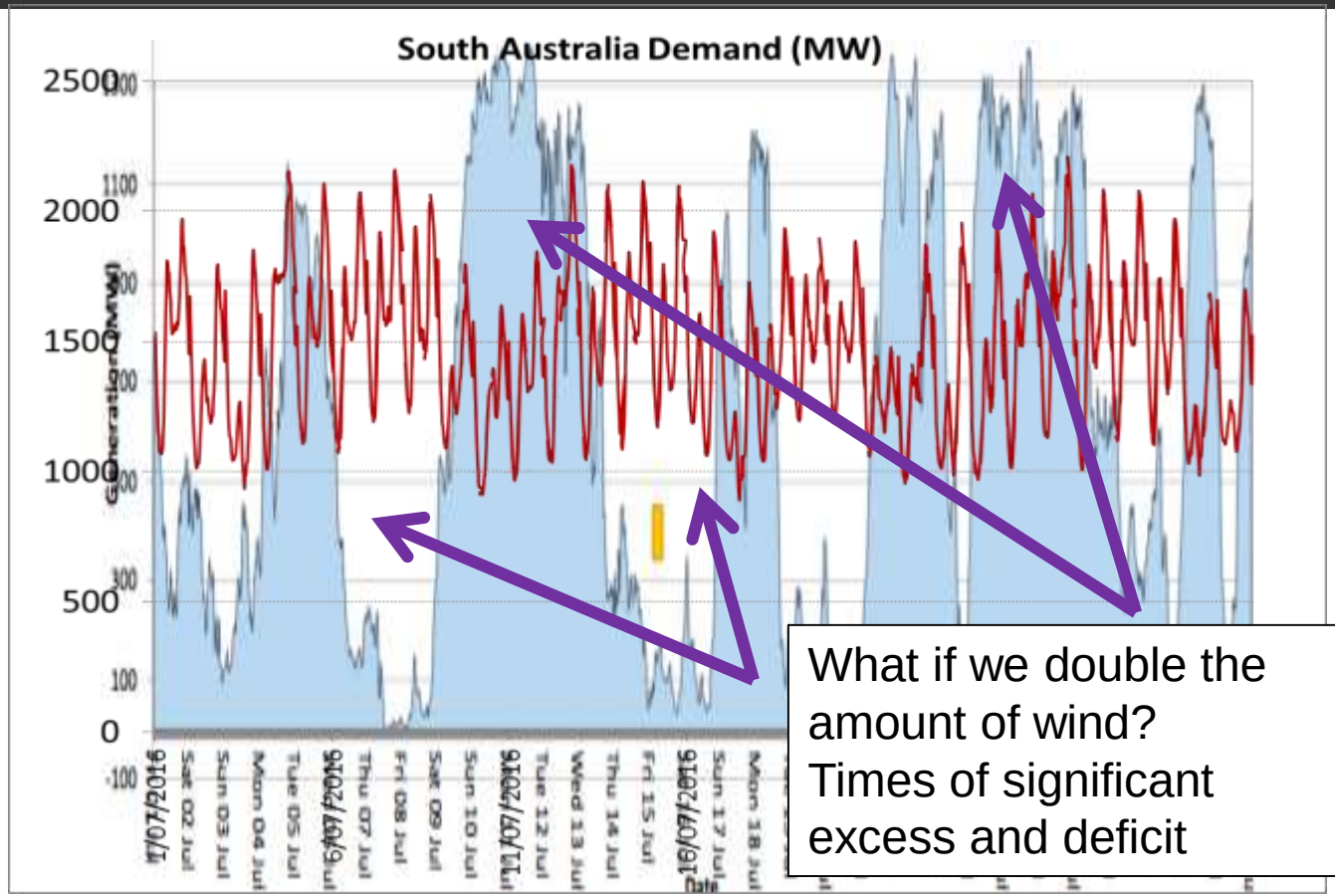
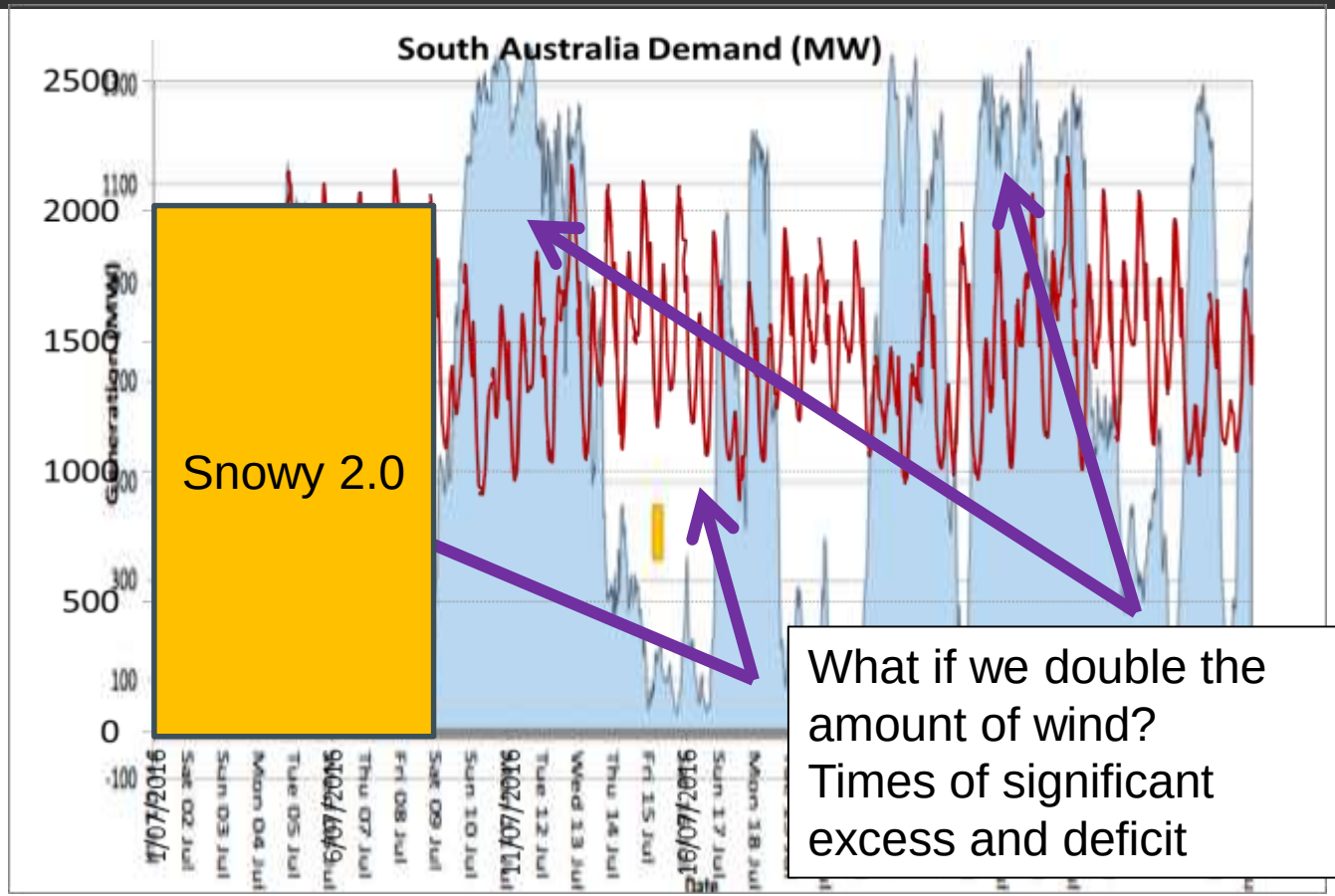


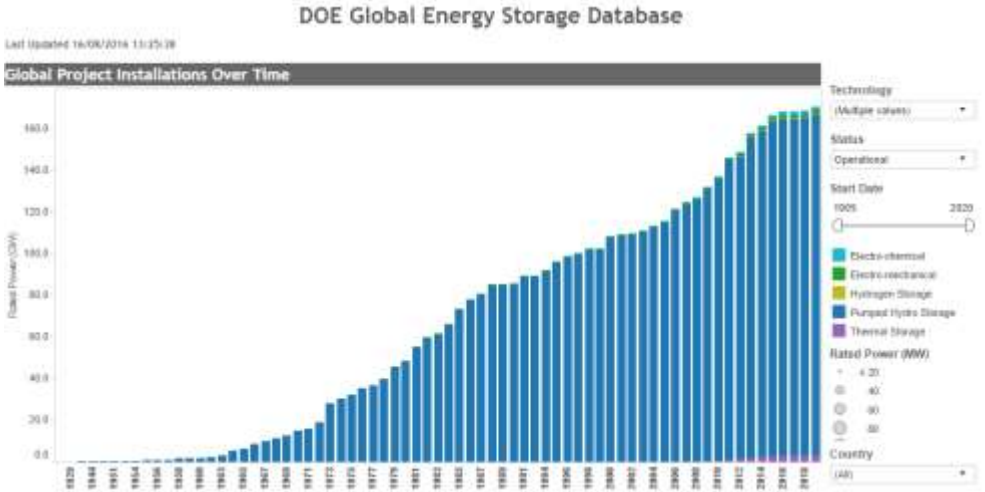
No room for “baseload”
South Australia closed its last coal fired plant in 2016


South Australia Demand (MW)
2500
2000
1500
1000
500
0
-100
Generation (MW)
What if we double the amount of wind?
Times of significant excess and deficit


South Australia Demand (MW)
2500
2000
1500
1000
500
0
Snowy 2.0
What if we double the amount of wind?
Times of significant excess and deficit

Pumped hydro storage

- Established, dominant technology
- Lowest cost for bulk energy storage
- Complementary to batteries (power vs energy)



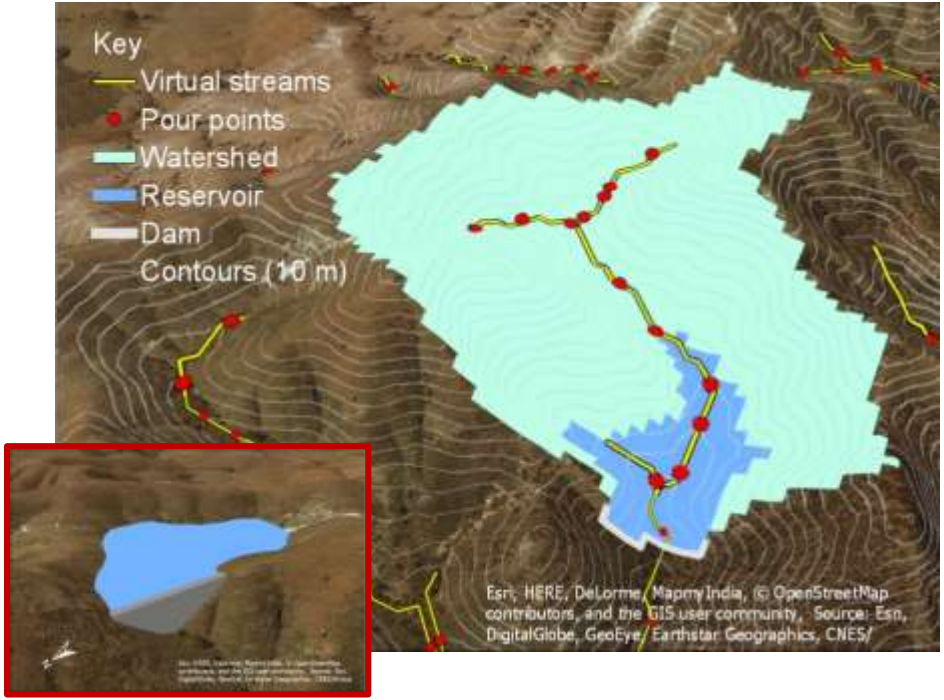
Site searching

Identify reservoirs locations

- Model watershed
- Simulate 10-80m dams
- Identify locations with >1GL of storage (~1GWh)

Key information recorded

- Reservoir volume and area, dam line and volume, reservoir shape file, etc



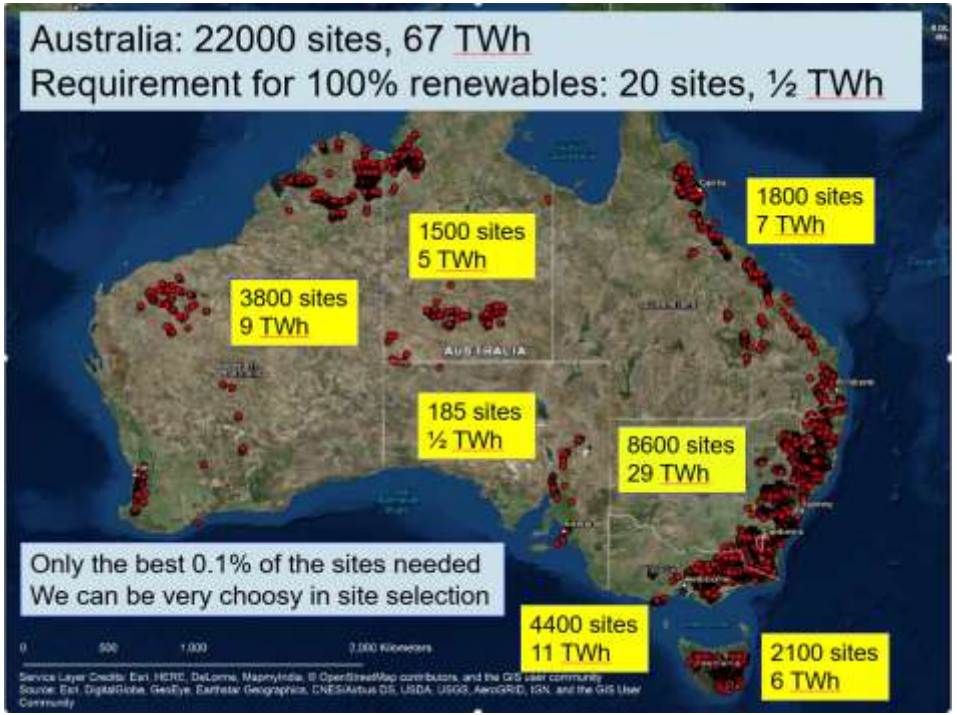
Search results

22,000 upper reservoir locations identified

- >>100x more storage identified than required to meet 100% renewable electrical grid

Which are best?

Cost model to rank best sites



Is this a good site?

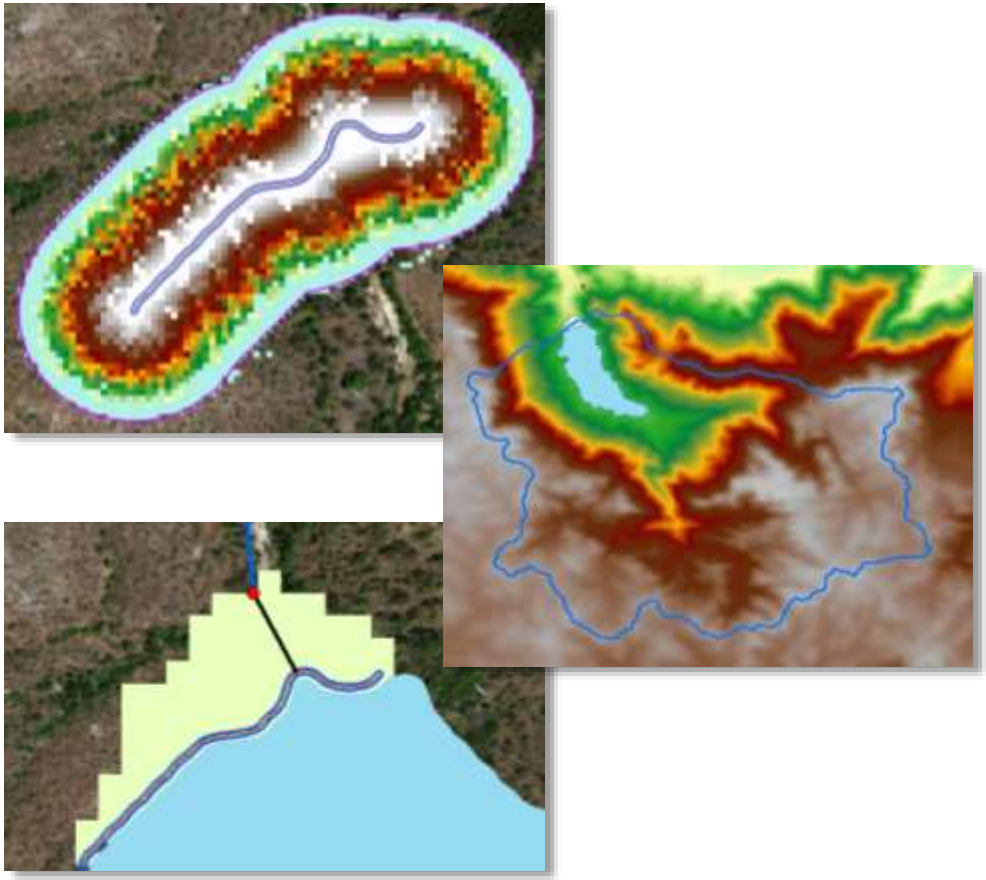
Why develop a cost model?

- A prefeasibility tool for identifying better potential sites
- Developed by experience hydro engineers, not academics
- Based on “vanilla” sites – if a site is geologically or environmentally difficult, move to another site
- Enables ranking of sites within regions
- **It’s not** a detailed design tool – engineering consultancies will still be necessary to progress projects
- **It’s not** a site evaluation tool – geological testing, environment assessments, local approvals, etc are out of scope

Reservoir

Energy storage cost $/kWh

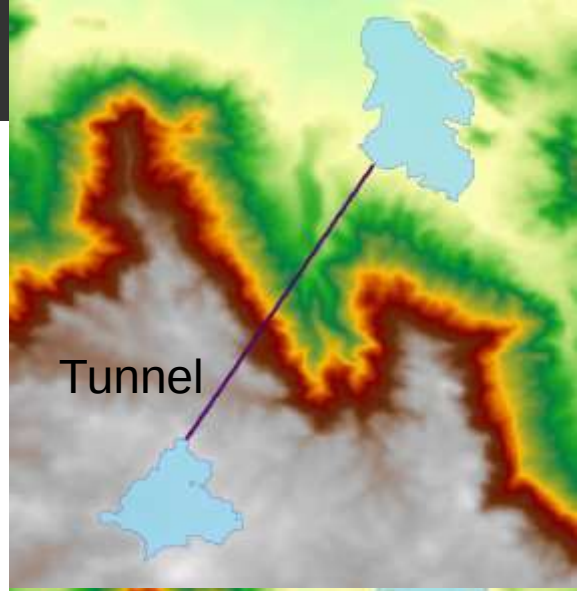
- Spatial model used to determine volume of dam wall (usually dominant cost)
- Catchment area and local rainfall used to determine spillway characteristics

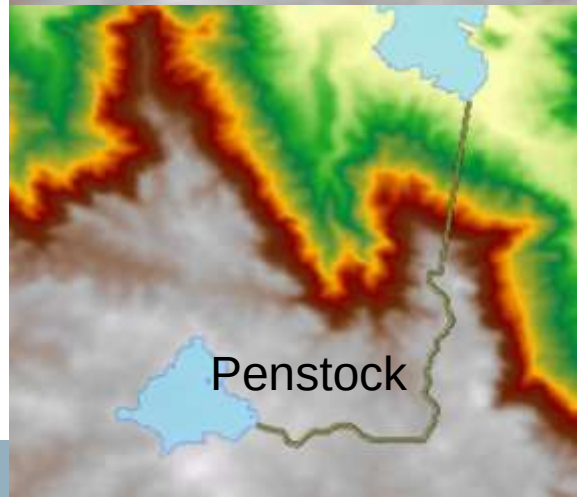


Water convenyance

Connection of the reservoirs largest power variable ($/kW)

- Tunnel
  - Nearest to nearest point
  - Vertical shaft
- Penstock (pipe)
  - Follow contour (cheaper low pressure pipe)
  - Minimise high pressure (straight to nearest point)
- Hybrid blend

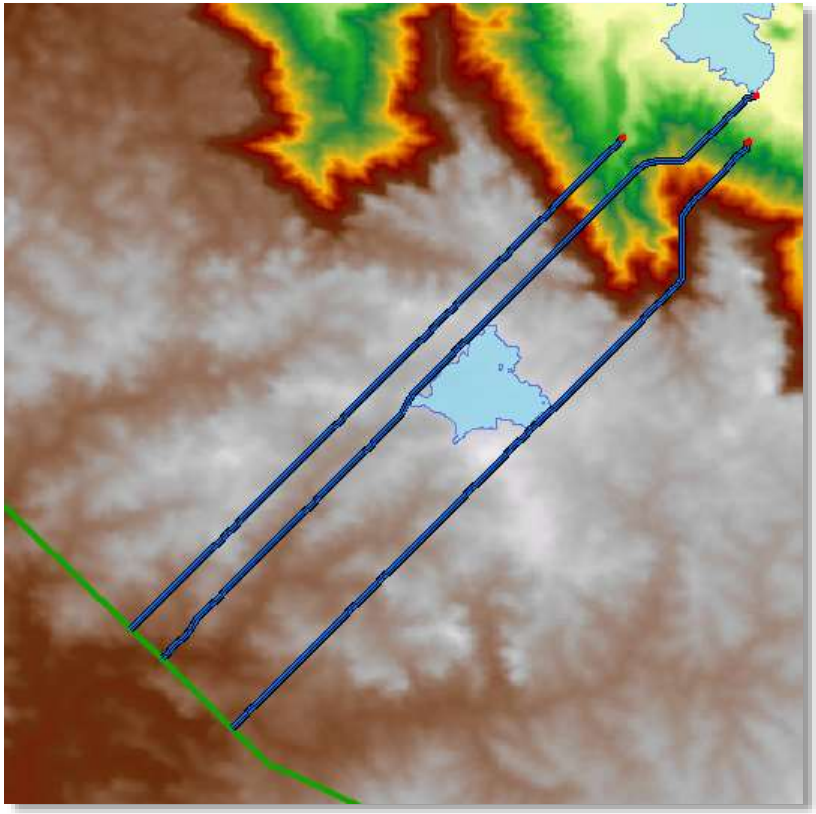




Powerhouse

Relatively fixed costs ($/kW)

- Powerhouse
  - Below lower reservoir for pumping
- Pump/turbine
- Motor/generator
- Switchyard
- Transmission lines/roads
  - Nearest suitable connection point (biggest variable)



Costing

- Spatial data transferred to “Beta” model spreadsheet
- Costing parameters developed by experienced hydro engineers
- Detailed breakdown of scheme costs

PHESCEM

Scheme Summary

Reservoir Pair Detail

Upper Reservoir	S19E145_41		
Lower Reservoir	S19E146_616		
Costs	**Penstock Option**	**Tunnel Option**	**Hybrid Option**
Total Construction Cost	$ 3,915,352,000	$ 3,575,360,000	$ 3,680,986,000
Cost per kWH	$ 126	$ 115	$ 118

Cost of Energy Storage Breakdown

	Penstock Option	Tunnel Option	Hybrid Option	
Design Plant Output	800	800	800	MW
Cost per kW Power Output	**$ 4,894**	**$ 4,469**	**$ 4,601**	**/kW**
Estimated Energy Storage	31	31	31	GWh
Cost per kWh	$ 126	$ 115	$ 118	/kWh
Hours of Storage	32	32	32	hrs
Energy Component Cost	$ 105	$ 102	$ 104	/kWh
Power Component Cost	$ 1,508	$ 1,155	$ 1,225	/kW

Construction Cost Summary		**Penstock Option**	**Tunnel Option**	**Hybrid Option**	**Penstock Option**	**Tunnel Option**	**Hybrid Option**
Use Case	Component	Direct Cost	Direct Cost	Direct Cost	% of Total Direct Cost	% of Total Direct Cost	% of Total Direct Cost
UC6B	**Power House**	**$ 398,769,000**	**$ 399,660,000**	**$ 398,769,000**	**14.2%**	**15.5%**	**15.1%**
	Civil Works	$ 109,637,000	$ 110,528,000	$ 109,637,000	3.9%	4.3%	4.1%
	Mechanical Works	$ 206,523,000	$ 206,523,000	$ 206,523,000	7.3%	8.0%	7.8%
	Electrical, Instrumentation & Control Works	$ 82,609,000	$ 82,609,000	$ 82,609,000	2.9%	3.2%	3.1%
UC7B	**Conveyance System**	**$ 383,614,000**	**$ 180,134,000**	**$ 221,226,000**	**13.6%**	**7.0%**	**8.4%**
	Civil Works	$ 381,718,000	$ 178,238,000	$ 219,330,000	13.6%	6.9%	8.3%
	Mechanical	$ 1,896,000	$ 1,896,000	$ 1,896,000	0.1%	0.1%	0.1%
UC8B	**Upper Reservoir**	**$ 1,459,016,000**	**$ 1,417,060,000**	**$ 1,459,016,000**	**51.8%**	**55.1%**	**55.1%**
	Clay Core Rockfill	$ 1,437,079,000	$ 1,395,123,000	$ 1,437,079,000	51.0%	54.2%	54.3%
	Spillway and Stilling Basin	$ 21,937,000	$ 21,937,000	$ 21,937,000	0.8%	0.9%	0.8%
UC9B	**Lower Reservoir**	**$ 332,144,000**	**$ 332,960,000**	**$ 326,333,000**	**11.8%**	**12.9%**	**12.3%**
	Clay Core Rockfill	$ 302,233,000	$ 303,049,000	$ 296,422,000	10.7%	11.8%	11.2%
	Spillway and Stilling Basin	$ 29,911,000	$ 29,911,000	$ 29,911,000	1.1%	1.2%	1.1%
UC10B	**Transmission**	**$ 76,588,000**	**$ 76,664,000**	**$ 76,230,000**	**2.7%**	**3.0%**	**2.9%**
UC11B	**Road**	**$ 9,103,000**	**$ 8,158,000**	**$ 9,052,000**	**0.3%**	**0.3%**	**0.3%**
UC12B	**Water Supply**	**$ 157,566,000**	**$ 157,566,000**	**$ 157,566,000**	**5.6%**	**6.1%**	**5.9%**

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Construction Cost Summary

Tunnel lowest cost

Total costs dominated by upper reservoir

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What next?

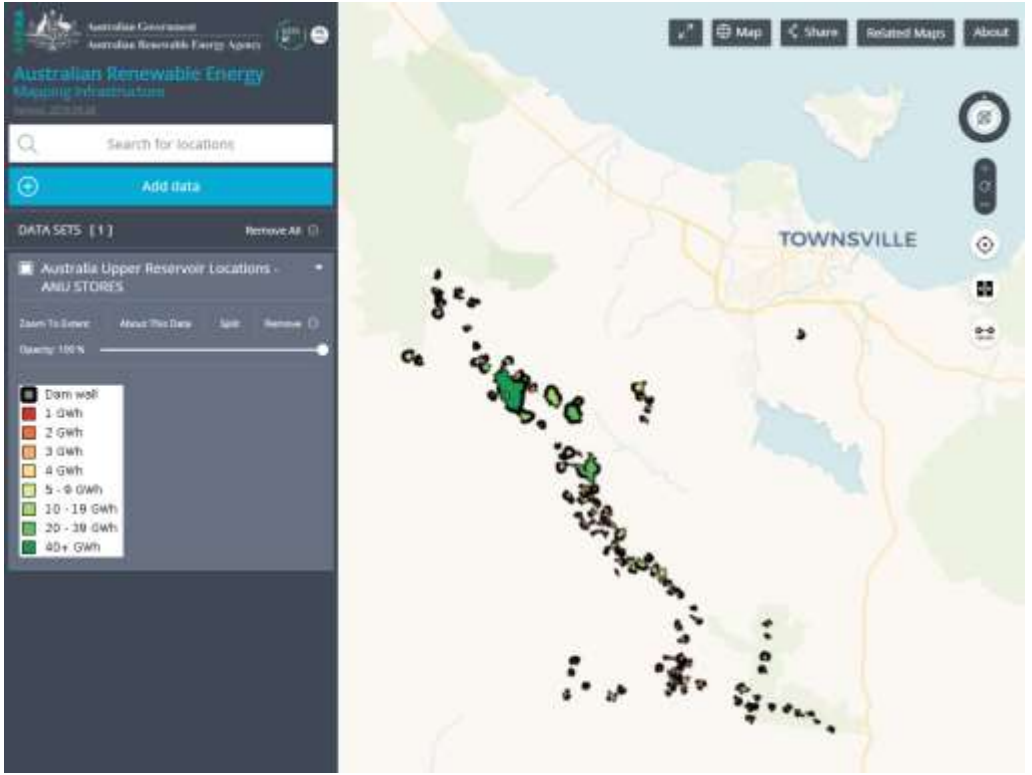
Current process manual

- site by site input

Automation needed for all sites

- Info presented in publically accessible database e.g. AREMI

Had discussions with ARENA for funding of this stage



Conclusion

- More pumped hydro sites available than needed for 100%
- Cost model enables better sites to be distinguished
- Further development needed for easy to use tool for widespread public use

Acknowledgments

- Thanks to ARENA for funding STORES project
- Black and Veatch and GHD for spatial model development and engineering costings