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Pumped Hydro Using the Downstream River Channel for Time Shifting Storage

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Abstract

The surge of Renewable Energy (RE) and particularly Solar PV in the journey to replace fossil fuels, is producing excess energy that is way more than the demand on sunny days. The visible network demand too is getting reduced by behind the meter installed residential PV. This is leading to energy prices approaching close to zero and even negative in sunny parts of the day.The lack of demand is leading to widespread curtailment of RE. This near free energy is creating opportunities for lower round trip efficiency storage options. Pumped hydro energy storage(PHES) operates between two reservoirs by pumping from lower to the higher reservoir when energy is cheap, to store gravitational energy and allows water to flow down from higher to lower through a turbine to dispatch the stored energy during peak demand. Freshwater PHES traditionally offered 80 to 90% efficiency, though seawater PHES can be as low as 72% if the sea is 3 to 4 km away from the dam. Market share of PHES is still around 95% of energy storage in 2019. However there are not enough sites available to scale PHES by 10 times to meet the projected demand to 2040. Building new dams or boring long tunnels is expensive and the low cost sites are already developed and water is scarce globally especially inland. All of which makes it very difficult to use conventional PHES to meet the urgent new large (over 1000GW) global energy storage requirements necessary to firm Renewable Energy sources.

This paper examines the existing river channel downstream of existing dams, as the potential free lower reservoir. Water from the dam is allowed to dispatch energy by installing hydro turbines or using existing hydro turbines. The water flows down stream at rates around 0.5 to 1m/s causing it to take several hours to flow down 10km to 30km. A suitable point is found where the river meanders back towards the dam and the straight-line distance is shorter. Water is pumped back from such downstream location(s) back into the dam using close to zero or negative cost(a revenue opportunity) RE. The low cost of the energy used for pumping up say between -1000 and 10$/MWH makes it viable to operate such river channel based pumped hydro even if the round trip percentage efficiency is only in the high 50s. We modelled the Burrinjuck Dam and the Murrumbidgee river down stream of the dam, to find a 1210MWH daily storage opportunity offering a round trip efficiency of 58% using only 7GL (7%) of the 1026GL capacity of the dam. This means the PHES operation can continue even, if in the dry years the dam is only 30% full(300GL). We believe such a river channel based PHES is possible in most existing dams all over the world unlocking a new massive potential for PHES, to ease the transition to renewables at an affordable cost. This could be the missing piece of the puzzle.

Disciplines

Engineering | Science and Technology Studies

Publication Details

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Pumped Hydro using the downstream river channel for time shifting storage

Dr Saugato Mukerji and AProf Peter Gibson

Presented at All Energy Australia 2019, Melbourne 24 Oct 2019

This is a new opportunity has emerged in the last 5 years due to the surge in RE and the Ducks Curve

- Mid day on sunny days energy is in excess and network demand is well below supply leading to very low or negative whole sale prices.
- This is matched by a supply shortage caused by absence of Solar in the evening and normal rise in demand. The shortage causes higher peak prices. Peaking gas turbines meet the shortfall at a higher cost
- **The new opportunity is to buy likely to curtailed power, to store enormous amounts of energy at a low cost using existing infrastructure, and deliver it reliably in the peak price period .**
- A low round trip efficiency of even 50% may be acceptable if say 2000 MWH can be delivered reliably between 5 and 8 pm everyday now or in future at anytime between sunset to sunrise, as fossil plants retire.

A River Channel is a Virtual Dam

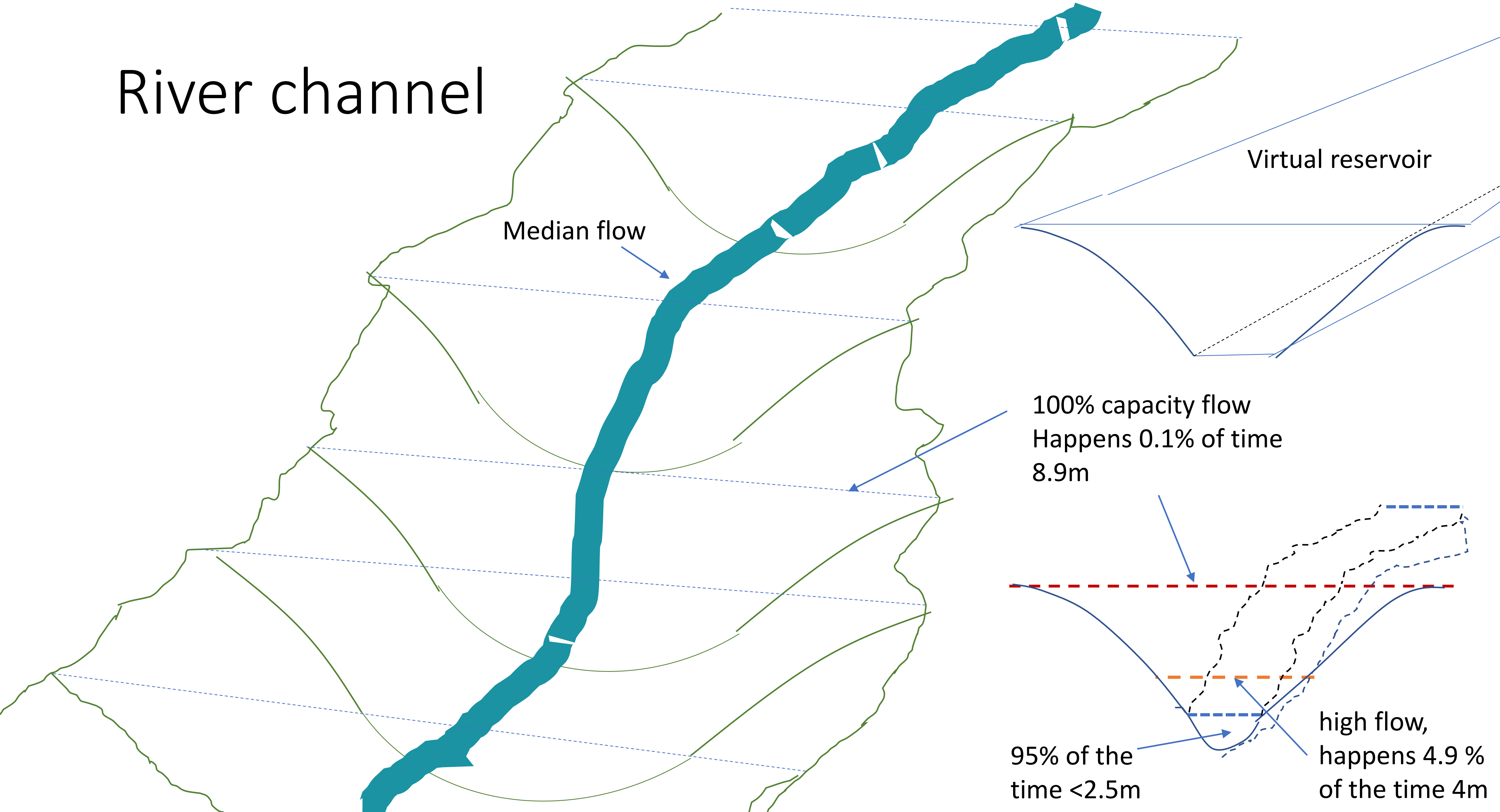
- Pumped Hydro needs 2 reservoirs at an elevation difference
- The easy lower cost pumped hydro sites are already developed.
- There is only one Snowy 2 on mainland Australia and building it is not cheap(AUD7B ? And rising)
- **There is a virtual 2nd reservoir in the every river channel if the first reservoir is the existing Dam.**

Almost every dam in the world can use the downstream channel for pumped hydro energy storage

Almost every dam in the world can become a pumped hydro without building a 2nd dam. Here are three global examples one of which is in NSW Australia:

- Burrinjuck dam and the Murrumbidgee river, NSW Australia
- Aswan High dam and the Nile river, Egypt
- Grand Coulee Dam on the Columbia River, WA USA

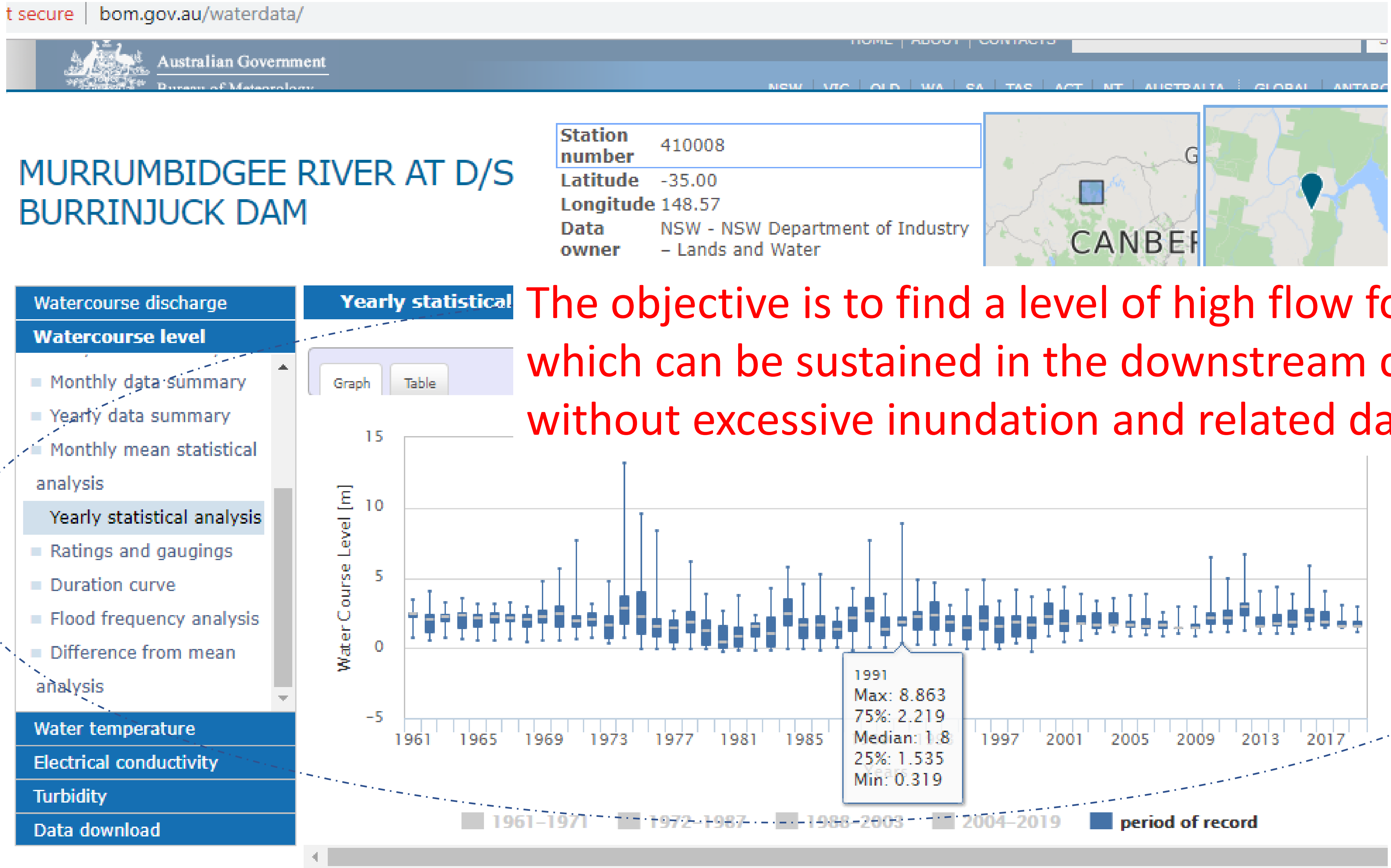
River channel



River channels carry the once in a decade peak flow but median flow can be 1000 times less

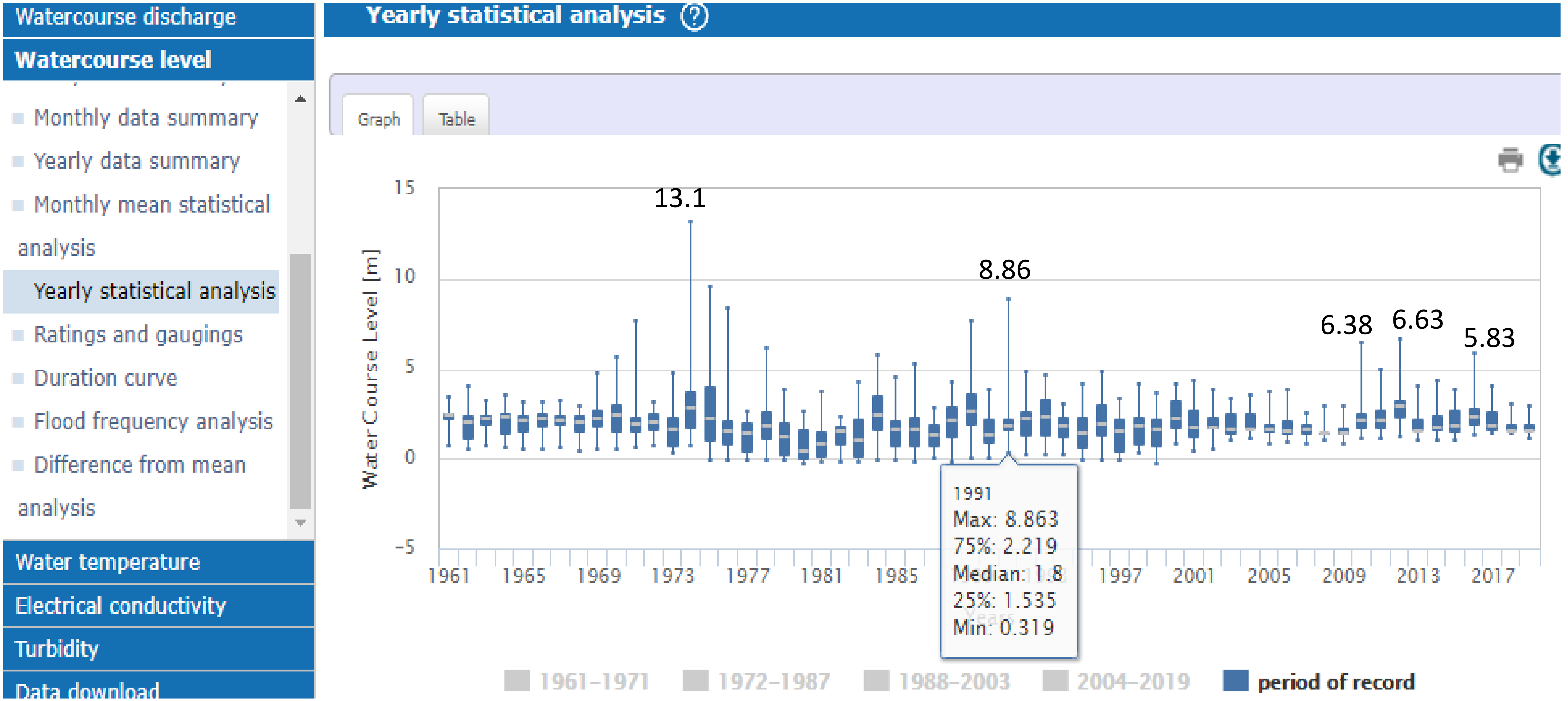
- In the upper reaches (typically 0 to 15km) of the down stream channel, the peak flow is mainly managed by rise in level and velocity of flow and is contained in the channel and its adjacent sides that rise from the channel
- The upper reaches of the river channel can therefore be treated like an empty container for 95% of the time.
- In the wet season the river channel gets partially filled in most years and this only happens for a few days. For just 0.1% of the time in a decade, does the channel get filled to 100% of capacity.
- Once the river reaches the plains the peak flow spreads into the flood plain and can span several kilometers.

5 point summary water depth in meters (min, Q1, median,Q3,max)

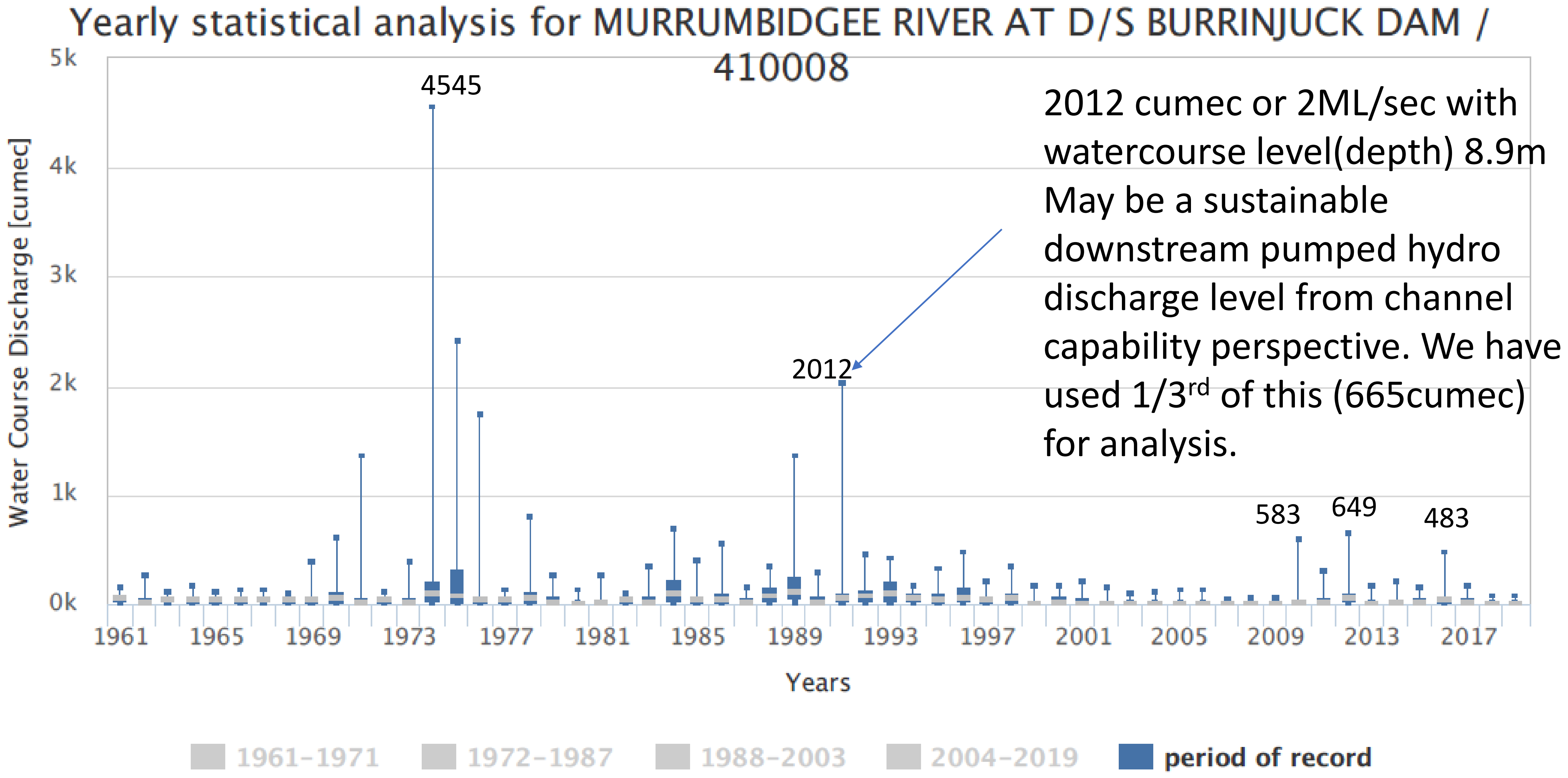


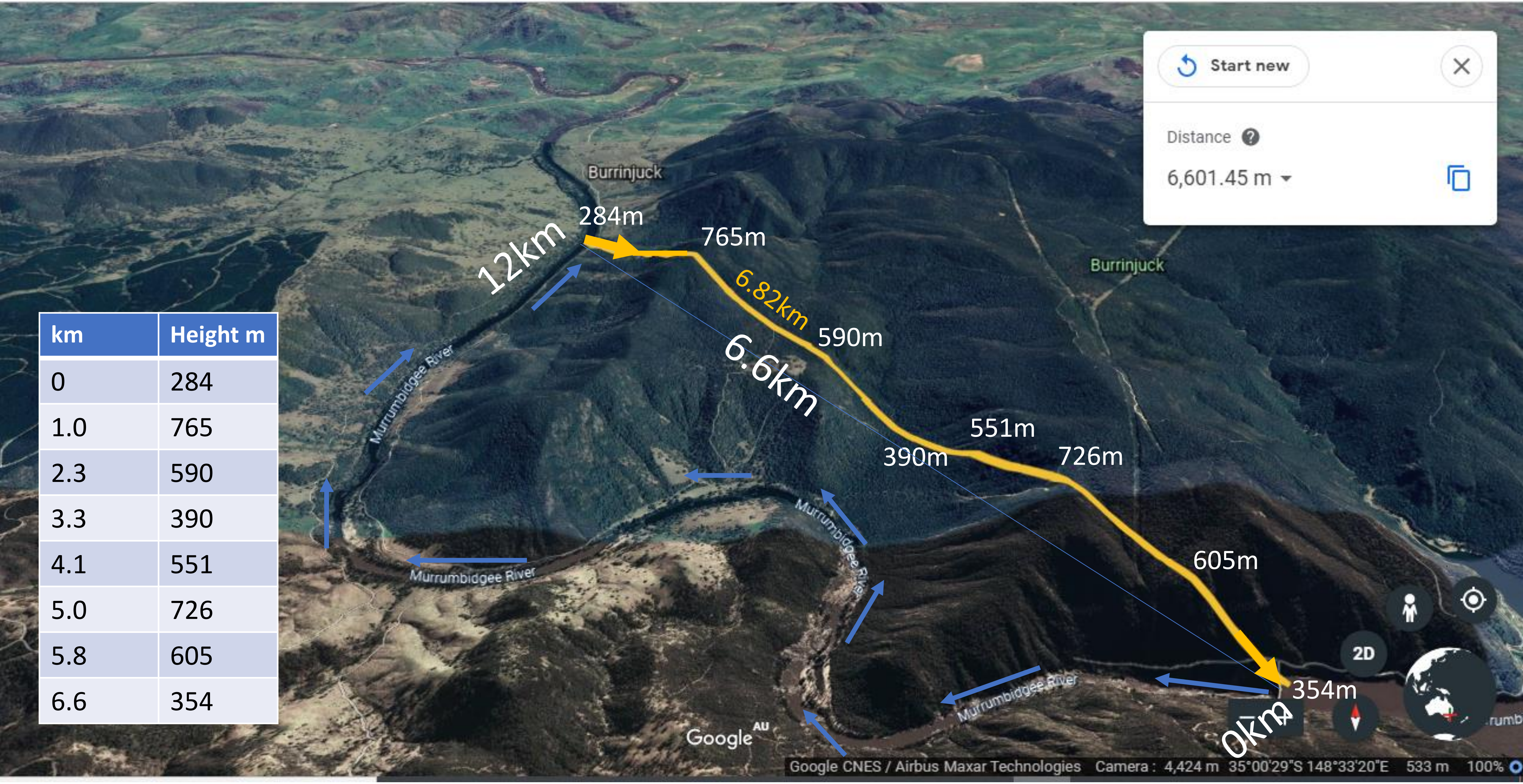
The objective is to find a level of high flow for hydro which can be sustained in the downstream channel without excessive inundation and related damage

5 point summary water depth in meters (min, Q1, median,Q3,max)



5 point summary of discharge cumec (m^3/sec) (min, Q1, median,Q3,max)





km	Height m
0	284
1.0	765
2.3	590
3.3	390
4.1	551
5.0	726
5.8	605
6.6	354

Storage potential of channel : Dam to 12km down stream of Burrinjuck

Average channel width 65m (Estimated using Google Earth)

Height of channel assumed 6m (flows ~600m^3/s occurred 3 times since 2010 at 6m)

Length 12km (12000m)

Channel volume for assuming rectangular = 12000 x 65 x 6 = 4,680,000m^3
= 4,680,000kL = 4,680ML = 4.68GL

Volume corrected for actual shape = 7.080GL **(Area of CS = 590m^2 at 6m channel depth)**

Hydro Dispatchable MWH
= 95% x 7,080,000 x 1000 x 9.8 x 60 ÷ 1000,000 ÷3600 ≈1100MWH

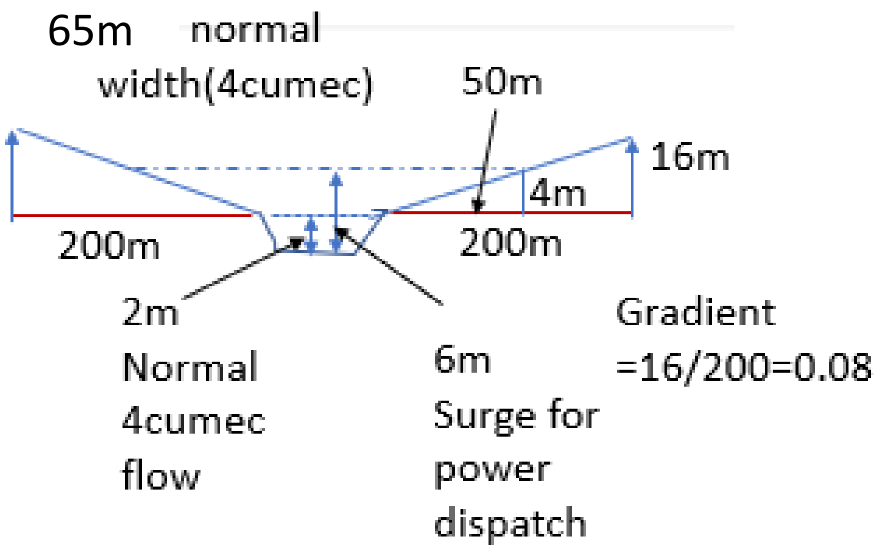
Estimated Run of river for 30m drop to 12km downstream of dam(20% of Hydro) =110MWH

Total dispatchable potential = 1100 +110 = 1210MWH (3h x 403MW)

Flow calculation assuming 3 hours dispatch during peak demand

Q flow in cumec (m^3/s) = 7,080,000÷(3x3600) = 655 cumec (m^3/s)

Assuming 65 m avg channel width
uniform slope 16/200= 0.08 and 6m channel depth
Average area of cross section
= (6 x 65 + 2 x 0.5 x 4 x 50) = **590m^2**
Volume of 12km channel= 12000 x 590
= 7,080,000m^3 = 7080ML ≈ 7GL



Flow rate in cumec(m^3/s)
Q = Area of cross section of channel (m^2) x velocity of water (m/s)

velocity of water (m/s) = 655÷590 = 1.11 m/s (if W1 =50+50+65=165, W2=192)

(actual velocity is slower by v= $\left(\frac{gSQ}{C_D W}\right)^{\frac{1}{3}}$ $\frac{v2}{v1} = \left(\frac{pW1}{W2}\right)^{1/3}$ $v2$= $1.11\left(0.4 \times \frac{165}{192}\right)^{1/3}$ = 0.777m/s p=$\frac{S_2}{C_{D2}} \times \frac{C_{D1}}{S_1}$ $let CD_1/\ C_{D2}$=0.8
S_2/S_1=½ so p=0.5 × 0.8 = 0.4

Storage time to travel 12km downstream and fill the river channel

Without slowing down the flow by artificial means the time taken to reach 12km is

Time = 12000m ÷ 0.777m/s ÷3600 = 4.29h

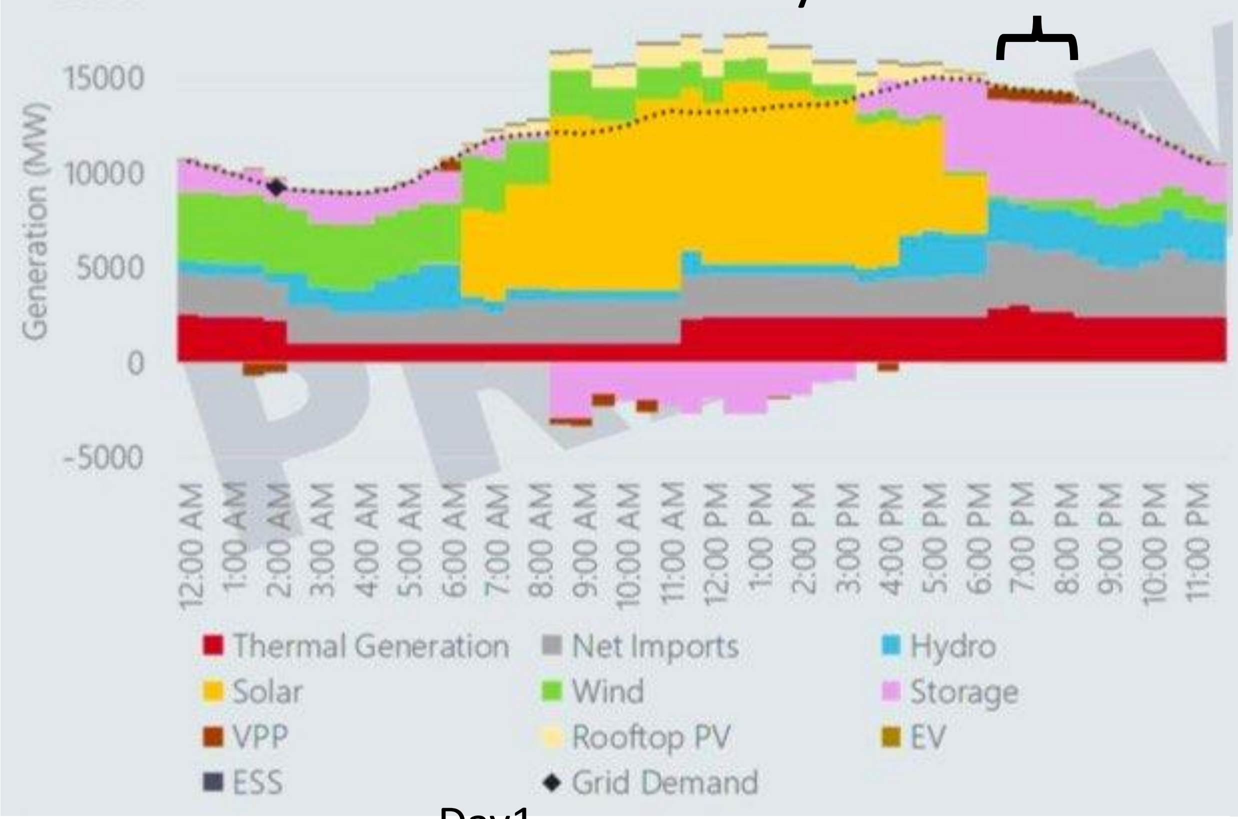
The velocity can be reduced and storage time increased by :

- Placing weirs with gates or slots that allow the normal flow but hold back until full for the large (over 600cumec) discharge for 2 hours creating mini dams
- Using low head turbines can be placed to extract the kinetic energy from the water and reduce its velocity
- Creating small ponds in natural/excavated hollows on the bank or low lands which are filled by the river flow using the pipes from upstream to utilize the natural head. Energy can even be recovered by discharging at low river levels further downstream within the next 24 hours using low head micro turbines.

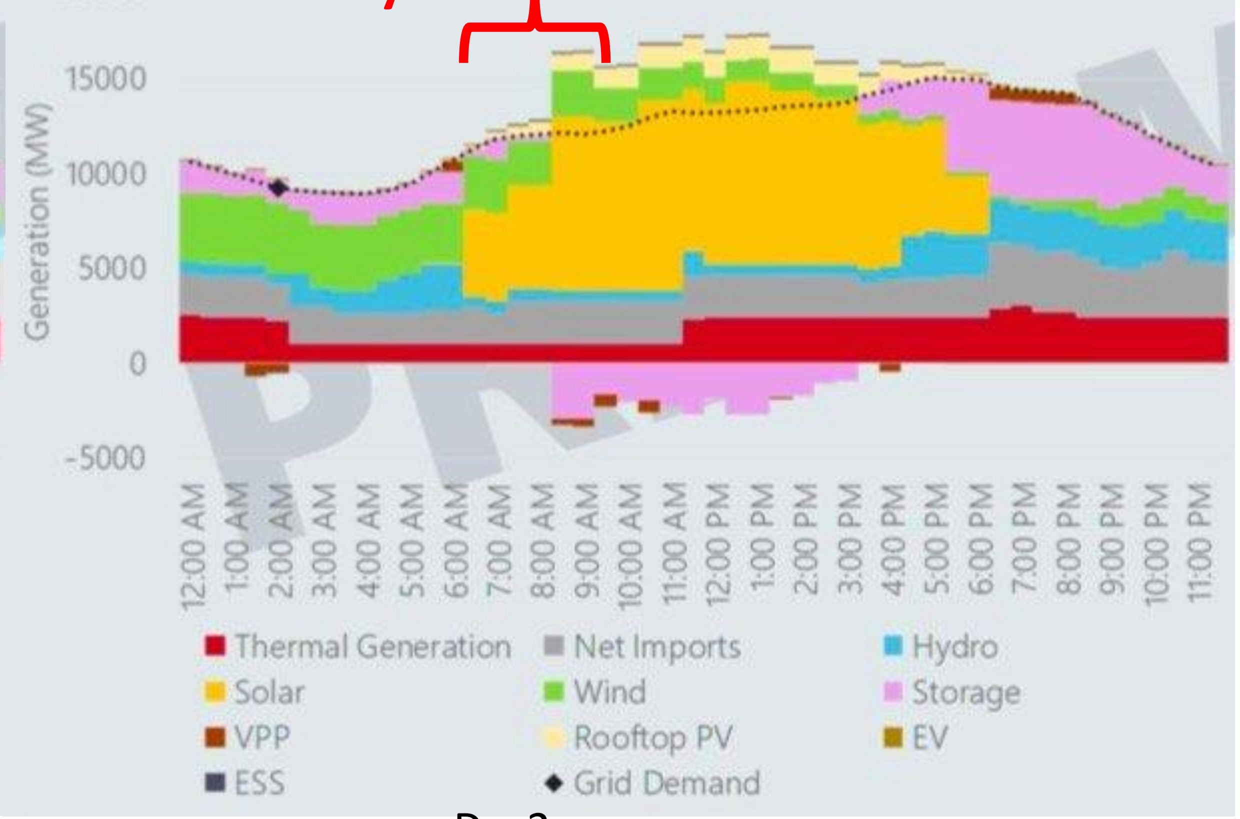
If extra 7-8 hours of delay is created on top of 4.29 hours It is perfect for capitalizing on low cost Solar PV and wind the next day

Dispatch massive hydro into river channel 5pm-8pm day1

Pump up back to dam 6.8km from river channel 7am-11am day2



Day1



Day2

https://reneweconomy.com.au/aemo-provides-glimpse-of-future-grid-not-much-fossil-fuel-even-less-base-load-78954/

Operation of proposed 13 hour Murrumbidgee downstream River Channel storage recycling 7GL of water from Burrinjuck Dam To provide **1210GWH** daily as (3h x 403MW)

Since the delay to arrive at the 12km mark, at a discharge of 665 cumec (over 3 hours) is only 4.3 hours the options are:

- Build weirs and temporarily hold the water over a 7-8 more hours and extract energy using low head turbines on the weirs.
- Do the 3hour 665 cumec energy release later in the night along with other Hydro as indicated by the modelling say between 230am and 6am to allow the released water to reach 12km pump-up point after sunrise(pump-up7am to 11 am)
- Reduce the quantum of release to 200 cumec and release it over 9hr 50min hours aimed at creating a lower steady flow arriving at the 12km downstream from 6am to 3pm and be pumped up.
- The last 2 options will become more important as the coal plants which provide over 70% of post sunset power in NSW,QLD,VIC retire

Weirs on Murrumbidgee downstream of Burrinjuck are great destination for the spoil from Snowy2 tunneling works instead of dumping on Alpine plains

It may make sense to use the rock debris excavated from the tunneling in Snowy2 to build multiple weirs on the Murrumbidgee in the 12km downstream of burrinjuck if the logistics of transport can be addressed.

Making the normal 3 to 6 cumec of Murrumbidgee flow through permanently open gates at the bottom of the weir

The purpose of the weirs would be to slow down the water and to utilize the down stream river channel for storage

The weirs could be used to recover energy using low head turbines as they emptied.

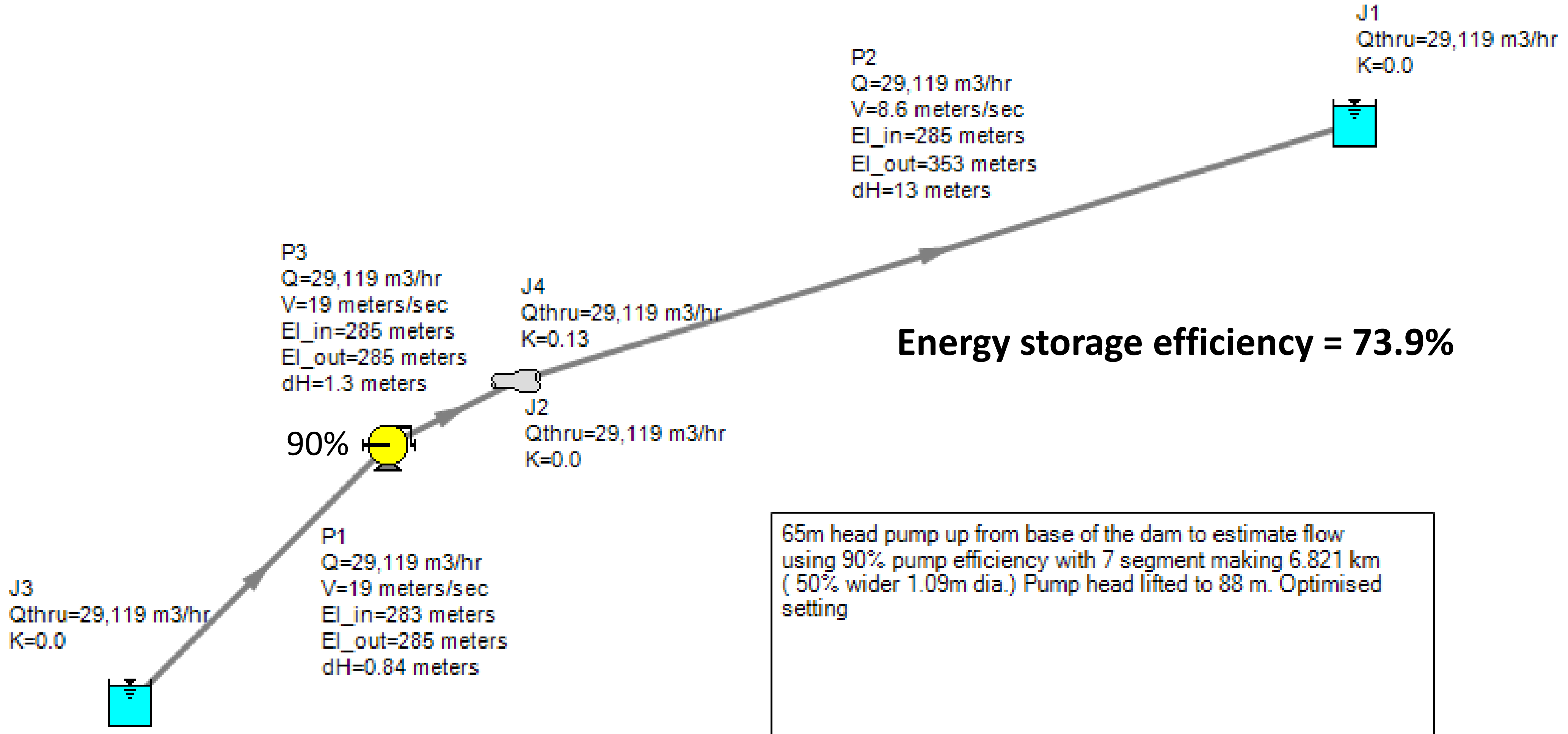
The weirs would be fully empty for around 12 hours a day unless energy was not available for the pumping up operation due to daytime energy shortage (eastern states have cloudcover and wind is not high)

Alternative use of the River channel by spreading the 1210MWH evenly as a 200cumec(m³/sec) discharge for 9.8hrs from 10pm to 6am creating a steady flow

By evening out the flow over 9.8 hours (instead of 3hours)and reducing the quantum of the discharge 3.325 times the flow will only arrive at 12km down stream after the sun rises as the time would increase marginally from 4. 3 hours to 6.4 hours ($4.3 \times 3.325^{1/3}$ =6.4hours). So only 3.4 hours (9.8-6.4=3.4h) of 200cumec discharge or 2.45GL would arrive before sunrise at 6am.

This would reduce the need to build big weirs as only 2.45GL would need to be held in a weir. The discharge can be further modulated up or down to respond to network energy requirements but still maintain the arrival at 12km downstream past sunrise constraint.

A weir could be built 12km downstream, if there is a desire to ensure there is no leakage of the 7GL daily discharge downstream due to any rare day time energy shortage event (wide spread cloud cover or equipment / line outages on the grid)
Alternatively 3 or 4 smaller weirs of collective capacity equivalent to 2.45GL can be built in the 12km stretch to get the same slow down and allow pumpingup after sunrise



65m head pump up from base of the dam to estimate flow using 90% pump efficiency with 7 segment making 6.821 km (50% wider 1.09m dia.) Pump head lifted to 88 m. Optimised setting

AFT Fathom Model
C:\AFT Products\AFT Fathom 10\river\pump up base of dam wider(1.09m) 6.6 km multi segment pump heac
Base Scenario

Round trip efficiency for Burrinjuck 58%

Avg Hydro power head H= 60m

Head from base of dam to pumping location 12km downstream
h = 313 – 283 = 30m

Head recovered by run of river turbines r= 10m

Efficiency of the generation processes= 100 x (H+r)/(H+h)
=0.95x(60 + 10)(100)/ (60+30) = 73.88%

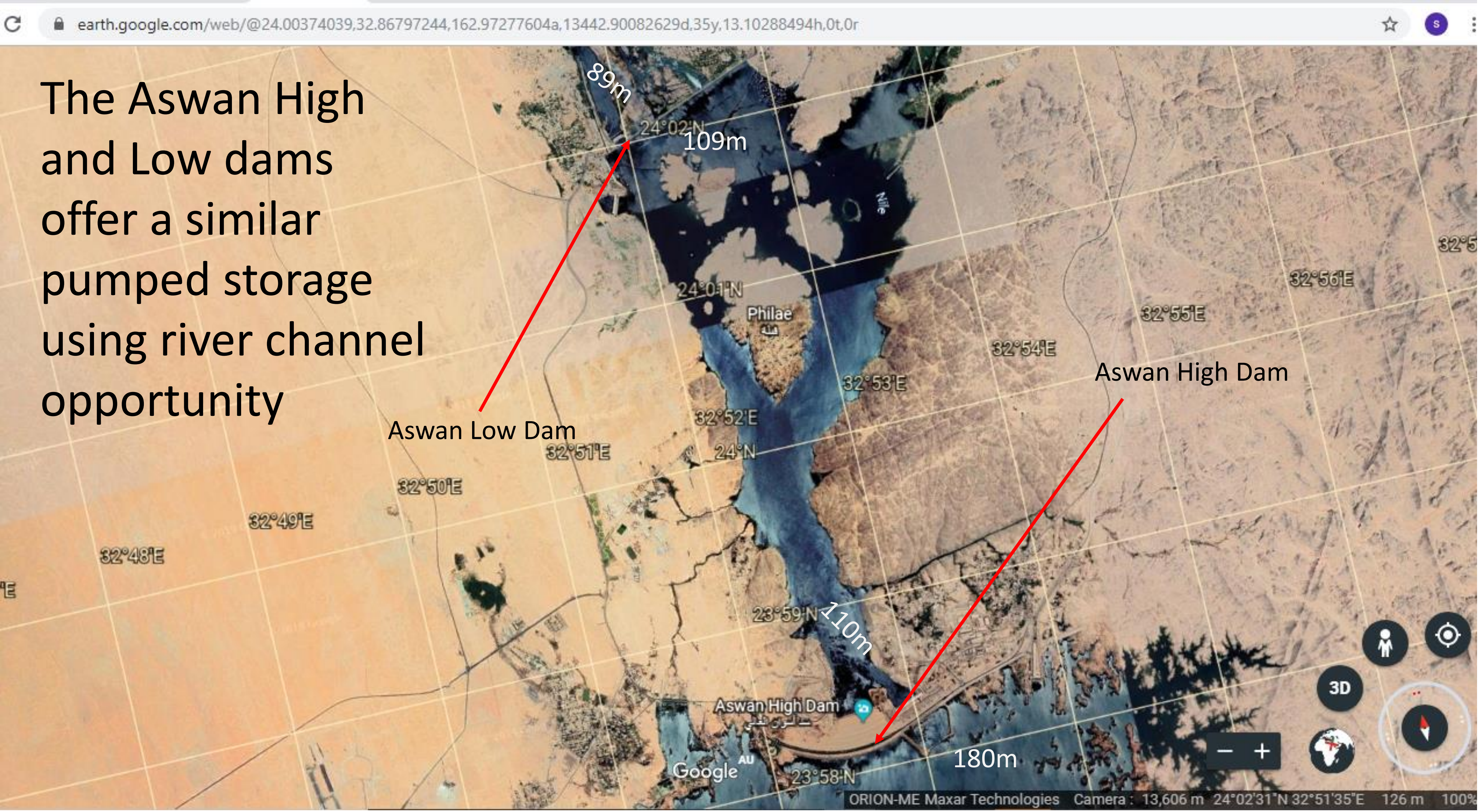
Let head loss in the pumping process = l pump efficiency = 90% loss=10% let pump power = p in terms of head delivered head = 0.9p=60+30 so p=100 pumping head loss l = 0.1p = 10m friction loss in pipes f =13+0.84+1.3=15.14

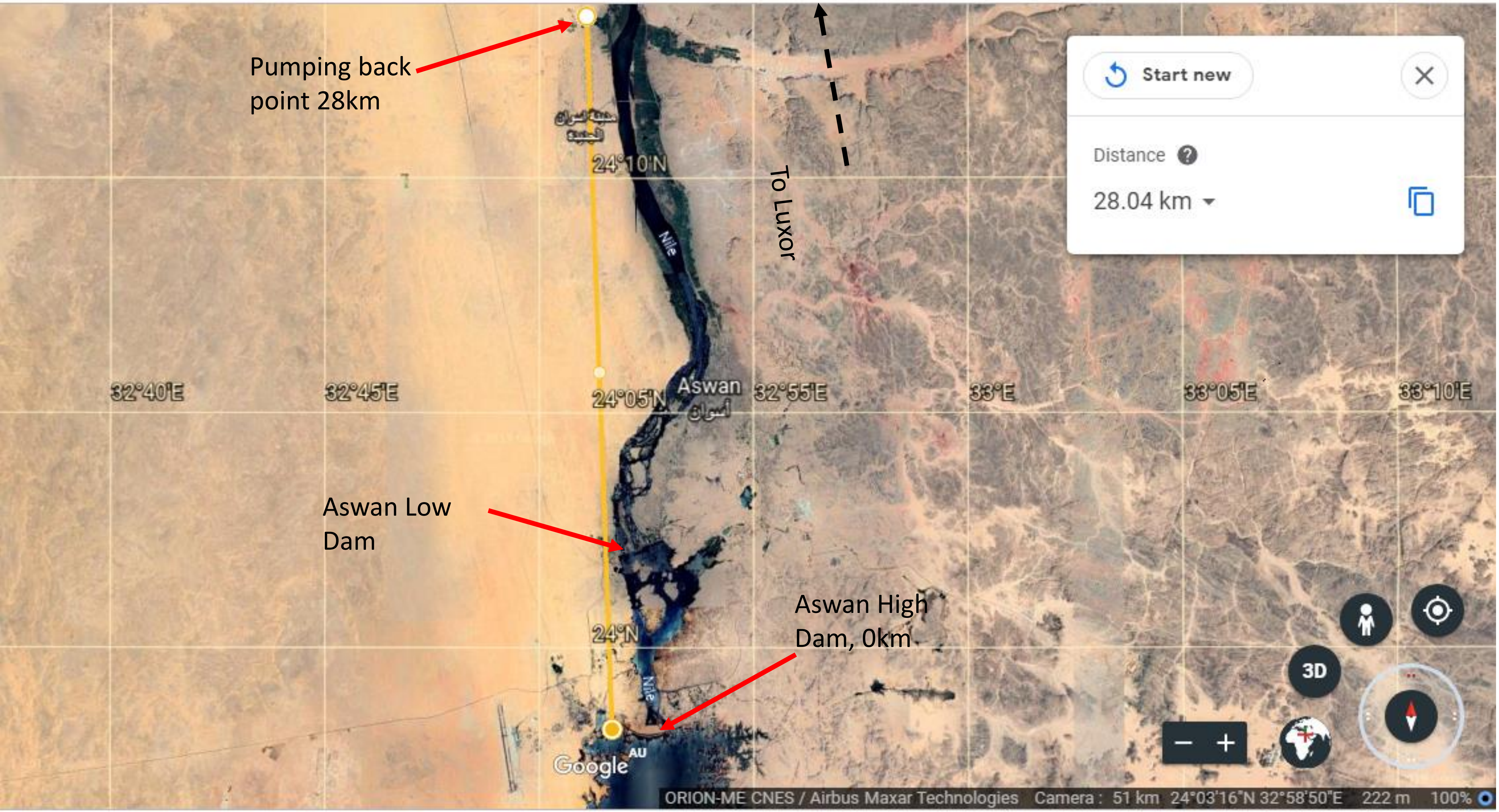
Efficiency of the storage(pumping) processes= 100 x (H+h)/(H+h+l+f)
= 100 x (60+30)/(60+30+10+15.4) = 77.92%

Efficiency of the generation process = 73.88%

Round trip efficiency of the storage process = 73.88% x 77.92% = 57.56% ≈ 58%

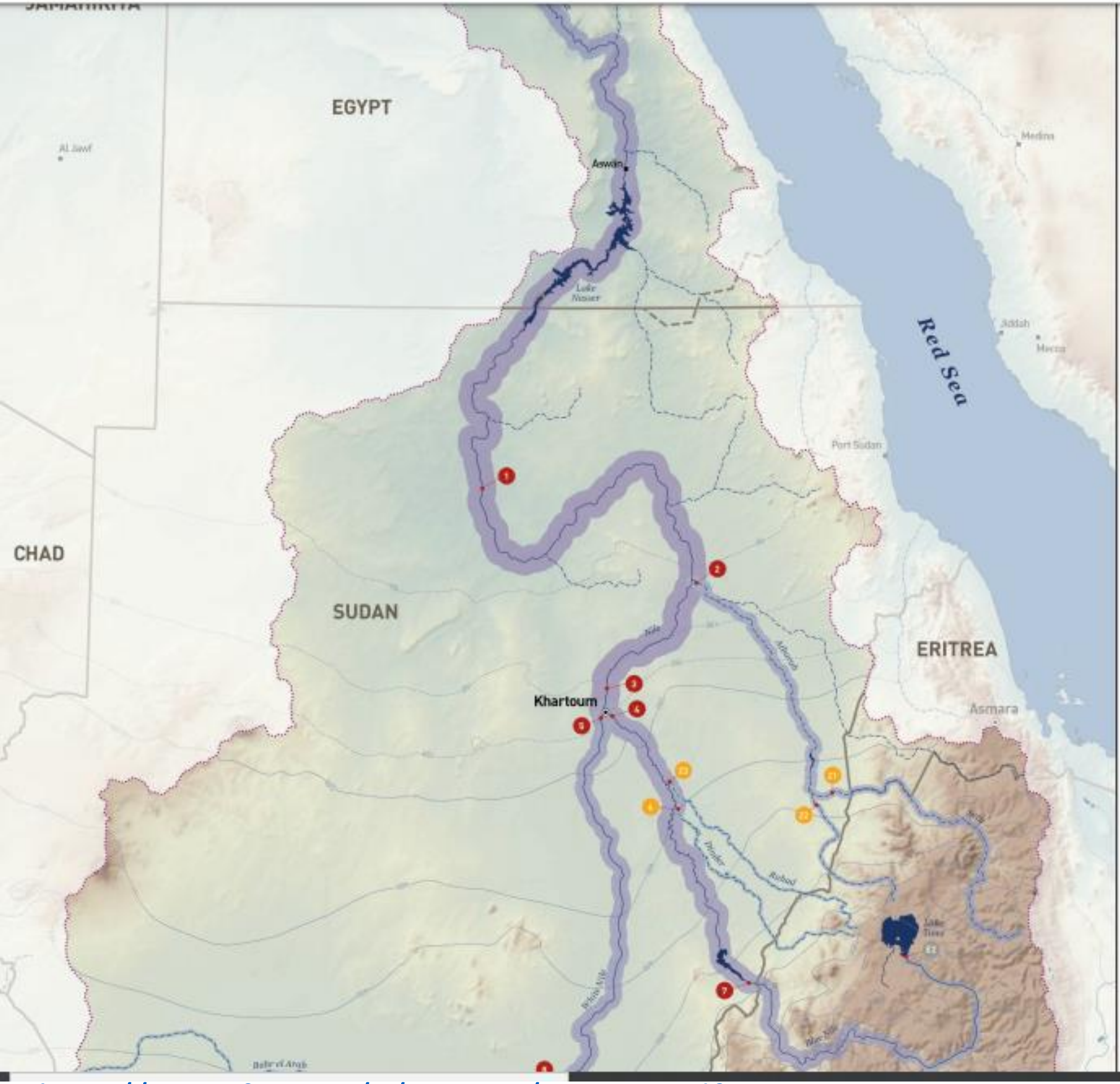
The Aswan High and Low dams offer a similar pumped storage using river channel opportunity



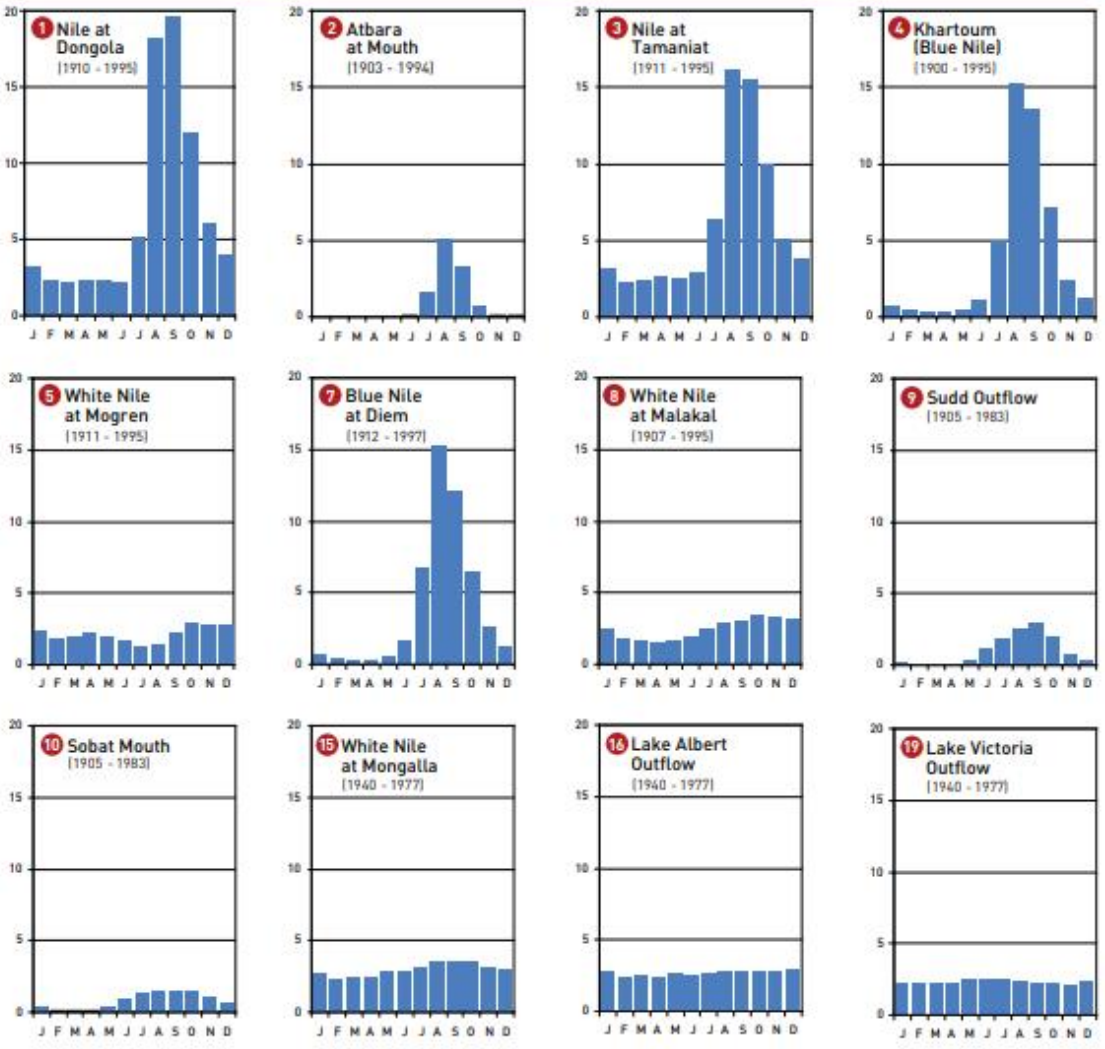


Pumping back point 28km
To Luxor
Start new
Distance
28.04 km
24°10'N
Nile
32°40'E
32°45'E
24°05'N
Aswan
أسوان
32°55'E
33°E
33°05'E
33°10'E
Aswan Low Dam
Aswan High Dam, 0km
24°N
Nile
3D
Google
ORION-ME CNES / Airbus Maxar Technologies Camera : 51 km 24°03'16"N 32°58'50"E 222 m 100%

Not secure | fao.org/3/an530e/an530e.pdf



Mean monthly flow in cubic kilometers (km³) at key stations (numbers indicated on map)



Mean annual flow in cubic kilometers (km³) at key stations (numbers indicated on map)

http://www.fao.org/3/an530e/an530e.pdf

Aswan High Dam river channel pumped storage capability

- The Aswan High Dam present pumped hydro opportunity using the down stream channel to the Aswan low dam and the Nile river channel downstream of the low dam towards Luxor.
- The pumped hydro opportunity is mainly during the dry season Nov-June as the 2100MW high dam and the Aswan 1 and 2 power stations (combined 590MW) on the low dam 6.5km down stream of the high dam are likely to run at capacity during the Jul-Oct wet season.
- Considering the abundant wind and solar PV resources and the plan to harness them, there is potential to overbuild and utilize the existing hydro generators to provide 2800MW hydro between sunset sunrise during dry season (Nov to Jun).
- The Hydro released water can be pumped back up from the river between sunrise and sunset using the excess solar and wind.
- The annual GWH produced which is around 11000GWH vs the 100% output of 18396GWH (2.1GWx365x24) this works out to 59.7% of potential dispatchable power from the High Dam. So pumped hydro potential is of the order of 7000GWH

Conclusion

- The calculations show that the river channel can prove to be a very effective free second reservoir and can be used in conjunction with the existing dam and any hydro power.
- The 665 cumec(m3/s) water released for 3 hours from the Burrinjuck dam dam takes 4.3 hours to reach 12km down stream. This can be delayed by another 7 to 8 hours by extracting energy from the flow by flow of the river turbines and/or constructing small weirs. A delay of 12 hours is ideal as it allows the Solar PV from the next day to be used to pump back the water into the dam. A total of 7GL out of the 1000GL capacity is recycled daily with no loss of water.
- If weirs are not desired the 663 cumec can be released at 01:40AM for 4.3 hours to make sure no water arrives before sunrise(6am). Water release can be skipped prediction is overcast day.
- The existing hydropower capacity can be greatly enhanced since the water is pumped back after 12 to 14 hours using relatively plentiful low cost energy in the morning and noon (6am to 11AM). Ie Burrinjuck currently has 30MW this pumped hydro will make it 400MW.
- The river channel storage opportunity is even better when the dam height is higher and the gradient downstream of the dam is lower. The higher dam wall improves round trip efficiency and the lower gradient improves storage time and reduces the river channel head loss.
- Aswan provides this situation. Its wider(500m+) downstream river channel provides improved storage volume & energy storage and large 2800MW Hydro capacity can be utilized all night.

Conclusion continued

- The downstream river channel can be used to advantage in most major hydro dams to create large energy storage. This could solve the RE time shifting issue and ease the fossil to RE transition
- Dams like the Aswan Dam(2100MW), Grand Coulee and 3 Gorges already have massive hydro power installed which is used at reduced rates as water availably reduces in dryer months.
- This creates opportunity to go into pumped storage mode and recycle the water using the downstream river channel and the existing hydro capacity for just the cost of installing massive pumps to pump back water from 5 to 30km down stream using cheap daytime RE
- The additional hydro power generation which will be installed to do the river channel pumped hydro can in principle yield additional benefits 24 x 7 during the wet season to the extent of the daily discharges which can be of the order of 40 cumec for over 2.5 months on average in Burrinjuck and could be much more in other dams with high spillway flows (Aswan 11000cumec).
- There is also an ability to become an emergency hydro power supply for extended periods in case of major power supply shortages due to plant or transmission line outages. This can be done by running the hydro generators when required to meet the grid shortfall without pumping back later. In Burrinjuck 600MW can be supplied by discharging 3.5GL/hr. This can be adjusted against future planned irrigation or environmental releases where possible.
- Round trip efficiency 58% for 1210MWH pumped storage at Burrinjuck & 12km D/S river channel

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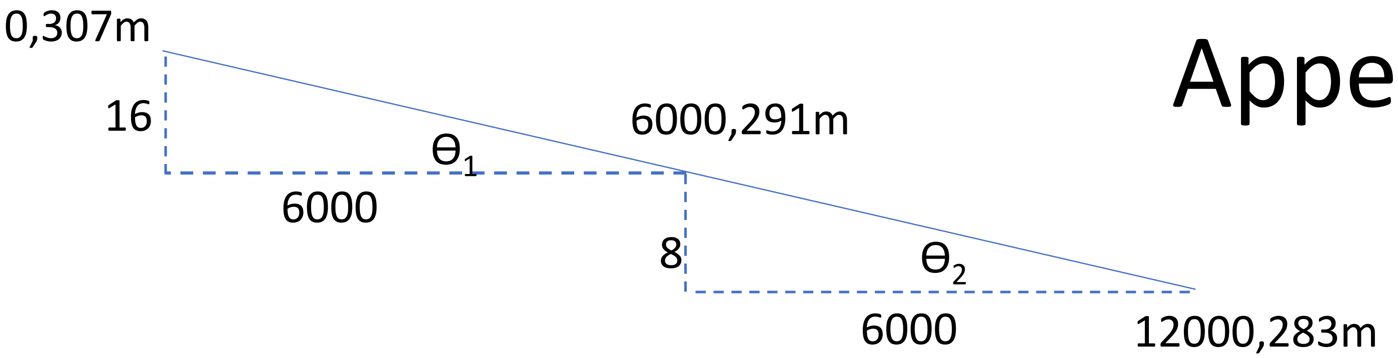
Appendix

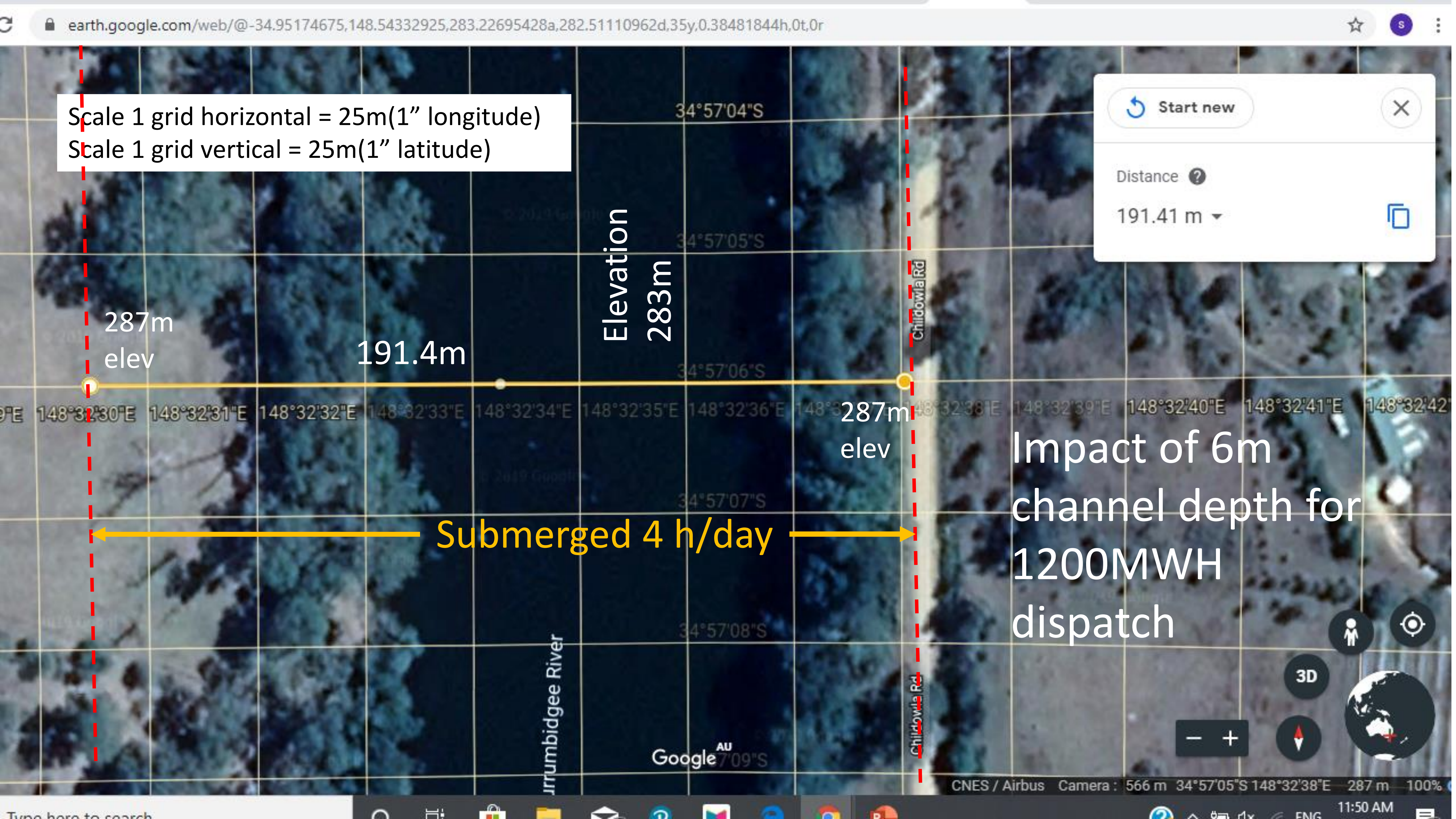


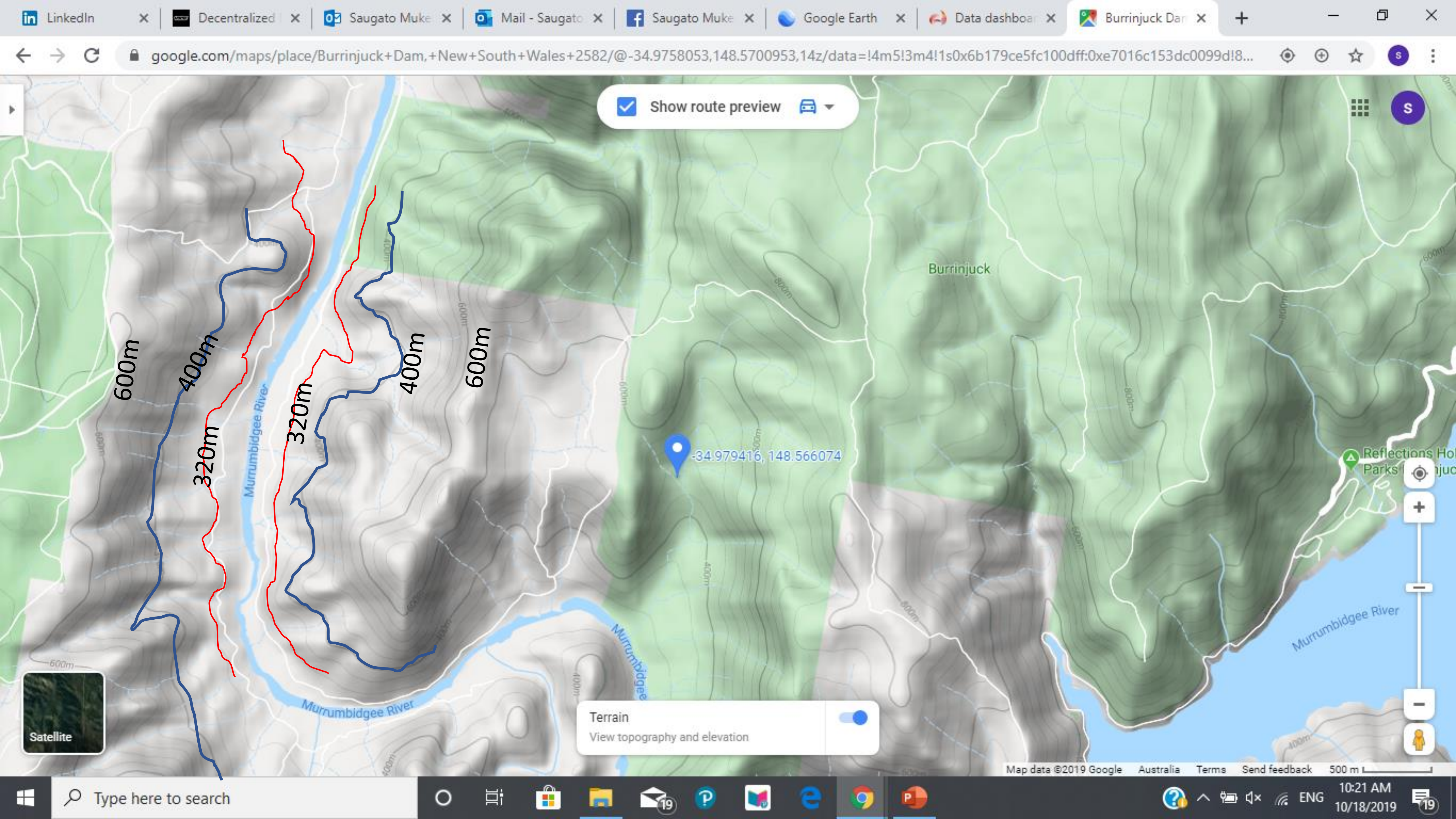
$$\sin \Theta_1 = \sin(\tan^{-1}(16/6000))$$
$$= 2.666657 \times 10^{-3}$$

$$\sin \Theta_2 = \sin(\tan^{-1}(8/6000))$$
$$= 1.3333321 \times 10^{-3}$$

$$S_2/S_1 = \sin \Theta_2 / \sin \Theta_1$$
$$= 1.3333321 \times 10^{-3} / 2.666657 \times 10^{-3}$$
$$= 0.5000013681 \approx 0.5$$

The drag coefficient of the channel tends to increase as the depth decreases and width increases downstream.


earth.google.com/web/@-34.95174675,148.54332925,283.22695428a,282.51110962d,35y,0.38481844h,0t,0r
Scale 1 grid horizontal = 25m(1” longitude)
Scale 1 grid vertical = 25m(1” latitude)
34°57'04"S
34°57'05"S
34°57'06"S
34°57'07"S
34°57'08"S
Elevation 283m
287m elev
191.4m
287m elev
148°32'30"E
148°32'31"E
148°32'32"E
148°32'33"E
148°32'34"E
148°32'35"E
148°32'36"E
148°32'40"E
148°32'41"E
Childowla Rd
Start new
Distance
191.41 m
Submerged 4 h/day
Impact of 6m channel depth for 1200MWH dispatch
Murrumbidgee River
3D
Google AU
CNES / Airbus Camera : 566 m 34°57'05"S 148°32'38"E 287 m 100%
11:50 AM


600m
400m
320m
Murrumbidgee River
320m
400m
600m
Burrinjuck
-34.979416, 148.566074
Reflections Ho
Murrumbidgee River
Murrumbidgee River
Show route preview
Terrain
View topography and elevation
Satellite
Map data ©2019 Google
Australia
Terms
Send feedback
500 m
google.com/maps/place/Burrinjuck+Dam,+New+South+Wales+2582/@-34.9758053,148.5700953,14z/data=!4m5!3m4!1s0x6b179ce5fc100dff:0xe7016c153dc0099d!8...
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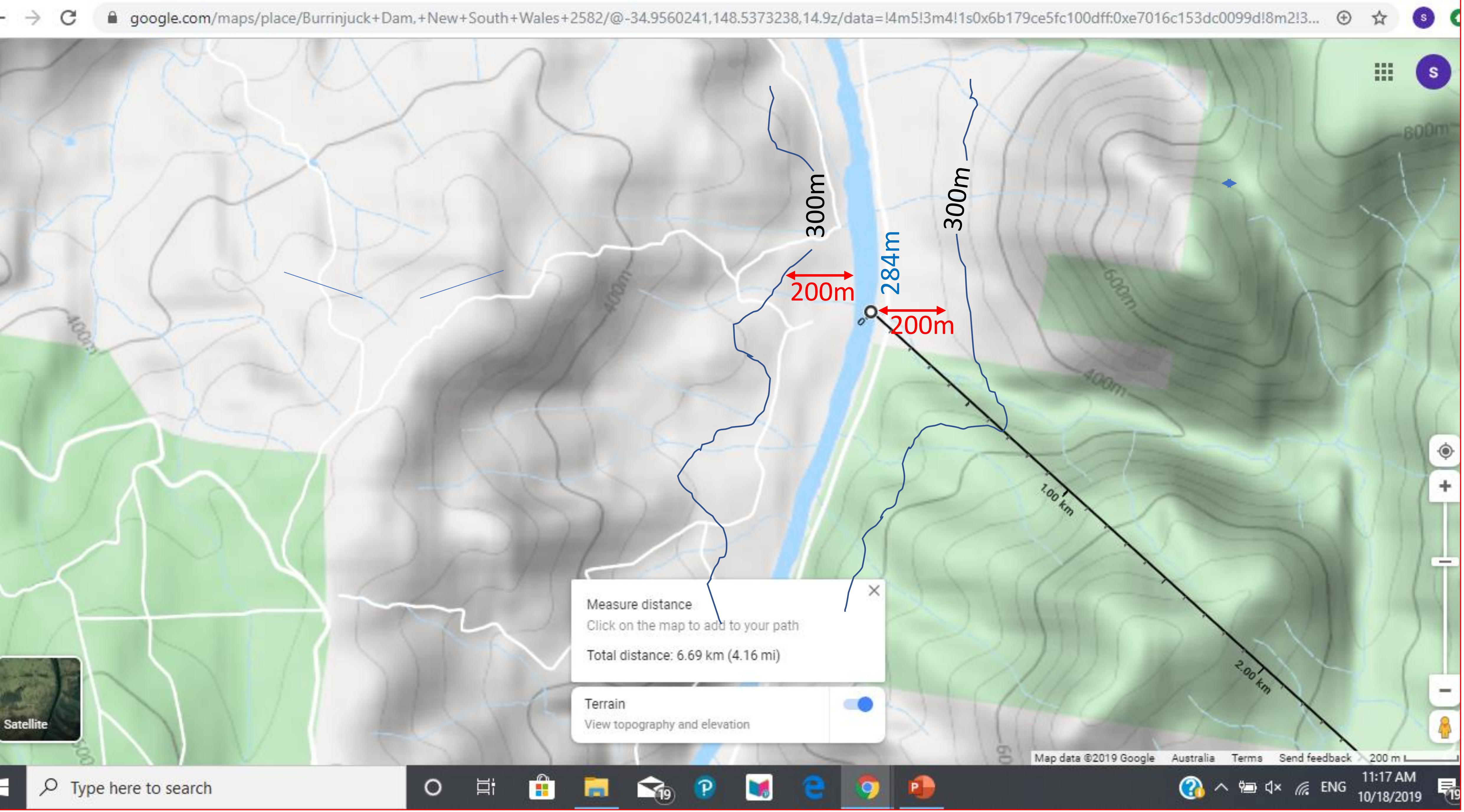
10:21 AM
10/18/2019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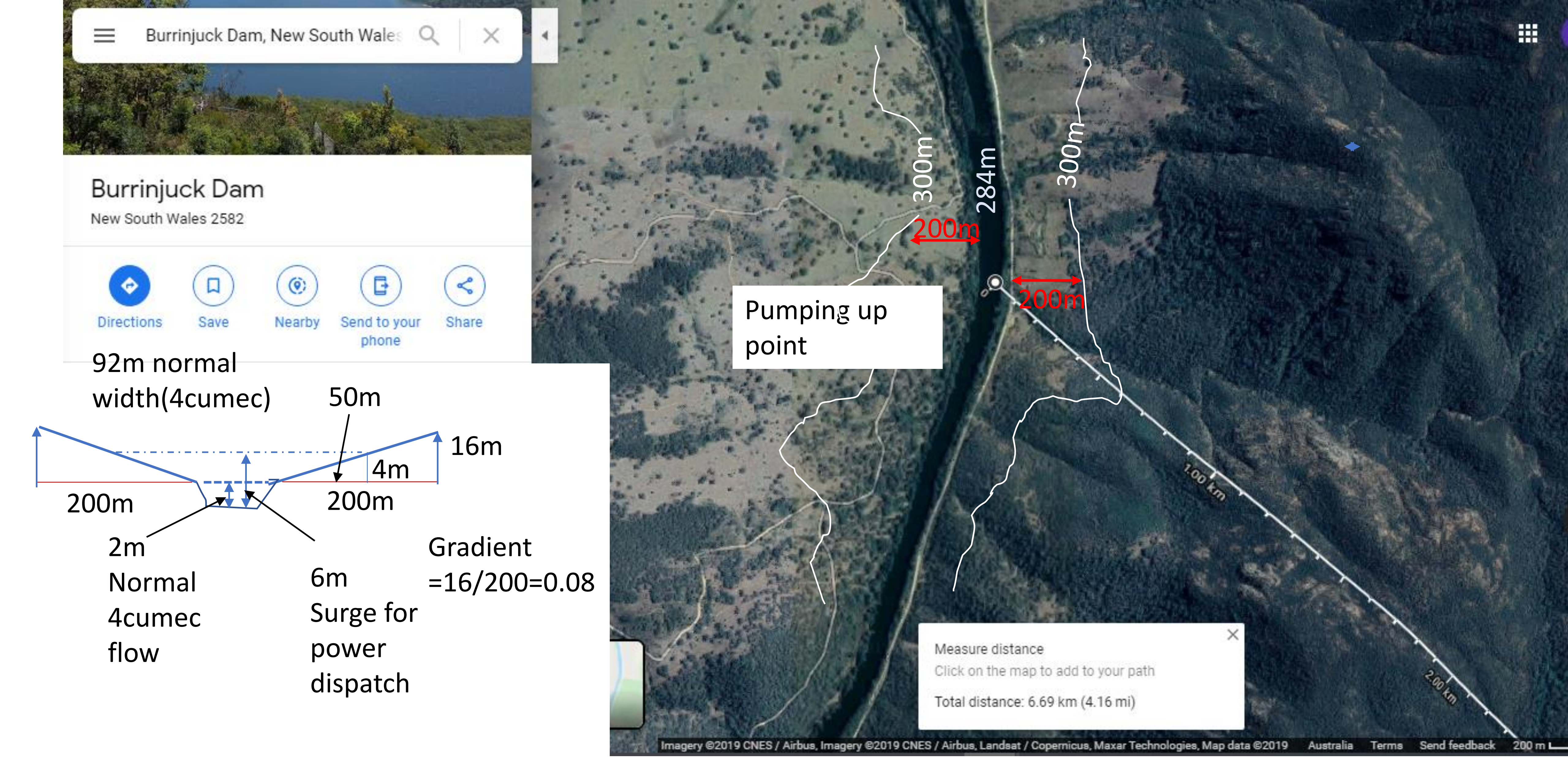
300m
300m
284m
200m
200m
800m
600m
400m
400m
400m
1.00 km
2.00 km
Measure distance
Click on the map to add to your path
Total distance: 6.69 km (4.16 mi)
Terrain
View topography and elevation
Satellite
Map data ©2019 Google
Australia
Terms
Send feedback
200 m
Type here to search
ENG
11:17 AM
10/18/2019



Assuming 65 m avg channel width and same slope 16/200= 0.08 and 6m discharge for power dispatch

Volume of 12km channel= 12000 x (6 x 65 + 2 x 0.5 x 4 x 50) = 7,080,000m³ = 7080ML ≈ 7GL