Locating Potential Sites for Pumped Hydroelectric Energy Storage

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Pumped hydroelectric energy storage (PHES) is the largest and most mature form of energy storage currently available. However, the capital costs required for a PHES are extremely large and suitable sites for PHES are deteriorating. Therefore, identifying the remaining sites available for PHES is becoming vital so that the most beneficial location is chosen: in terms of capacity and economics. As a result, the aim of this work is to develop a computer program that will scan a terrain and identify if there are any feasible PHES sites on it.

At the outset of this project, there were two primary concerns that needed to be addressed: 1) obtaining suitable data and 2) writing the software. The first issue was resolved by contacting the national mapping agency of the Republic of Ireland, Ordinance Survey Ireland (OSI). OSI was able to provide 10 m resolution height data for all of the Republic of Ireland [1]. In addition, OSI referred us to a software company, Atlas Computers Limited [2], who had experience using this data. Therefore, to tackle the second major issue (creating the program), a collaboration was developed with Atlas Computers Limited.

Atlas Computers Limited had already developed a Survey Control Centre (SCC) to manipulate the data provided by OSI. The SCC converted the 10 m resolution height data for the Republic of Ireland, into a Delaunay Triangulated Irregular Network model (TIN). A TIN model displays the 10 m data as a 3D terrain that can then be analysed using different constraints. Consequently, the specific constraints that need to be fulfilled at a suitable PHES location could be searched for using the TIN model.

To search the TIN model for pumped hydro facilities, an additional algorithm was added to the SCC to search for locations with the specific constraints associated with PHES facilities. This was based on searching the TIN to find adjacent polygonal areas of acceptable flatness, A_U and A_L, with a minimum acceptable vertical separation, H, and a maximum acceptable horizontal separation, d, as portrayed in Figure 1. The program created could only identify regular-shaped polygons as the areas for the reservoirs, and hence a circle was chosen.

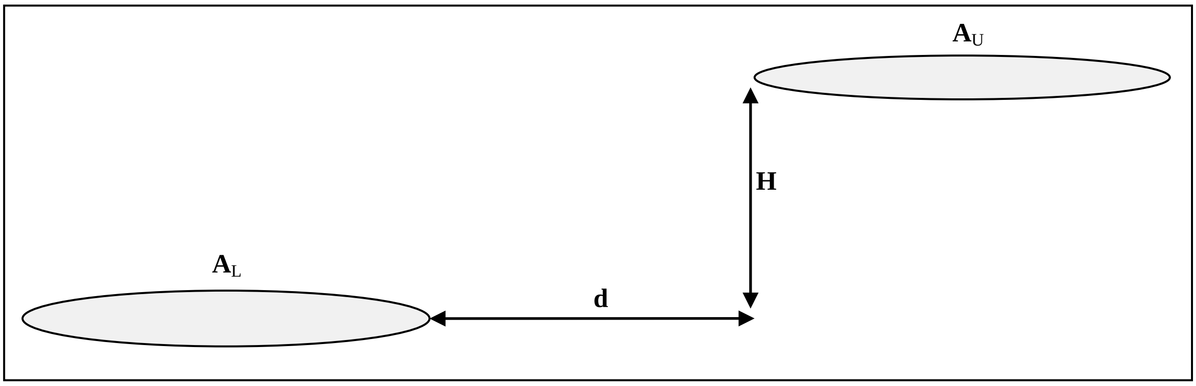

Figure 1: Area layout investigated by computer program

The upper and lower reservoir areas identified by the program had to be flat. Flatness in this case is specified in terms of the maximum allowable 'cut' and 'fill' excavation-volumes, E_U and E_L, which are required to construct a polygon at an arbitrary datum, where the software selects an optimal value for that datum. In other words, the level of flatness required was specified by quantifying the maximum amount of earth that could be moved in order to make the site flat, E, as displayed in Figure 2. The earth that must be moved to make the area flat must be obtained within the investigated site i.e. the circular area. There was an E value for the upper reservoir, E_U, and an E value for the lower reservoir, E_L.

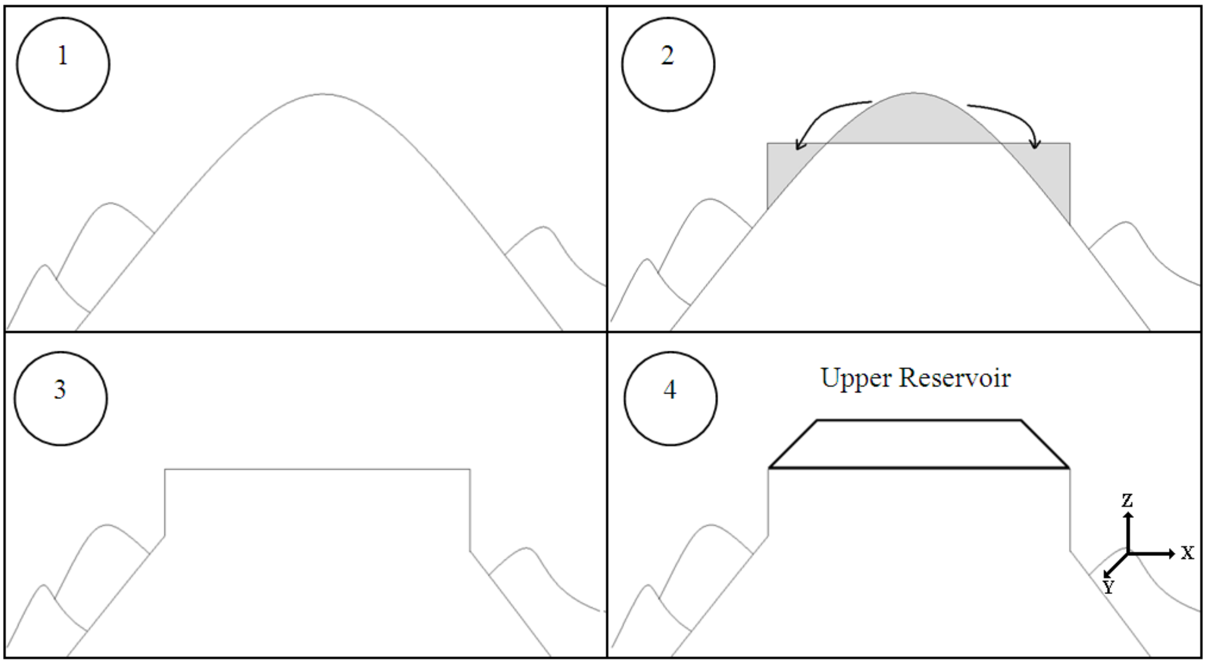

Figure 2: Earth moving procedure within the program to make the investigated area flat

The primary assumption using this technique was based on the fact that once the two areas could be made flat, a reservoir could be constructed for the PHES facility. This has already been carried for a number of existing PHES facilities as displayed in Figure 3. It is worth noting, that this might not even be necessary when a site is located but it enhances the credibility of those the sites which are found.

(a) (b)

Figure 3: PHES man-made reservoirs of (a) Taum Sauk, USA [3] and (b) Turlough Hill, Ireland [4]

The principal challenge in implementing the above search was speed. Given the combinatorial complexity of the above parameters, and the amount of data involved, a brute-force solution was shown not to give acceptable performance. For example, a test of a brute-force search for PHES facilities over 1 km^2 area took about 4 hours to process on a mid-range Windows workstation; thus processing a 20 km x 40 km area would take approximately 20 weeks. The solution was optimised to mask-out large areas that did not contain the required vertical separation. The TIN model was also optimised to remove all unnecessary points that were co-planar with their nearest neighbours. This yielded a routine that took 6 to 10 days to process a given scenario on a 20 km x 40 km area, with variation based on the parameters supplied and input data provided. The final analysis for a number of scenarios was distributed over a network of 8 Windows XP workstations to further reduce the time required.

To test the operation of the model, an initial analysis was carried out on a 20 km x 40 km area in Ireland which is illustrated in Figure 4. The region analysed was limited due to the costs associated with purchasing the required data files, and the cost of processing time for completing the analysis. However, the region in question provided a good indication of the results that can be achieved when analysing any terrain using the software.

Figure 4: Area analysed for initial investigation

For the initial analysis, a total of three different searches was completed. The search parameters used to search the TIN model for the three searches are illustrated in Table 1.

Table 1: Parameters used for first the initial analysis

Name	Symbol	Search 1	Search 2	Search 3	Unit
Area of the upper reservoir	A_U	120,000	120,000	180,000	m^2
Area of the lower reservoir	A_L	120,000	120,000	120,000	m^2
Height between reservoirs	H	200	200	150	m
Horizontal distance between areas	d	1,000	1,000	1,000	m
Flatness / maximum earth moved to make upper reservoir flat	E_U	300,000	300,000	400,000	m^3
Flatness / maximum earth moved to make lower reservoir flat	E_L	300,000	300,000	300,000	m^3

After the three searches were completed, five potential locations for PHES facilities were identified. These are illustrated in Figure 5. Only one location which marked with a rectangle was identified from the first search, while the other four locations were identified during the second search, and no locations were found during the third search.

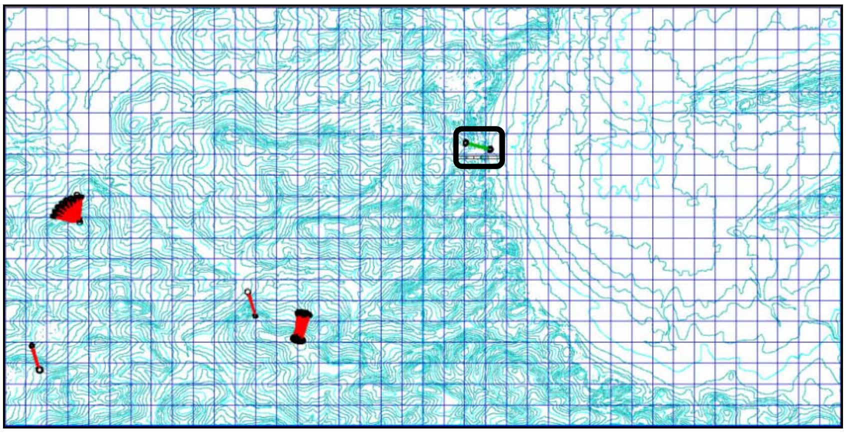

Figure 5: Potential PHES-sites identified after the initial analysis

The next step was to quantify the power and storage capacities that could be constructed at the locations identified by the software. This was done using equations 1-3 below. The power capacity *P*, was found using the density of water ρ, acceleration due to gravity g, the height between the two reservoirs H, the flow rate Q, and the pump/turbine efficiency η as displayed in equation 1.

$$P = \rho g H Q \eta \tag{1}$$

The storage capacity S, was obtained using the density of water ρ, acceleration due to gravity g, the height between the two reservoirs H, the volume of water that can be exchanged between the two reservoirs V, and the pump/turbine efficiency η as displayed in equation 2.

$$S = \frac{\rho g H V \eta}{3600} \tag{2}$$

The total volume that could be exchanged between the two reservoirs V, was calculated from the reservoir area specified in the program A, and the height of the reservoir wall that could be constructed at the site, R_H as displayed in equation 3.

$$V = AR_H \tag{3}$$

For each analysis all variables were constant except the height between the two reservoirs H, and the volume of water that can be exchanged between the two reservoirs V. Therefore, values had to be assumed for the flow rate Q, and the pump/turbine efficiency η. To ensure realistic options were taken, these values were taken from an existing PHES facility, Turlough Hill [4], in County Wicklow, Ireland. The flow rate (Q) assumed was 113.2 m^3/s and the pump/turbine efficiency (η) assumed was 80%. With these assumptions in mind, and using the parameters specified in the program during each search, the facilities identified by the program represent a combined power capacity of 710 MW, and a combined storage capacity of 8,634 MWh, as the distribution of which is displayed in Table 2.

Table 2: PHES-facilities identified during the initial analysis

Result	Search 1	Search 2	Search 3
Power Capacity at each facility (MW)	178	133	0
Storage Capacity at each facility (MWh)	1,570	1,766	0
Number of facilities found	1	4	0
Total Power Capacity (MW)	178	532	0
Total Storage Capacity (MWh)	1,570	7,064	0

Therefore, it is clear that the program developed has provided an excellent first step to evaluate the potential for suitable PHES-locations across a specified terrain. However, even though the program provided some very significant results already, a number of improvements are necessary. The primary objective for the future is to complete a manual investigation of the sites that have been identified by the program. This will further ensure that the sites being proposed by the software are realistic for constructing PHES facilities. In conjunction with this work, there are a number of improvements that will be attempted within the computer coding. These include:

1. Reducing the processing time required for the analysis by identifying areas where a PHES facility cannot be built such as towns and protected areas.
2. Reduce overlapping where desired
3. Adding a cost prediction tool to the software
4. Adding additional GIS layers to the software to improve site selection and cost predictions
5. Improve the use of existing terrain in the program

Once these updates have been completed, it is hoped that larger area will be investigated using the model for potential PHES locations. To conclude, this paper has provided a brief description of the program developed for identifying feasible locations to construct PHES facilities, including. Also, the results obtained to date using the program are discussed and finally, future improvements to advance the program's capabilities are identified. The program has proven to date that it can identify feasible locations for PHES, however, further investigation is necessary to improve the site-selection.

References

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