PUMPED STORAGE QATTARA DEPRESSION SOLAR-HYDROELECTRIC POWER GENERATION

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INTRODUCTION

The possibility of using pumped storage in conjunction with a nuclear power plant and desalination is presented as an alternative that would eliminate the need for previous excavation and tunneling schemes for a Solar-Hydroelectric-Nuclear Qattara Depression project.

The Qattara (Dripper) Depression is bounded on its north side and separated from the Mediterranean Sea by the El Diffa Plateau. With an average elevation of 200 meters at the top of the plateau. Its lowest point is 133 meters below sea level. If it were flooded to sea level, the lake formed would cover nearly 20,000 km^2 comparable to Lake Ontario, Canada. It would reach to 55 km from the Mediterranean Sea near the city of El Alamein (The two flags). A Terraforming or geoengineering feasibility study along the Plowshare peaceful nuclear explosives program proposed a series of 213 underground explosions as a way to excavate a canal to turn it into an inner lake or sea.

A 60 meters Below Sea Level (BSL) lake would have a surface area of 12,100 km^2 and a volume of 227 km^3. The lake would make the area cooler and more humid through evaporation. Measurements taken around Lake Nasser at the Aswan High Dam is 5.2 mm per day for a freshwater lake. For seawater this would drop to 5.0 mm / day or 1.8 m / year. The net evaporation amounts to 700 m^3/s. With a 60 m head and 100 percent efficiency, would generate an average sustainable power level of 412 MWe. The flow of 700 m^3 / sec of seawater across 55 - 80 km with only a 10 percent or 6 meter loss of head a tunnel 15 meters in diameter is needed.

Electricity from a nuclear power plant would be used to pump water to a pumped storage site 215 m in elevation along the rim of the depression. The pressure drop from the elevated pumped storage site to a 60 m elevation artificial lake with an evaporation rate of 18.92×10^9 m^3/yr at a discharge rate of 600 m^3/sec in the depression through a total of a 275 m pressure drop. The pressure drop can then be used for electricity or fresh water production using Reverse Osmosis, or the electrical power generation could produce fresh water through electro-dialysis.

Figure 1. Satellite picture of the Qattara Depression. Its area is comparable to the nation of Lebanon It is totally uninhabited except for a small oasis at its western edge. Source: NASA.

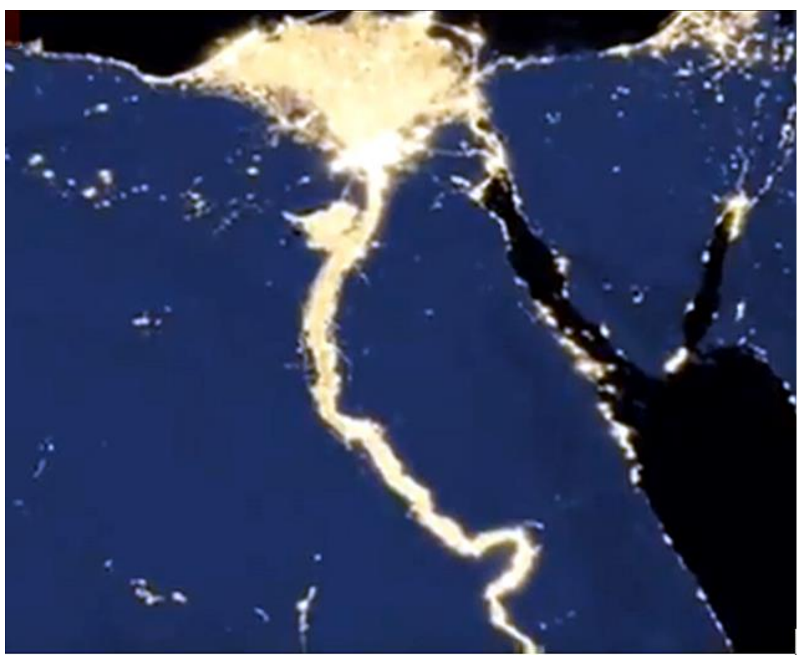

Figure 2. Satellite picture of lights at night shows sparse settlements along the southern and northern edges of the Qattara Depression. Source: NASA.

Figure 3. Geographical location of the Qattara Depression as the possible site of a future artificial inner lake that would be about half the size of Lake Erie in North America. Source: Geology.com.

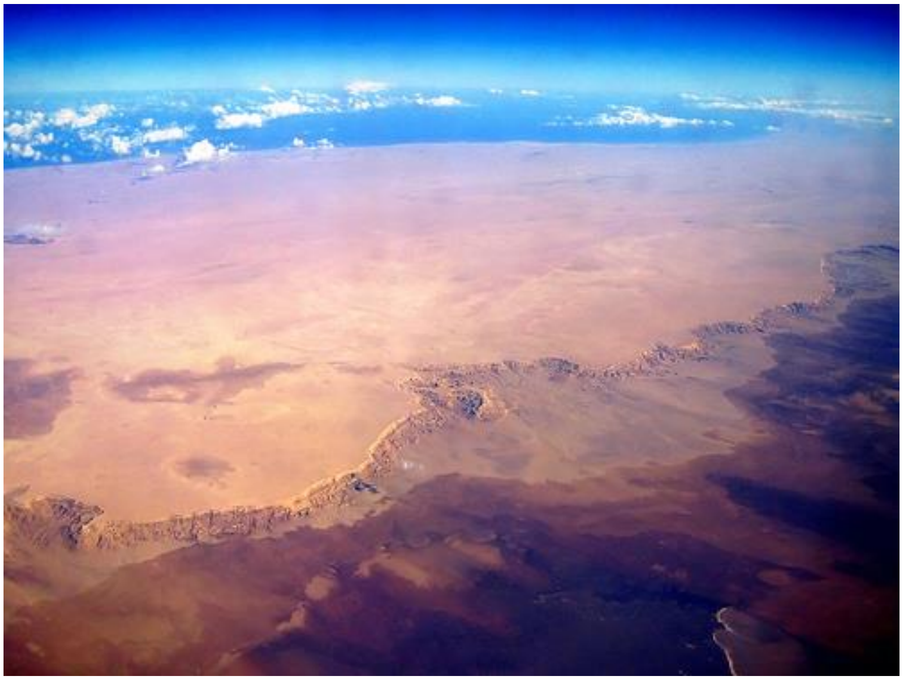

Figure 4. Aerial view from the Qattara Depression towards the Mediterranean Sea in the distance. Notice the cloud cover on the Mediterranean Sea. Cloud formation may be possible on a future inner lake because of the increased moisture level in the air and the increased vertical wind speed.

GEOGRAPHY

The Qattara Depression is located in Egypt's Western Desert with an elevation of 120-133 m below sea level. It is the world's 5th deepest depression. It is the second lowest point in Africa after Lake Assal in Djibouti. Its latitude is 29°32'N and longitude is 27°07'E, and is located at north western part of Egypt. It is 300 km in length and has a maximum 145 km width. It is composed of uninhabited and impassable "sebkhas" or salt marshes, dried up salt lake beds and shifting sands.

It is desolate, has few settlements on its south-western side, and the only economical activity it supports is sporadic nomadic herding. Its location below sea level offers the possibility of hydroelectric power production that can be coupled with a pumped storage system for peak power production. Its realization requires the connection of the depression to the Mediterranean Sea through a canal and/or pipeline system. After an initial water filling period to its maximum extent, the flow rate and hence power production capability would have to be matched to the high solar evaporation rate, due to its location in an arid hot desert area, from the surface of the generated lake.

An added environmental benefit would be that the moisture evaporation may act as a site for liquid drop nucleation and cloud formation that can add moisture and rainfall to a mostly arid area of the world. The generation of a lake breeze on its southern side can also offer a possibility of wind power generation.

Figure 5. Petrified tree logs in the Qattara Depression suggesting a previously wet geological environment.

Figure 6. View of the bottom of the Qattara Depression as a dried up salt lake bed with shifting sand.

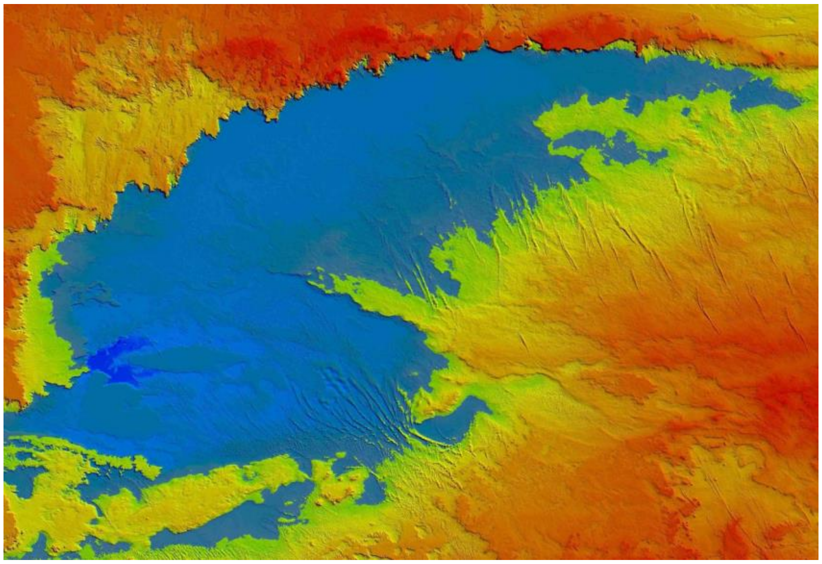

Figure 7. Qattara Depression Digital Elevation Data (DEM) originating from the NASA Shuttle Radar Topographic Data Mission (SRTM) from data held at the National Map Seamless Data Distribution System. [1].

Table 1: Major world depressions.

Depression	Location	Elevation below mean sea level, msl [m]	Surface Area below Sea Level [km^2]	Distance from Sea or Ocean [km]
Dead Sea shore	Jordan / Israel	401-408	3,800	72

Near Lake Tiberias	Syria	200-212		50
Lake Assal shore	Djibouti	154-155	80	15
Turfan Pendi	China	154	5,000	1,500
Qattara Depression	Egypt	120-134	26,000-44,000	56
Vpadina Kaundy	Kazakhstan	132		
Denakil Depression	Ethiopia	125		
Laguna del Carbon	Argentina	105		
Death valley	USA	86		
Near Kulul within the Denakil Depression	Eritrea	75		
Sebkha Tah	Morocco	55		
Sebjet Tah	Western Sahara	55		
Sabkhat Ghuzayyil	Libya	47		
Lago Enriquillo	Dominican Republic	46		
Chott Melrhir	Algeria	40		
Caspian shore	Azerbaijan/Iran/Russia	28		
Shatt Al Gharsah	Tunisia	17		
Lake Eyre	Australia	15		
Sariqarnish Kuli	Uzbekistan	12		
Laguna Salada	Mexico	10		

HISTORY

The Nile and the Qattara Depression are Egypt’s most prominent geological features. The Qattara Depression is covered with rock salt and slimy quicksand and is desolate and lifeless. In World War II, British General Bernard Montgomery judiciously concentrated his forces at a defensive line at El Alamein in the neck of land between the Mediterranean Sea and the nearly 1,000 ft. drop into the quicksand of the Qattara Depression. He succeeded in stopping the advance of German Field-Marshal Erwin Rommel's Afrika Korps towards Alexandria and the Suez Canal. The “Desert Fox” commented to the British: “The Qattara was worth 200 armored divisions.”

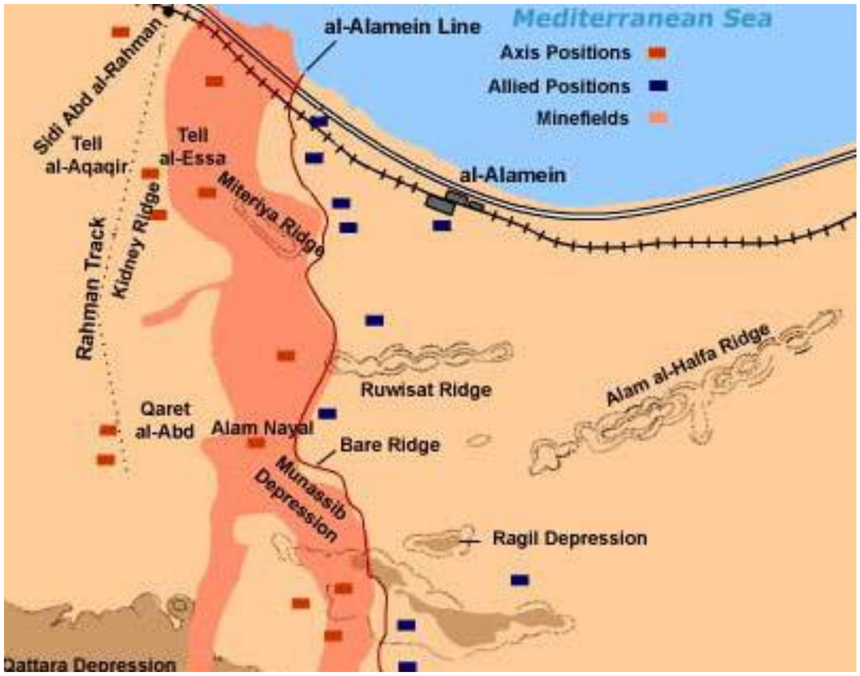

Figure 8. Kidney Ridge between the Mediterranean Sea and the Qattara Depression defined the Al-Alamein line positions during World War II. In military history it was the southern anchor of the British El Alamein line that stopped German "desert fox" Field Marshal Erwin Rommel's eastward advance toward the Suez Canal. The British and their allies did not need to extend the line further south, because the Qattara Depression was impassable to any mechanized infantry force. The depression is impassable due to its combination of fine loose drifting sand in some parts, rocks and wind-carved cliffs and gullies in others, and wide expanses of treacherous salt marshes and crusted mud flats that could swallow heavy vehicles.

The idea to dig a canal from the Mediterranean to within nine miles of the Qattara Depression followed by a tunnel that would be bored under the rocky escarpment arising along the Depression's northern rim has been considered several times. Emerging from the tunnel, the water would drop down the cliff into hydroelectric power plant to generate 2.7 billion kilowatt hours of electricity a year.

For 160 years the water level would gradually rise to form an inland sea about half as big as Lake Erie. The rapid evaporation in the hot desert air plus some seepage and regulation of the water intake would keep the level permanently some 150 ft below sea level, providing Egypt with a semi-perpetual source of power. The cost of the project is estimated at about $3 billion using 10 years of construction time.

The Qattara Depression generated-power could be a useful complement to the 10 billion kw.hr produced by the Aswan High Dam. Except for insignificant rainfall, Egypt depends totally on the Nile for irrigation and electrical power. Since 1,900 miles of the Upper Nile belong to the Sudan and its headwaters to four other countries with demands of their own, Egypt's future development may someday require more power than its share of the Nile can provide.

For a century, the new "Lake Qattara" could support a flourishing fishing industry until the salt concentration became too high. After that, the lake bottom could be mined like the Dead Sea for crystallized salt and other minerals such as potassium from potash as a fertilizer component.

DESCRIPTION

The Qattara Depression is a basin in Western Egyptian Desert with an area of 26,000-44,000 km^2 and about 120-134 m below mean sea level (msl). It extends a maximum length of 300 km from east to west, and 135 km from north to south. It is deeper in its west side than its east side.

The northern edge of the escarpment is bounded by a hilly ridge with an elevation of 200 m above mean sea level. The shortest distance from the Mediterranean Sea to the Depression is 56 km.

Even though groundwater seeps into the depression at a rate of 2.5 m^3/sec, which amounts to a value of 78.64×10^6 m^3/yr, the high evaporation rate evaporation does not allow for the formation of a permanent lake from the seepage [2]. Evaporite minerals produced by precipitation of minerals out of solution as water evaporates includes Halite, which is rock salt or NaCl, and calcium sulfate or gypsum, ($CaSO_4.nH_2O$). The growth of halite and gypsum crystals in rock fractures and pore spaces is an effective process of rock weathering in addition to Aeolian deflation or removal of the weathered material by the wind. In the Qattara Depression, the Aeolian deflation amounts to 9 cm/10^3 years measured vertically. Over the last two million years that would have removed 180 m of weathered material, creating the Qattara Depression. Cyclic patterns of wet and dry periods were a crucial process in deflation and the deepening of the depression.

The Qattara Depression is the largest natural closed depression of the Eastern Sahara. In this region salt weathering is particularly effective. In spite of earlier research in the 1940's and 1950's, the origin of the Depression is still a geological puzzle. One explanation of its origin is wind deflation to a base level controlled by the ground water table. Other explanations include solution, mass-wasting followed by wind deflation, or that the depression was originally excavated as a stream valley, to be subsequently modified by karstic activity, and was further deepened and extended by mass-wasting, deflation, and fluviatile processes. It has also been suggested that the Depression is of structural control origin.

We suggest an alternate plausible explanation in that the Qattara Depression could have been formed as part of the ancient Thetys Sea [3].

The Qattara Depression constitutes one of the most significant geomorphological features of the NW desert of Egypt. It is a closed inland basin bounded from the north and west by steep escarpments, with an average elevation of 200 m above sea level (asl). Towards the south and east, the floor of the Qattara Depression rises gradually from 60 m below sea level (bsl) to the general desert level of 200 m asl again. The Qattara Depression has an area of some 18,130 to 19,500 km^2 and an average depth of 60 m bsl; the lowest point, lies at the SW part, being 134 m bsl. The Qattara Depression is estimated to have an excavated volume of 3,200 km^3.

Within the Qattara Depression, cones, towers, mushrooms, and plateau-like hills, ranging in height from 5 to 30 m, are common, especially near the western escarpment.

Sinkholes and caves are also common in the northern Diffa Plateau, separating the Qattara Depression from the Mediterranean frontal plain. The northern and western escarpments are dominated by large mass-wasted blocks.

The Qattara Depression is excavated into northerly dipping Miocene and Eocene rocks. Sandy and clayey layers of the Lower Miocene Moghra Formation form its bottom and surroundings, where the elevation ranges from 50 to 80 m bsl. In some areas, the Moghra sediments occur as small plateaus and dissected hills within the sabkhas. Middle Eocene calcareous sediments of the Mokattam Formation form the southern scarp of the Depression. The Upper Eocene-Oligocene Dabaa Formation underlies the SW part of the Depression, including all areas below 100 m bsl. It consists of black shales and contains abundant gypsum veins and prehistoric ancient-ocean shark teeth and remains. The northern steep escarpment is associated with the Middle Miocene calcareous sediments of the Marmarica Formation, with a thickness of a few meters at the rim of the Depression, increasing to several hundred meters at the coast, where Pliocene carbonate rocks are exposed. Over large areas of the floor of the Depression, the bedrock is covered by younger deposits including wind-blown sand, sabkhas, and Quaternary evaporite sediments.

The sands that cover most of the Qattara Depression are associated with moist sand sheets with adhesion ripples at the surface in the NE part, and large parallel longitudinal lunette, seif (sword in Arabic), and complex dune belts in the southern part. The dune axes trend north-north-west to south-south-east, parallel with the prevailing wind direction. The dunes are composed mostly of quartz sand mixed with minor carbonate, mud, shale, and gypsum fragments. Near the SW part of the Depression, the dunes are black, named El-Ghorood El Sood or (black dunes in Arabic), due to their high content of black shale fragments, derived from the Dabaa Formation.

Since the Qattara Depression forms the deepest point in the Egyptian Western Desert, groundwater flow in all aquifers bordering the area is consequently directed to this final base level. Most of the groundwater comes from the Moghra Aquifer system, recharged from four sources: the Nubia Sandstone aquifer in the south, Nile water in the east, saline water from the Mediterranean Sea to the north, and rain water. In contrast, in the western part of the Depression, groundwater seepage is recharged from Nubian and Upper Cretaceous-Eocene aquifer systems. The near-surface groundwater ranges in salinity from mostly NaCl from 3.3 g/l around the Moghra Lake, to 38.4 g/l at the center, to about 300 g/l in the sabkha area to the west. An exception to this east-west increase in salinity is found around fresh water springs such as the Bir Qifar area. This increase in salinity from 43.6 to 421.0 g/l, has been attributed to the leaching of salts by surface water and groundwater, and to excessive evaporation of groundwater at or slightly below the surface in the lowest part of the depression [2].

PROPOSED PUMPED STORAGE PROJECT

Such type of a project could be designated as a Solar-hydro project. It is made possible by the existence of a wide depression at a short distance from the sea in an arid region with limited rainfall with a large evaporation rate, which would be associated with a high evaporation rate precluding its total filling with water from the neighboring body of water.

To produce hydroelectric power from this geographical feature, a project would involve two stages. In an initial stage, the basin would be filled with water from the Mediterranean Sea to a stable design level covering most of the area to allow water evaporation. In the second stage, water would be transferred from the Mediterranean Sea to replace just the evaporated water, and in the process, hydroelectric power would be produced from a power station positioned just above the design steady level.

The Qattara Depression is situated about 56 km from the Mediterranean Sea. A similar project has been considered for Lake Assal in Djibouti which would require a water conduit of just 15 km from the Red Sea. Another project considers the Dead Sea to be connected to the Red Sea by a canal. However, the area covered by the Qattara Depression is about 26,000-44,000 km^2 compared with 3,800 km^2 for the Dead Sea and 15 km^2 for Lake Assal.

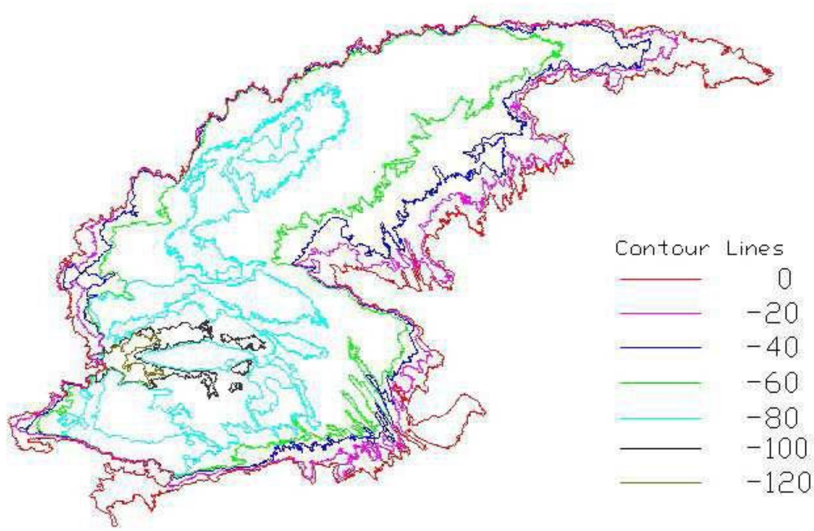

Figure 9: Qattara Depression contour lines.

A combination of canal and tunnel and possibly a pipeline would convey sea water from the Mediterranean Sea. If the formed lake would be maintained at a level of 60 m below sea level, this would form a lake with an area of about 19,500 km^2. Without pumped storage, it is estimated that replacing the evaporation rate with water flow from the Mediterranean would provide 670 MW of basic electrical capacity.

Table 2: Qattara Depression planar areas and water volumes at different contour levels. The zero contour level represents the boundary of the depression [1].

Planar area [km^2]	Filled water volume [km^3]	Contour level
19,605	1,213.0	0
17.646	839.0	20
15,405	508.0	40

12,510	227.0	60
4,652	39.3	80
526	6.3	100
153	0.8	120

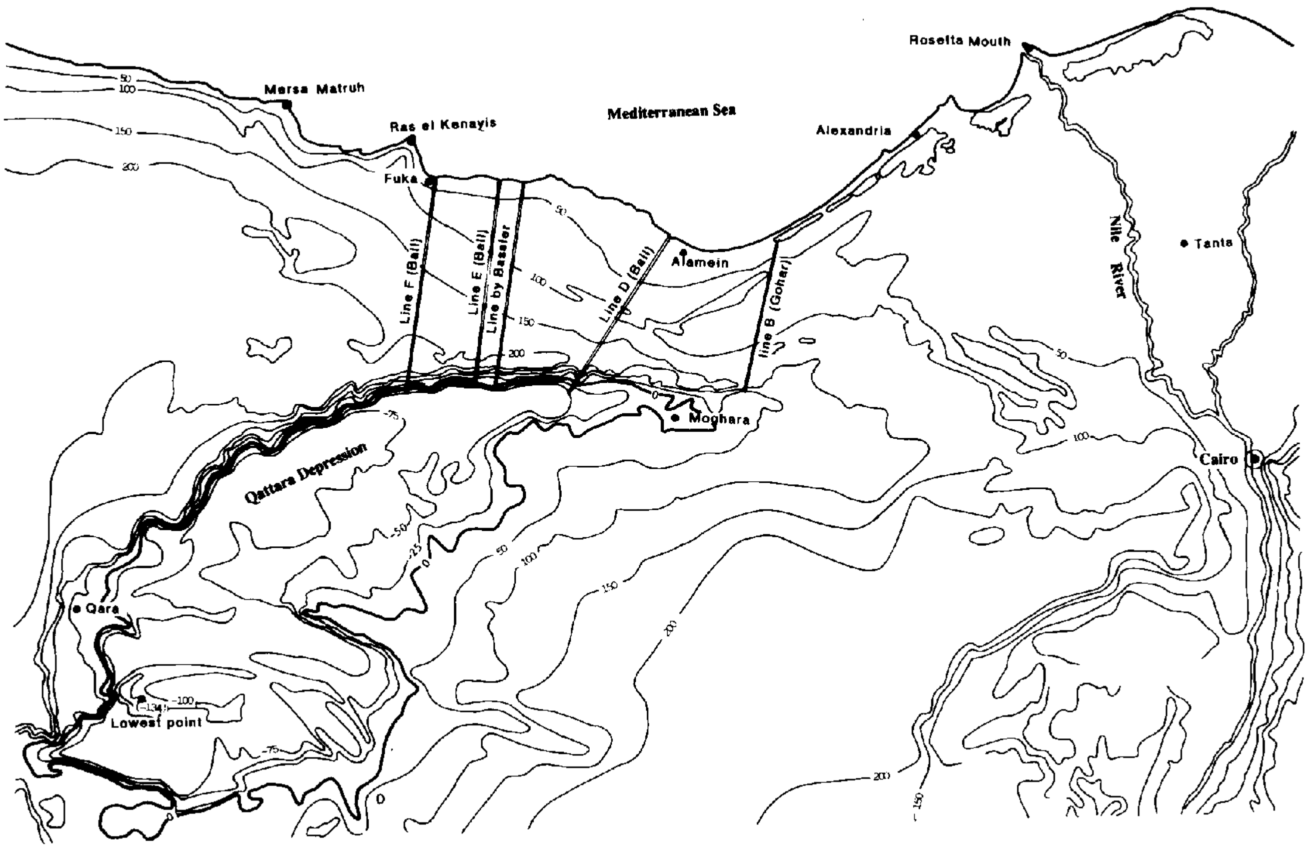

Figure 10. Suggested routes for connection of the Qattara Depression to the Mediterranean Sea [2].

Figure 11. View of hills at the edge of the Qattara Depression.

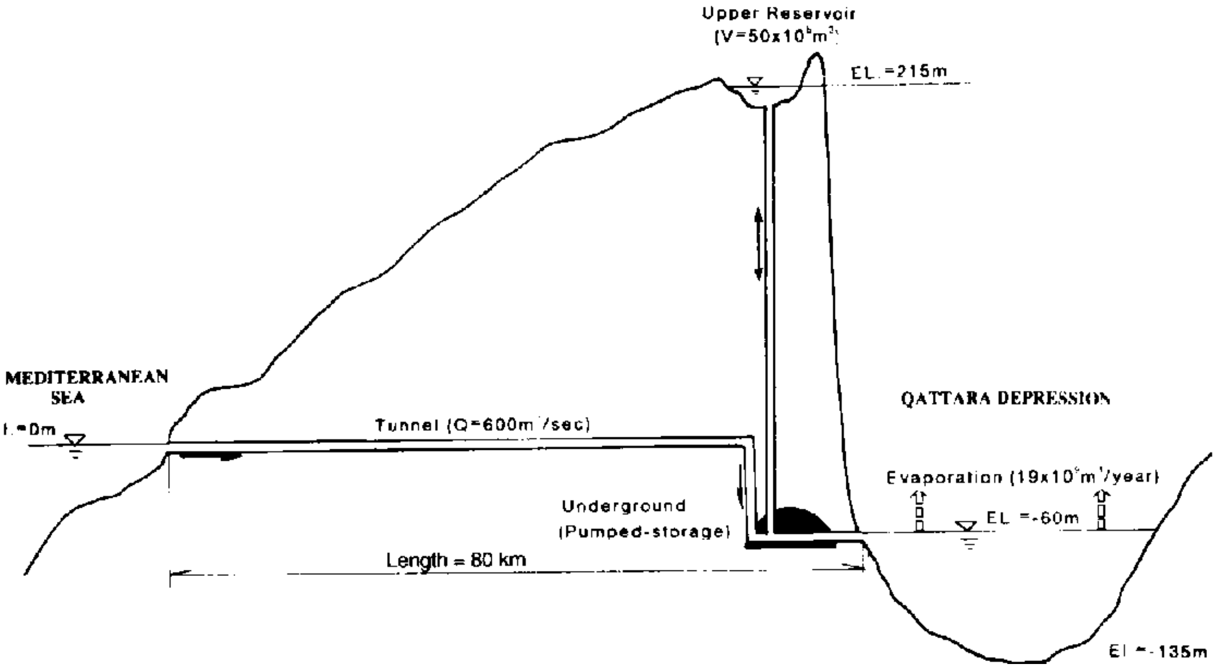

Figure 12. Qattara Depression project with pumped storage [2].

HISTORICAL PERSPECTIVE

Berlin geographer Penk first suggested the use of the Qattara Depression as a hydroelectric project in 1912. He was followed by Ball in 1927 who studied its use for hydroelectric purposes with lakes at different levels below mean sea level, and hence different surface areas and evaporation rates. He considered the effects of possible climatic changes, evaporation, seepage, electrical transmission loss, cost per MW of installed capacity, geology, and topography. He recommended a lake at a 50 m depth below msl, and a route starting west of El Alamein in a south-west direction.

Table 3. Hydroelectric power potential for lake at different levels.

Depth below mean sea level, msl [m]	Lake area [km^2]
50	13,500
60	12,100
70	8,600

FFESTINIOG PUMPED STORAGE POWER STATION

As an example of the type of pumped storage system that can be adapted to the Qattara Depression is the Ffestiniog Power Station. Commissioned in 1963, it was the

UK's first major pumped storage power facility. Although of an older generation to those at Dinorwig, Ffestiniog's four generating units are capable of achieving a combined output of 360 MW of electricity; enough to supply the entire power needs of North Wales for several hours.

The generation cycle starts at Llyn Stwlan, Ffestiniog's upper reservoir. Large screens inside the intake towers are opened to activate the high-pressure water down flow. A flow of 27 m^3/sec of water per second is discharged through two high-pressure shafts each 200 m in depth, which are connected to four concrete-lined tunnels. Steel penstocks then direct the discharge into the station via inlet pipes and valves to start generation.

Water is captured in the Tan-y-Grisiau lower reservoir and pumped back to Llyn Stwlan, usually overnight, to complete the cycle.

Figure 13. View of the Ffestiniog pumped storage project on Stwlan Dam and Reservoir, UK [4].

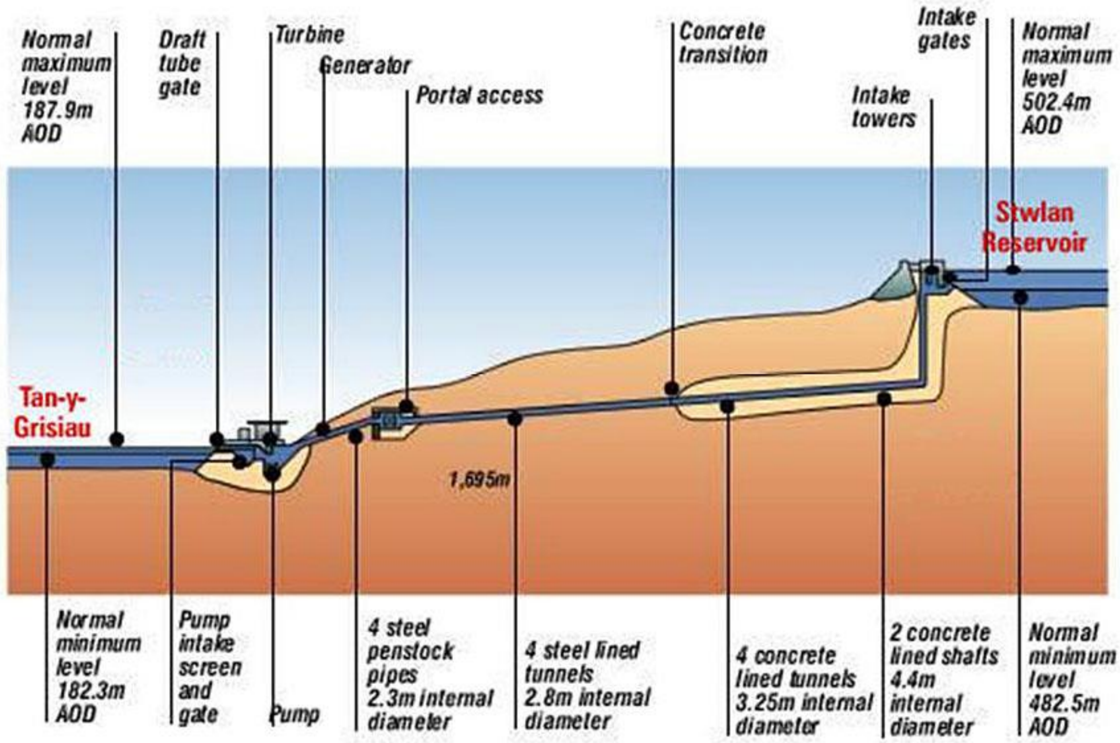

Figure 14. The layout of the Ffestiniog pumped storage project, UK [4].

PUMPED STORAGE ALTERNATIVE

A project in the region of Qattara could use pumped storage for peak rather than base-load operation. Two development options, either by tunnel or by canal, were examined by Basseler in 1975 [5], based on combined hydro-solar and pumped storage with a total installed capacity of 2,400 MW.

In the tunnel alternative, the hydro-solar plant would be based on the evaporation from the lake surface when it rises to a design level such as 60 m below sea level. The theoretical hydro-potential at an equilibrium point of 60 m below sea level is estimated to be 315 MW, assuming a water surface area of 12,100 km^2, evaporation of 1.41 m per year, specific weight of the seawater of 1.02782, and an effective differential head of water at 57 m.

The installed capacity of 315 MW was estimated by assuming twin tunnels with a maximum flow discharge of 656 m^3/sec (328 x 2 = 656), which would require approximately 35 years to fill the lake to 62.5 m below sea level.

THE DESALINATION ALTERNATIVE

Instead of turbines producing electricity to be conveyed through High Voltage DC (HVDC) or alternating conventional high voltage power lines to the population consumption centers at the Nile Delta, desalting sea water could use the pressure gradient in a reverse osmosis plant to produce fresh water from the sea water flow into the lake.

This would be particularly useful for agricultural and municipal purposes in a primarily arid environment.

Alternatively, the generated electricity can be used for water desalination using an electro-dialysis approach.

EXCAVATION OPTIONS

In the canal excavation alternative, nuclear excavation was suggested for an open canal with a total length of 60 km. The plan could have doubled the hydro-solar capacity by 15 years after the commencement of taking water from the Mediterranean Sea. Excavation by a tunnel-boring machine would be practical and economical in the unsaturated rocks of the Neogene Tertiary.

The nuclear alternative would double the hydro-solar capacity by 15 years after the start of taking water from the Mediterranean Sea.

Table 4. Project stages using nuclear excavation.

Stage	Construction time [years]	Electrical Capacity	Plant Type	Operation period [years]
1	7	670	Solar-hydro	1-10
2	3	1.200	Solar-hydro	11-15
3	4	2,400	Pumped storage Solar-hydro	16-160

DISCUSSION

The technical problems to be considered are related to the corrosion of any used piping and the excavation of a canal and tunnel system.

The electrical power supply in Egypt is heavily dependent on the Nile River, including 9,801 GW.hr from the Aswan High Dam hydroelectric power station. The water levels in the Nile have been falling for several years, which has restricted generation at Aswan. The production of electrical energy from the waters of the Nile River is subordinated to the demand for water for agriculture, and this does not correspond generally to the demand for electrical energy. The electric power that these waters can produce is used mainly in industrial zones in the Nile Valley, and there is only a fluctuating energy supply available for the northern industries.

The project would add to a slew of projects accommodating the increased needs for fresh water and electrical energy. These include agricultural expansions at the Siwa Oasis and parts of the Tahrir Province. Land reclamation projects are envisioned for the Bahariya and Farafra Oases. The electrical and fresh water generation from the Qattara Depression pumped storage system would contribute to the planned new population centers in what is presently an arid unpopulated desert.

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