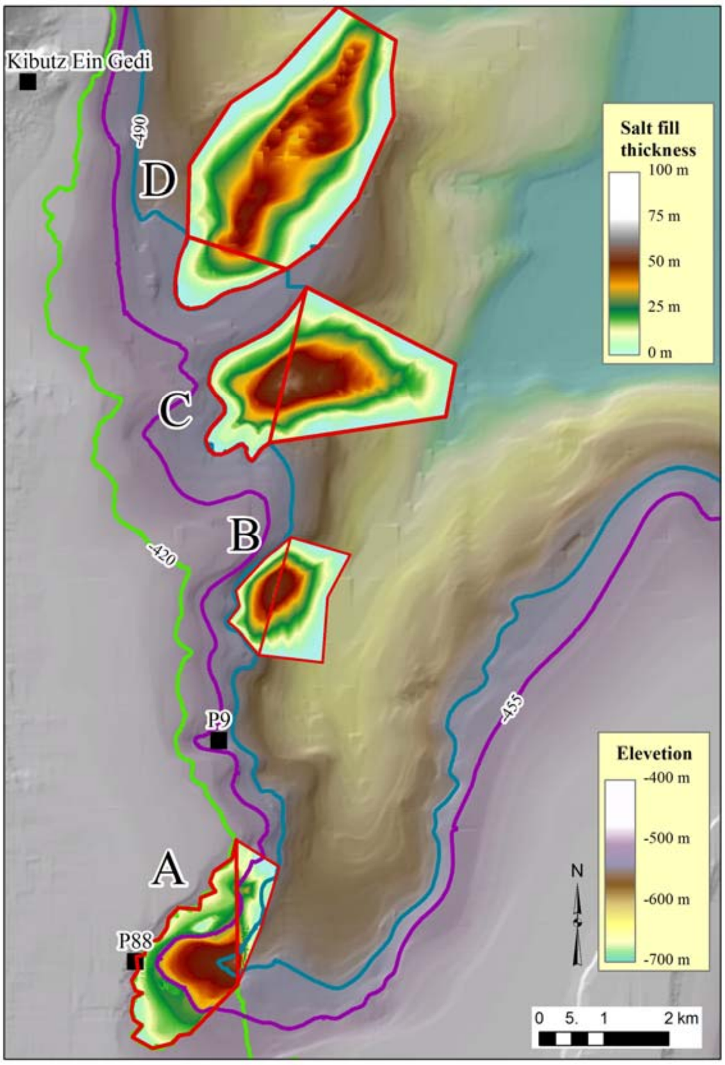
Ministry of National Infrastructures

Geological Survey of Israel

Alternative dumping sites in the Dead Sea for harvested salt from pond 5

Preliminary study based on existing knowledge

Nadav Lensky, Ran Calvo and Ittai Gavrieli



GSI/22/2009

Jerusalem, September 2009

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1. Abstract

Harvesting of 400 MCM of salt from pond 5 (Sdom, Israel) in 25 years demands a dumping site that meets some operational and environmental restrictions. This report presents alternative dumping sites in the Dead Sea (DS) based on preexisting data. The sites were chosen to optimize the following restrictions: minimum transportation distance, avoid exposure of salt piles with the expected level decline, allow free flow of the gravity current of the industrial end-brines down the sub sea gully, avoid possible damage to the pumping stations due to suspended salts, dumping within the Israeli side of the DS, forecast for DS level in the next 25 years and the possible introduction of Red Sea water (or brine). The design of the sites is based on existing bathymetric maps, assumptions on the dynamic and static repose angle and the knowledge of the DS limnology (dynamics). The proposed sites lie on the slopes of the SW part of the DS. Part of the site are in the vicinity of the DS Works (DSW) pumping stations and thus need to be filled before the initiation of P9 and after the abundance of P88. The safety distance between active dumping site and active pumping stations will be analyzed in the next stages when more information on currents and more on the engineering aspects of dumping techniques will be available. For the next stage of the project we need an updated bathymetric map, the repose angle of salt grains in the DS brine (static and dynamic) and characterization of the currents in the SW part of the DS.

2. Introduction

2.1. *The need for salt harvesting*

Over the past several decades, halite (table salt- NaCl) accumulates in the northern evaporation pond (pond 5) of the Dead Sea Works Ltd. (DSW) at a rate of ~20 cm/yr. In order to maintain its operation, the DSW raise the water level in the pond at the same rate, thereby presenting risks to the hotels along its shores. The Dead Sea Preservation Government Company Ltd. (DSPGC) is studying the alternatives to solve this problem. One of the leading alternatives is harvesting the salt from the bottom of pond 5 to stable its level. This alternative requires that huge volumes of salt be removed from the pond; harvesting of the entire pond area (~80 km^2) translates to 16 million cubic meters per year (MCM/yr), or 400 MCM over the next 25 years. For illustration, this volume is equivalent to more than 3 times the volume of Mt. Messada, from bottom to top (Fig. 1). Unfortunately due to the price of transportation, this halite has no economical value. Thus the question is where and how to place this amount of salt.

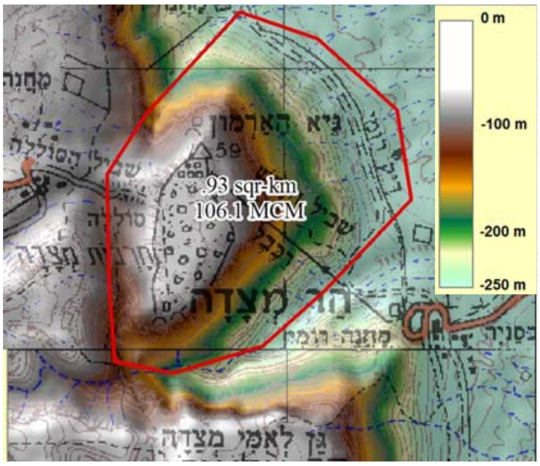


Figure 1: Map of Mt. Messada. The harvested salt volume is more than three times larger than Messada from bottom to top. The red polygon represents the base of Messada used in the calculation of its volume (106 MCM). DTM based on Hall (1997).

2.2. *Where to dump the harvested salt?*

The natural dumping place for the hundreds of million cubic meters of harvested salt is the Dead Sea, from which it was pumped in dissolved form. The DSPGC asked the Geological Survey of Israel (GSI) to propose potential dumping sites in the Dead Sea that will meet relevant operational and environmental restrictions. In this report we identify and outline these restrictions, present relevant data sources, and suggest four alternative sites that can meet the operational and environmental requirements. The plan of four sites is modular and allows filling the sites according to the schedule limitations and the actual amount of salt that will be harvested, partial harvest with total of 50 MCM is also considered by DSPGC.

3. Operational and environmental restrictions

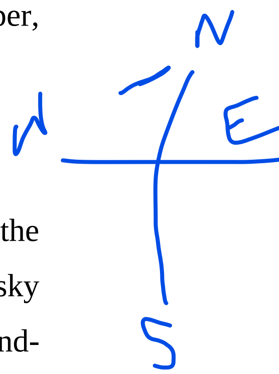
The following points were considered while suggesting sites for salt deposition.

3.1. Minimum distance from pond 5

To minimize transportation costs and environmental impacts on land we searched for minimum distance from the salt source, i.e. pond 5.

3.2. Avoidance of exposure of salt

To avoid the unwanted scene of salt piles along the DS shores, we suggest locating the salt at sites that will not be exposed, due to DS water level decline, during the coming 25 years. This limits the top of the salt piles to elevation of -450 m bsl. To prevent salt piles in the upper mixed layer we suggest locating the salt even deeper, below the future thermocline. This limits the top of the salt piles to -490 m bsl.



3.3. Avoid blockage of the sub-Sea gully

A subsea gully stretches N-NW from the end-brine outlet to the deeper parts of the DS. A gravity current of dens end-brines flows along the bottom of this gully (Lensky et al. 2008). Blockage of this gully with salt piles may result in accumulation of end-brine in the area of the DSW pumping station and may result in pumping of DS brines with some content of the rejected end-brine. Thus we suggest avoiding filling the bottom of the gully with salt.

3.4. Priority to DSW pumping stations

The active and planned DSW pumping stations (P88 and P9, respectively) are within the potential area for the dumping of the salt (see section 5.2 and Fig. 4). There is some conflict between the two projects because of the risk of pumping DS brine that may be loaded with suspended halite particles that were dumped in the vicinity. According to DSPGC, priority should be given to the pumping stations. This implies that some potential areas for salt dumping must be ruled out. In addition, the timing of dumping in the various sites should be planned so as to avoid such a conflict. For example, salt can be deposited at a site that will be adjacent to P9 only prior to its inauguration, while salt deposition near P88 will be allowed only after it will cease to operate. The minimum acceptable distance between active pumping station and the unloading site should be determined. This distance depends on the following: (i) the range of grain size (ii) the dumping techniques (iii) currents in the DS.

3.5. Volume

In the case of full harvest, 400 MCM of salt will have to be transferred to the DS. The volume of the proposed sites is based on the existing bathymetric maps.

3.6. International border

The proposed sites are located west of the international border and do not cross it.

3.7. Red Sea – DS conduit

The proposed Red Sea – Dead Sea conduit is planned to introduce a yet undetermined volume (between 100 and 1000 MCM/yr) of seawater or reject brine from desalination project. This is not considered in the present report, but should be taken into account in the future, as plans for the two projects materialize. An example of possible interaction between these projects may be dissolution of the harvested salt (16 mcm/yr) by the inflowing seawater (or brine) as the latter flow to the DS.

4. Background data

4.1. Bathymetry

The bathymetric maps of the DS are a basic tool in determining potential dumping sites. The available maps are those of Hall (1975) and Golan and Amit (1997). Hall's map covers the entire DS whereas Golan and Amit's map covers the southwest tip of the DS (Fig. 2a-b). The difference between these maps is presented in Fig 2c. The largest deviation is found around the active salt delta, whereby the seafloor in the newer map is more than 50 m higher than in the older map. This is attributed here to the buildup of the salt delta northwards due to the continuous salt supply and the northwards migration of the end-brine outlet following the DS level drop (Beyth et al. 1993). Accordingly, an update map is required for the next stages of this project.

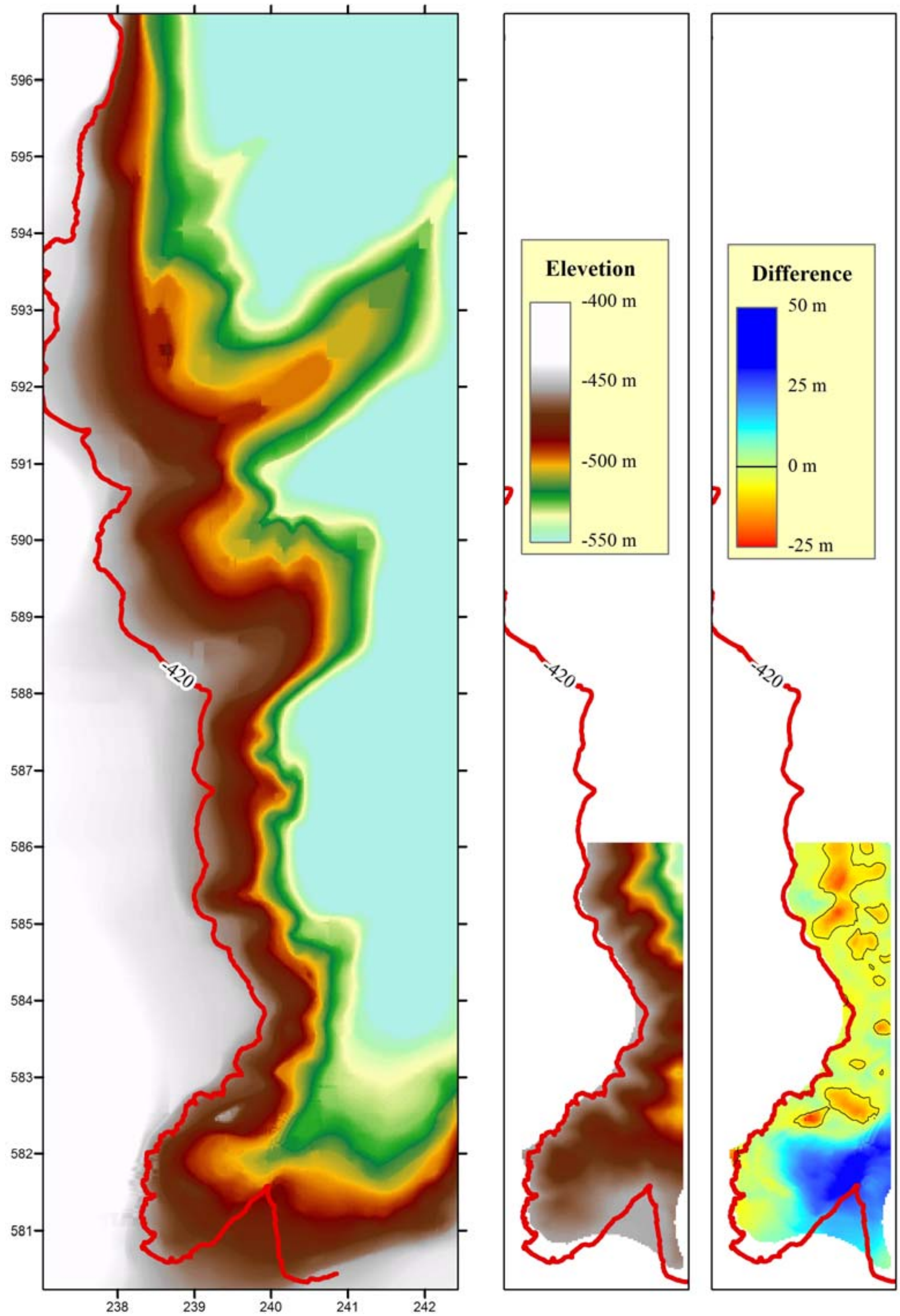


Figure 2: Bathynetric maps of the south-west Dead Sea (A) Hall (1976) (B) Golan and Amit (1996) (C) difference between the two maps (B)-(A). The legend for A and B is in map B. Note the large deviation between the maps in the vicinity of the active salt delta (outlet of the end-brine).

4.2. *Salt grains settling and transport by currents*

Salt grains that will be unloaded near the surface will settle to the bottom, which may be more than 100 m deep. The settling velocity depends on the size and shape of the grains as well as on fixed parameters (viscosity and density difference). The larger the grain the faster they will sink. As an approximation for settling velocity one may take Stokes' law

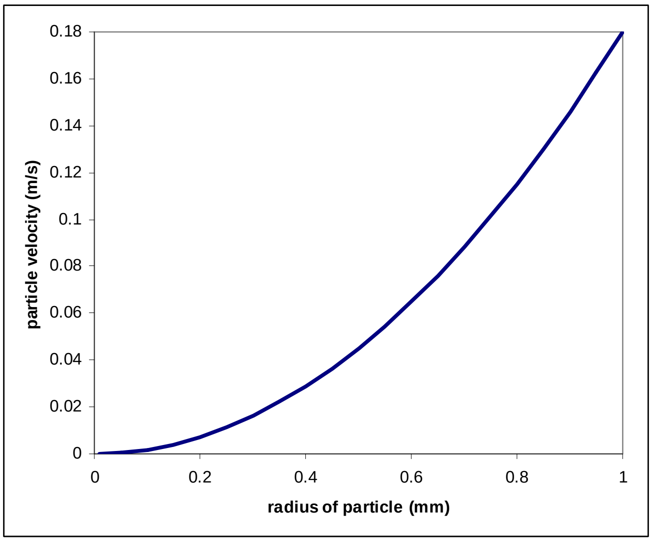
$v=r^2g(\rho_s-\rho_{DS})/18\mu$

where r is the radius of the spherical salt particle, ρ_{DS} and ρ_s - density of the DS brine and of halite, ~1240 and ~2200 kg/m^3 respectively, μ is the viscosity of the DS brine (~3 times larger than that of freshwater at the same temperature, Noam Weisbrod pers. Com.).

The relation between the settling velocity (m/s) and the particle radius (m) is $v(m/s) \sim 0.18 \cdot 10^{-6}(m^{-1}s^{-1}) \cdot 10^6(mm^2/m^2) \cdot r^2(m^2)$, see Figure 3.

Figure 3: Stokes' law - particle velocity as function of radius of spherical salt particle in DS brine. A table of values is provided

Radius of particle (mm)	Particle velocity (m/s)
0.01	0.000018
0.1	0.0018
0.2	0.0072
0.5	0.045
1	0.18
2	0.72



During the grain's travel to the bottom it is subjected to currents in the DS water mass which may carry it away. The distance of such horizontal transport depends on the settling velocity (which depends on grain size), the horizontal component of the current velocity and the local water depth. Fine grains, fast currents and greater depth will result in increasing transport distances.

To quantify the grain distribution we need to know the currents in the DS and the proposed way to unload the salt. First cruise to measure currents was conducted during August 2009 by a joint GSI - Israel Oceanographic and Limnological Research (IOLR) – Bar Ilan University (BIU) team; the results will be reported in the next stage of this project.

The unloading method is very important in this aspect. The DSPGC presented two alternatives that they consider: unloading of dry salt from ferry and a slurry conduit. The slurry jet will produce a wide distribution of the grain in the bottom. Further work is needed here to obtain the behavior of particles during their ascent.

4.3. Salt repose angle – static and dynamic

The repose angle of the granular salt piles is needed for the design of the piles. Re-crystallization of the granular salt piles can significantly increase the cohesion and the repose angle.

The static repose angle represents the maximum angle of the slopes during the buildup of the piles from a point source. This is needed to plan the distribution of salt over the designed sites – steeper angle means that the distribution of the salt should be from more sites, less local.

The dynamic repose angle is smaller than the static one and is the angle below which an earthquake will not cause collapse of the piles. This is very relevant since the DS is located within an active seismic area.

Measurements of the static and dynamic angles will be held during field and laboratory experiments to be conducted by the DSPGC (and DSW) based in coordination with GSI.

In the present report we use a maximum slope of 8% in the design of the eastern slopes. This value is less than the steepest natural sea bottom slopes in the study area. If the dynamic slope will be found to be lower than 8%, the slope will be redesigned accordingly.

5. Suggested sites for the harvested salt

5.1. General outline

Based on existing data and the restriction presented above, four alternative sites were identified (table 1). The sites are named, from south to north, by letters "A", "B", "C" and "D". Figure 4 presents on a bathymetric map, the outline of the sites with the volume, area and maximum depth of each site. In Figure 5 the bathymetry is corrected as to account for the dumping of the salt once the filling has been completed. Figure 6 present the thickness of accumulated salt at each site. Figure 7 is a 3D view of the area from east, before and after the suggested salt deposition.

Table 1: Damping sites characteristics

Site	Volume (MCM)	Area (km^2)	Maximum thickness (m)	Distance from P88	Time restrictions
A	105	3	80	0	After 2014
B	55	2.3	75	4	Before 2014
C	162	6.1	81	8	-
D	245	9.1	64	10	-
B*	190	5	97	4	Before 2014

The maximum volume of salt to be deposited over the 25 years of the project is 400 MCM. The alternatives presented above add up to a total of 700 MCM thereby allowing flexibility in the planning phase. All sites were chosen to be away from the bottom of the gully stretching NNW from the south west of the DS toward its center (Fig. 4) and are located away from the international border. The top of sites B-C-D is at elevation -490 bsl, following the considerations listed in table 1. Site A is located in the bay of the currently active pumping station (P88). The salt at this site will be exposed within a few years, in a similar fashion to the exposure of the salt delta at the end-brine outlet. In fact much of the exposed surface sediments in the Lynch straits comprise of such salt. It should be noted that shortly after its exposure the salt delta attains a brown color (probably dust accumulation). We expect that the same will occur at site A.

5.2. Specific comments on the sites

<u>Site A</u> - This site can accommodate more than a hundred MCM of salt with top elevation of -420 m bsl (2 m above the current level). It can accommodate 105 MCM; every added meter in height will add 3 MCM. The advantage of this site is that it is the closest to pond 5. However, this site should be carefully considered for its environmental aspects and impact because the salt here is planned to be exposed on land. To be noted, the eastward migrating mouth of Nahal Ze'elim is within this area and thus any salt that will be dumped along its future path will be dissolved and removed to the DS. This site can be filled after P88 is abandoned, which means not before 2014.

Site B – This site can accommodate about 55 MCM over an area of ~2.3 km^2 with maximum pile thickness of ~75m. This site lies one km north-east to the planned P9 pumping station. The exact location of P9 is not finalized yet but it will apparently lay at a depth of -475 m bsl. It is suggested that this site will be filled prior to the beginning of operation of P9, i.e. before 2014. Filling this site with synchronous with the pumping in P9 needs a determination of safety distance from the pump. This distance needs to be determined based on the solution of salt dumping (suspension from a conduit, dry salt dumping from ferries), the grain size distribution, typical currents in the area, adhesion and re-crystallization of the salt grains once they settle. Options A and B together can accommodate some 160 MCM, but the time table must be synchronized in accordance with the planned operation of the DSW pumping stations.

Potentially, site B can be extended southwards to the area of P9, and then it will accommodate a total of 188 MCM (B* in table 1). However this will be in the immediate vicinity of the pump station P9. Dumping salt to this extension of site B calls for more detailed examinations to make sure that it will not harm the function of the pump station.

Sites C and D – The northern options, with the disadvantage of longer distance, more than 10 km from the end-brine outlet and about 5 km north of the planned P9. These sites can accommodate some 400 MCM over an area of 15 km^2.

5.3. Required Information for further work

- Bathymetry – to be conducted by IOLR, report expected by Jan. 2010.
- Salt repose angle – static and dynamic, based on field and laboratory experiments, to be conducted by DSW.
- Currents - based on ADCP measurements, drifters and remote sensing, to be conducted by GSI, IOLR and BIU.
- Plans for P9 – location and timetable, to be provided by DSW.
- DS Red Sea conduit – plans and timetable, input from World Bank feasibility study.
- Distribution techniques – dry salt by ferries, slurry, to be provided by DSPGC.
- Adhesion and re-crystallization of the salt piles in the DS – explore the rate of transformation from loose salt grains to a massive salt rock.

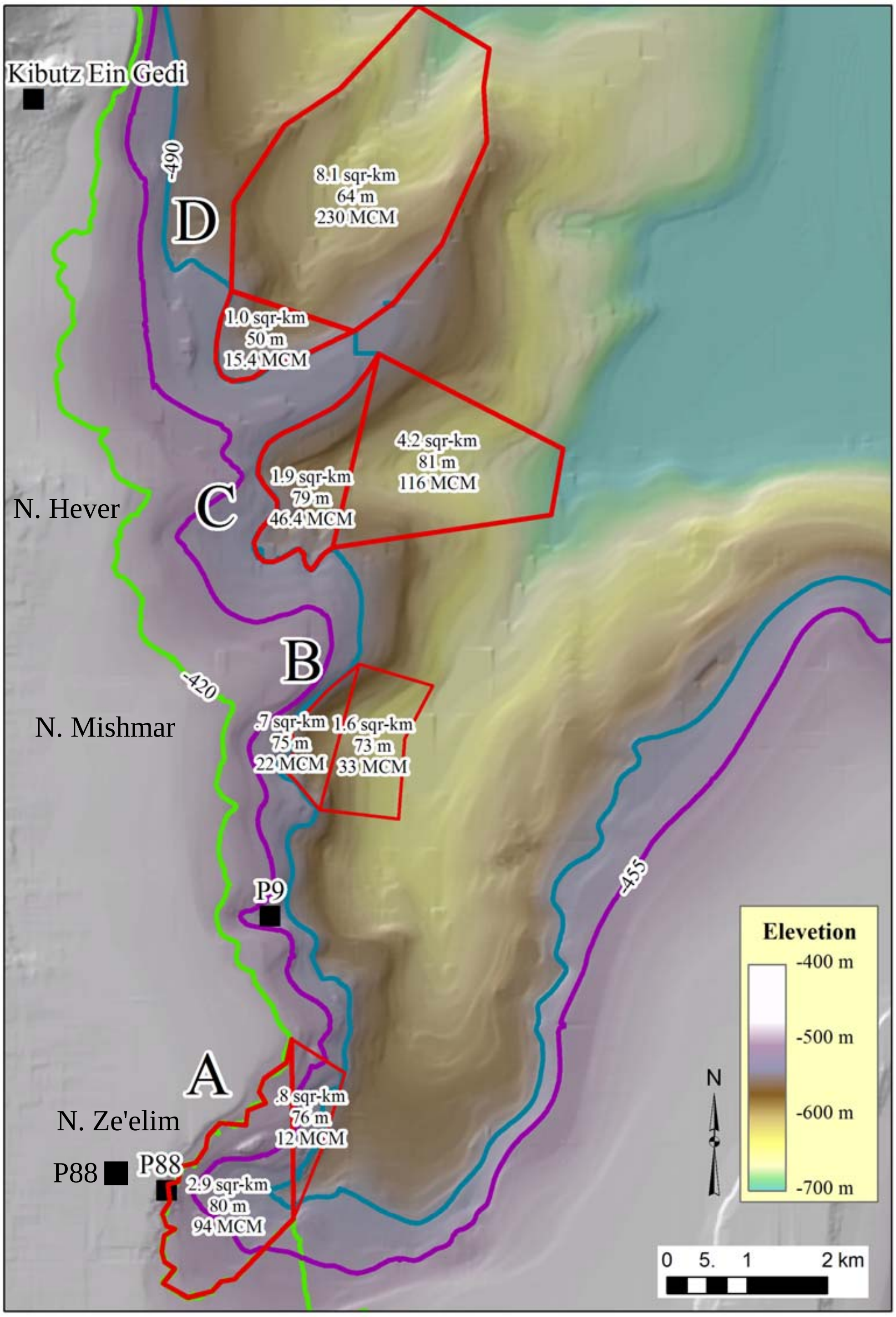


Figure 4: Bathymetric map with the proposed dumping sites. The four sites are marked with block letters, each site has an eastern part which slopes to the east and a western part with flat roof. The volume, area and maximum thickness of each site is marked. The base map is a shaded relief bathymetric map based on the bathymetry of Hall (1976). Location of the pumping stations P88 and the planned P9 are marked (the location of P9 is preliminary).

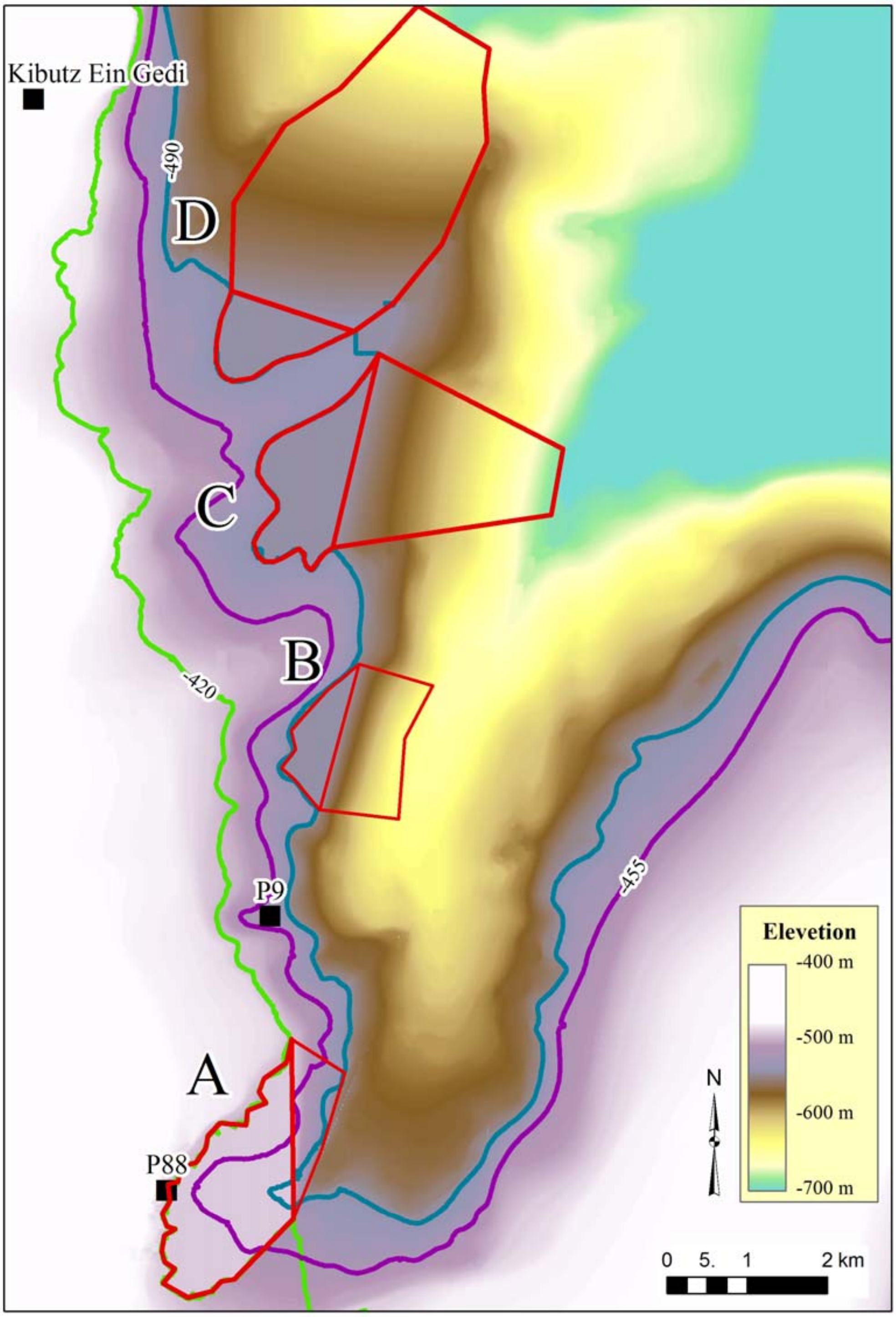


Figure 5 Bathymetric map with the proposed dumping sites after their filling (see Fig 4 for more details). P88 – DSW active pumping station, P9 – location of the southern-most alternative of the planned station, might be up to 2 km further north at the same depth (pers. comm. DSW).

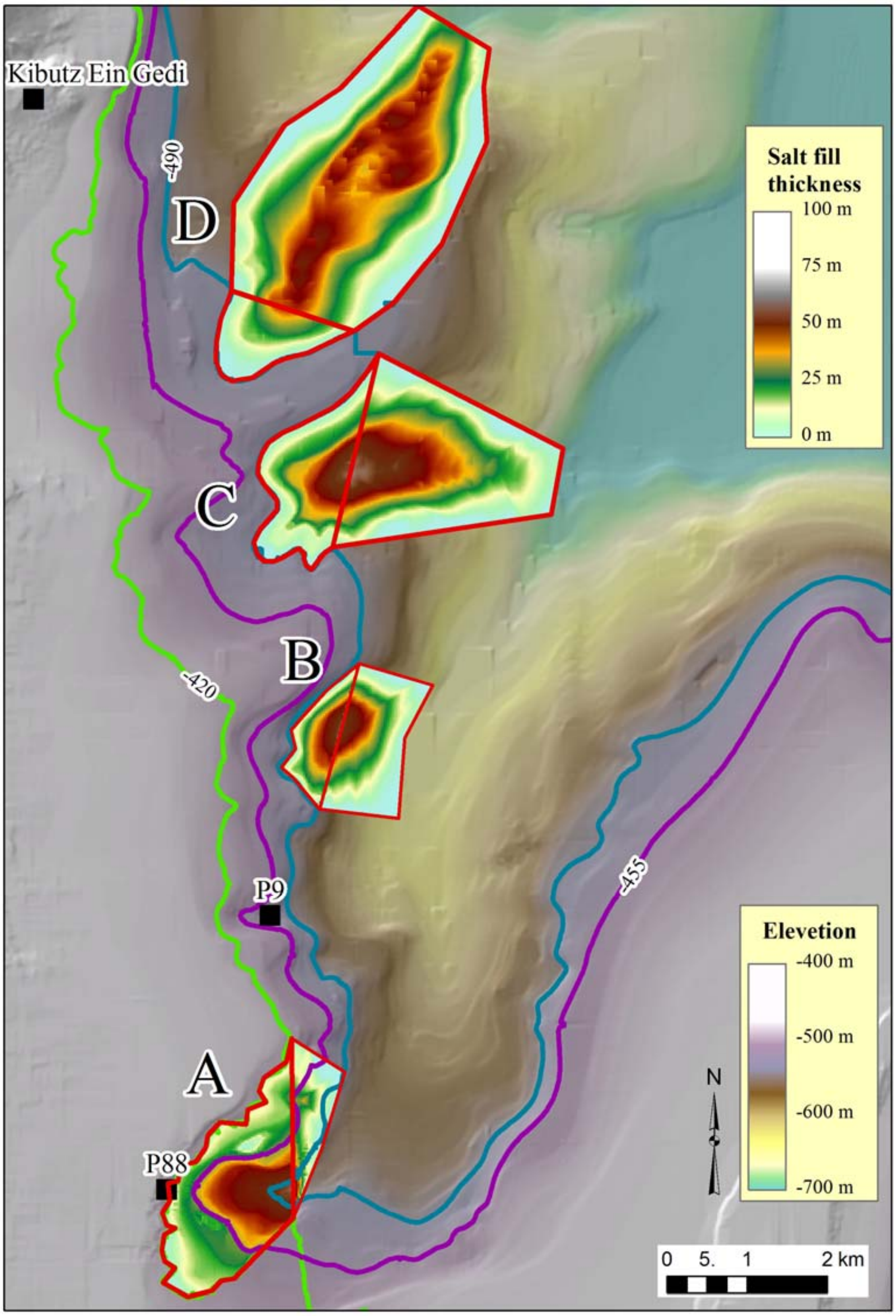


Figure 6: Bathymetric map with the proposed sites for salt deposition including the thickness of salt deposits at the sites (see Fig 4 for more details).

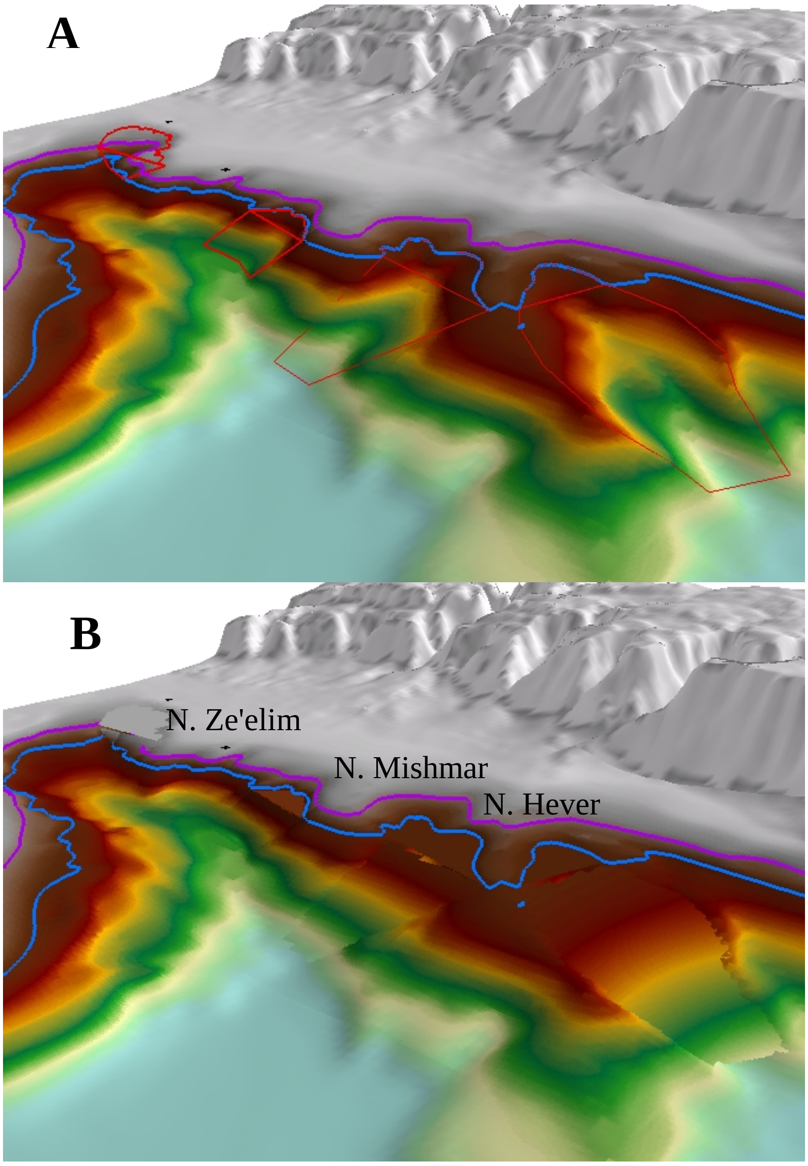


Figure 7: 3D illustration of the south western DS with the proposed sites (A) as polygons on the DTM and (B) after their filling with salt (see Fig 4 for more details).

6. References

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