Three-Dimensional Digital Elevation Model of the Karashor Depression and Altyn Asyr Lake

Andrey G. Kostianoy and Sergey A. Lebedev

Abstract Digital elevation model of the Karashor Depression was constructed on the base of the Shuttle Radar Topography Mission with the horizontal resolution of 90 m and the vertical resolution of 1 m. The model allowed to get a highly precise three-dimensional topography of the Karashor Depression, to analyze it at several sections crossing the depression, to investigate morphometric characteristics of the future Altyn Asyr Lake at all stages of its filling with a step of 1 m depth, and to establish real values of the lake maximum allowed depth, surface, and volume, as well as estimate the time of the lake filling.

Keywords Altyn Asyr Lake, Digital elevation model, Karashor Depression, Shuttle Radar Topography Mission, Turkmenistan

Contents

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1 Introduction

Today there is an increasing demand for satellite and in situ environmental data for scientific and practical purposes. In many cases the analysis of these data requires high-resolution models of the surface topography. Digital terrain modelling is a very useful tool for professionals working on the applications of terrain models in support for policies and decision making [1]. Digital elevation models (DEM) are widely used in many hydrogeological applications, such as delineation and analysis of watersheds and drainage networks, flood simulation, flood risk mapping and the design of flood emergency reservoirs, as well as agriculture, melioration of lands, construction of canals, roads, pipelines, and tunnels, civil engineering, military applications, etc. [1]. Turkmenistan is a country where the "Altyn Asyr" Project is developing, which includes a constriction of a long chain of drainage canals, which will forward drainage water from arable lands to the Karashor Depression, where during 15 years Altyn Asyr Lake will be formed. DEM technologies should be used implementing this greatest national project.

According to the Project, Altyn Asyr Lake will be 103 km long, 18.6 km wide, and 69 m deep. It will have a surface of about 1,915.8 km^2 and a volume of 132 km^3 [2, 3]. It is planned that the depression will receive annually 10 km^3 of collector-drainage water (CDW); thus it will be filled during about 15 years. It seems that these characteristics of the lake represent only some rough estimates, which are far from real values, knowledge of which is very important for calculation of the water budget of the lake, the amount of year-to-year water supply required for filling the depression, and the forecast of the time of the lake filling. This is explained by the fact that the high-resolution DEM of the Karashor Depression was not constructed and used for the analysis of morphometric characteristics of the future lake. Instead, conventional topographic cartography of uneven quality was used, and the surface and volume of the lake were calculated by a simple multiplication of the length, width, and depth of the lake which is not correct, because the Karashor Depression is not a rectangular body.

In this chapter we describe the DEM of the Karashor Depression we constructed on the base of digital surface topography of the area with the spatial resolution of 90 m and the vertical resolution of 1 m, provided by the Shuttle Radar Topography Mission (SRTM) [1, 4–6]. We hope that the obtained results will help decision-makers in Turkmenistan to take correct decisions at the final stage of the Altyn Asyr Lake construction.

2 Shuttle Radar Topography Mission

The SRTM acquired surface topography elevation data on a near-global scale (80 % of Earth's land surface from 60°N to 54°S, see Fig. 1) to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system (interferometric Synthetic Aperture Radar) that flew onboard
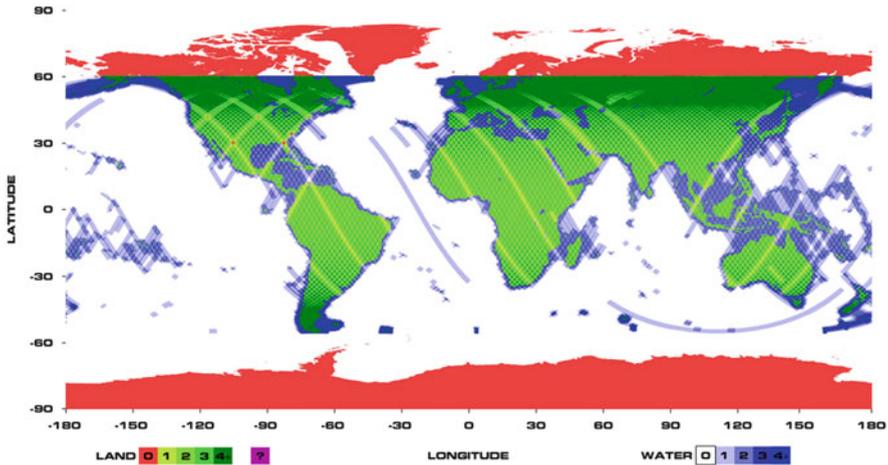
Fig. 1 The SRTM global coverage map [5]

the Space Shuttle "Endeavour" during an 11-day mission in February of 2000. In order to gather topographic (elevation) data of Earth's surface, SRTM used the technique of interferometry, when two images are taken from different vantage points of the same area. The slight difference in the two images allows scientists to determine the height of the surface with high accuracy. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) of the USA [4–6].

The SRTM radar contained two types of antenna panels, C-band and X-band. The near-global topographic maps of Earth called DEMs are made from the C-band radar data. These data were processed at the Jet Propulsion Laboratory (USA) and are being distributed through the US Geological Survey's EROS Data Center. The data are available from the USGS server at http://dds.cr.usgs.gov/srtm/. The data are also available through the USGS seamless server at http://seamless.usgs.gov/. Data from the X-band radar are used to create slightly higher resolution DEMs but without global coverage of the C-band radar. SRTM X-band radar data are being processed and distributed by the German Aerospace Center (DLR) [4, 5].

Users should be aware that these data are intended for use with the Geographic Information System (GIS) or other special application software, and are not directly viewable in a browser. Also, users should be aware that the digital topographic data and images are unedited and are intended for scientific use and evaluation. The SRTM data may contain numerous voids (areas without data), water bodies that may not appear flat, and coastlines that may be ill defined [4, 5]. NASA has released version 2 of the SRTM digital topographic data (also known as the "finished" version). Version 2 is the result of a substantial editing effort by the NGA and exhibits well-defined water bodies and coastlines and the absence of spikes and wells (single-pixel errors), although some areas of missing data ("voids") are still present. The version 2 directory also contains the vector coastline mask derived by

the NGA during the editing, called the SRTM Water Body Data (SWBD), in ESRI Shapefile format [4, 5].

Figure 1 shows global coverage of the SRTM mission. The colors of the swaths indicate the number of times the area was imaged by SRTM. For land, one-time coverage is green, twice is yellow-green, and so on, as shown in the color palette at lower left. Over water, the color code is in shades of blue as shown in the color palette at lower right. Areas in red could not be mapped. SRTM is a topography mission, so data were mostly acquired over Earth's land. Small amounts of data were collected over water for calibration purposes [4]. The cartographic products derived from the SRTM data were to be sampled over a grid of 1 arc-s by 1 arc-s (approximately 30 m by 30 m), with a linear vertical absolute height error of less than 16 m, and a linear vertical relative height error of less than 10 m. A comparison with available ground truth data showed that the absolute vertical error is better than 9 m globally (better than 5 m for the Turkmenistan territory) and the vertical resolution is about 1 m [5].

Raw data, full-resolution terrain height data, and strip DEMs with the 1 arc-s (30 m) spatial resolution for areas outside the territory of the USA are under the control of the Department of Defense. NASA and the NGA are trying to work out a policy allowing access to 1 arc-s non-US SRTM data for scientific use. The same types of data for areas within the USA and its possessions are not subject to restrictions. Distribution of terrain height data with the spatial resolution larger than or equal to 3 arc-s (90 m) is not subject to restrictions [5]. In the present analysis we used this restriction-free type of data.

3 Digital Elevation Model of the Karashor Depression

The Karashor Depression (Altyn Asyr Lake) is located in the northwestern part of the country between the Kara-Bogaz-Gol Bay of the Caspian Sea on the west and Lake Sarykamysh on the northeast (see Fig. 2 for location). From the west the depression is surrounded by Uchtagan Sands which close the Chulyungkyr Plateau. From the south, the ancient riverbed of Uzboy River limits a trough and plateau Kaplankyr. To the northwest of the Karashor Depression there is a smaller dry saline depression Kazakhlyshor (Kazakh Shor). Karashor is a deep dry depression with some salt deposits at the bottom. Its length along the long axis is about 110 km, it is 20 km wide in the northwest, and in the southeasterly direction, it gradually narrows (Fig. 3). In the northeast it is bordered by a high (up to 319 m) chink of the Kaplankyr Plateau. From the west it adjoins a large array of hilly sands. The bottom of the depression is located at a level of −28 m (28 m below the ocean level) [3].

The Karashor Depression DEM was constructed from the SRTM data with the spatial resolution of 90 m and the vertical resolution of about 1 m. We limited the model by the following geographical coordinates – 40.25–41.15°N and 56.35–57.15°E (Fig. 3). The depression is stretched from the southeast to the northwest with the deepest part there. The bottom of the depression is quite flat and inclined into the northwestern direction, where it reaches −32 m level, i.e., 32 m below
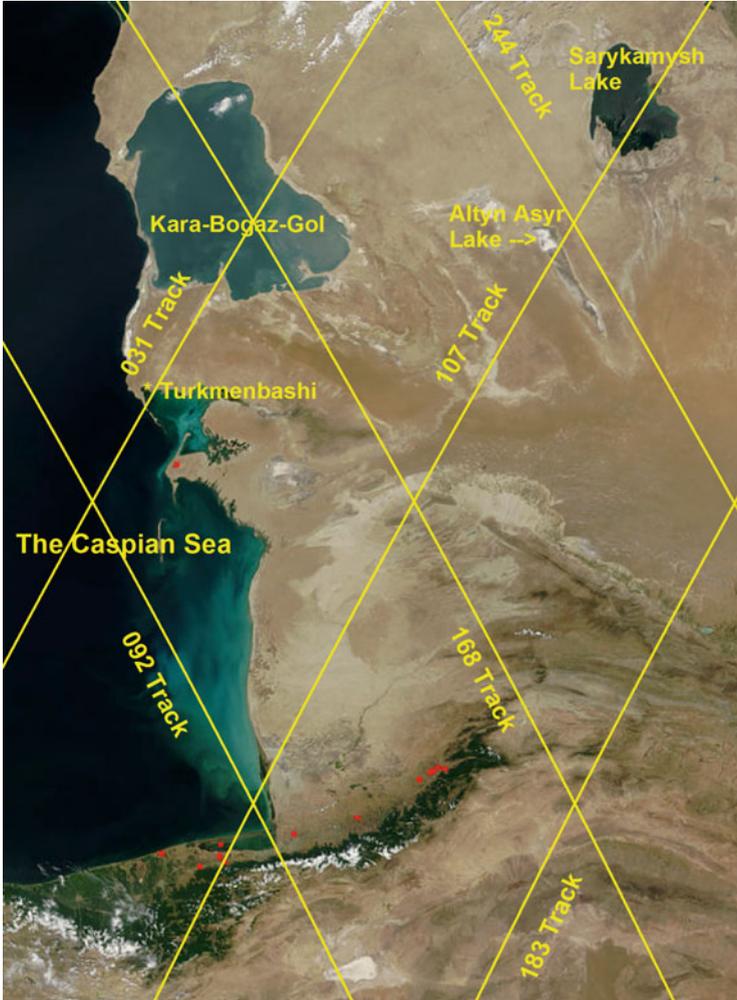
Fig. 2 The Caspian Sea, Kara-Bogaz-Gol Bay, Sarykamysh Lake, Altyn Asyr Lake (the Karashor Depression) on MODIS image acquired on 28 May 2002 with the superposition of the TOPEX/ Poseidon and Jason-1/2 satellite ground tracks

the ocean level, which corresponds well with in situ topographic measurements (-28 m) [3]. The difference in 4 m abs. level may be explained by the absolute vertical error of about 5 m for Turkmenistan. The walls of the depression look to be very steep, as the gradient of the level changes very sharply at the borders of the depression. The maximum length of the depression is 110 km and the maximum width is 21.5 km in its northwestern part (Fig. 3). The 107 ground track of the TOPEX/Poseidon, Jason-1, and Jason-2 satellites crosses the northwestern part of the depression (Figs. 2 and 3). The length of the track inside the depression is 21 km. In the future it will be possible to
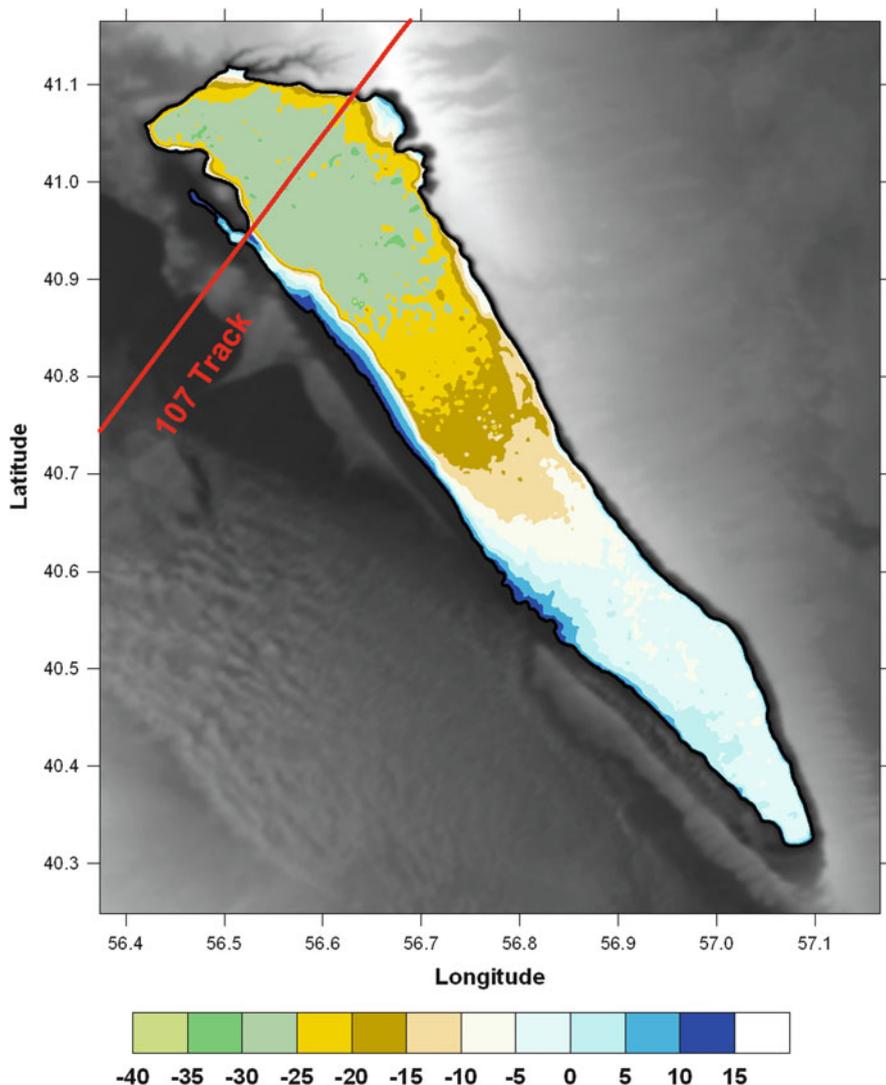
Fig. 3 The topography map of the Karashor Depression. *Color palette* shows the absolute level in meters in the depression. Areas outside the depression were shaded by *grey* colors. *Red line* shows the 107 ground track of the TOPEX/Poseidon and Jason-1/2 altimetry satellites

follow water filling of the lake basing on satellite altimetry data along this track as it has been done since 1993 for the Kara-Bogaz-Gol Bay case study [7].

Three-dimensional topography of the Karashor Depression is presented in Fig. 4, where there are two airviews – from the southwest (transversely to the depression) and from the northwest (along the axis of the depression). The first view shows that the depression has high steep walls at its back northeastern side with the highest
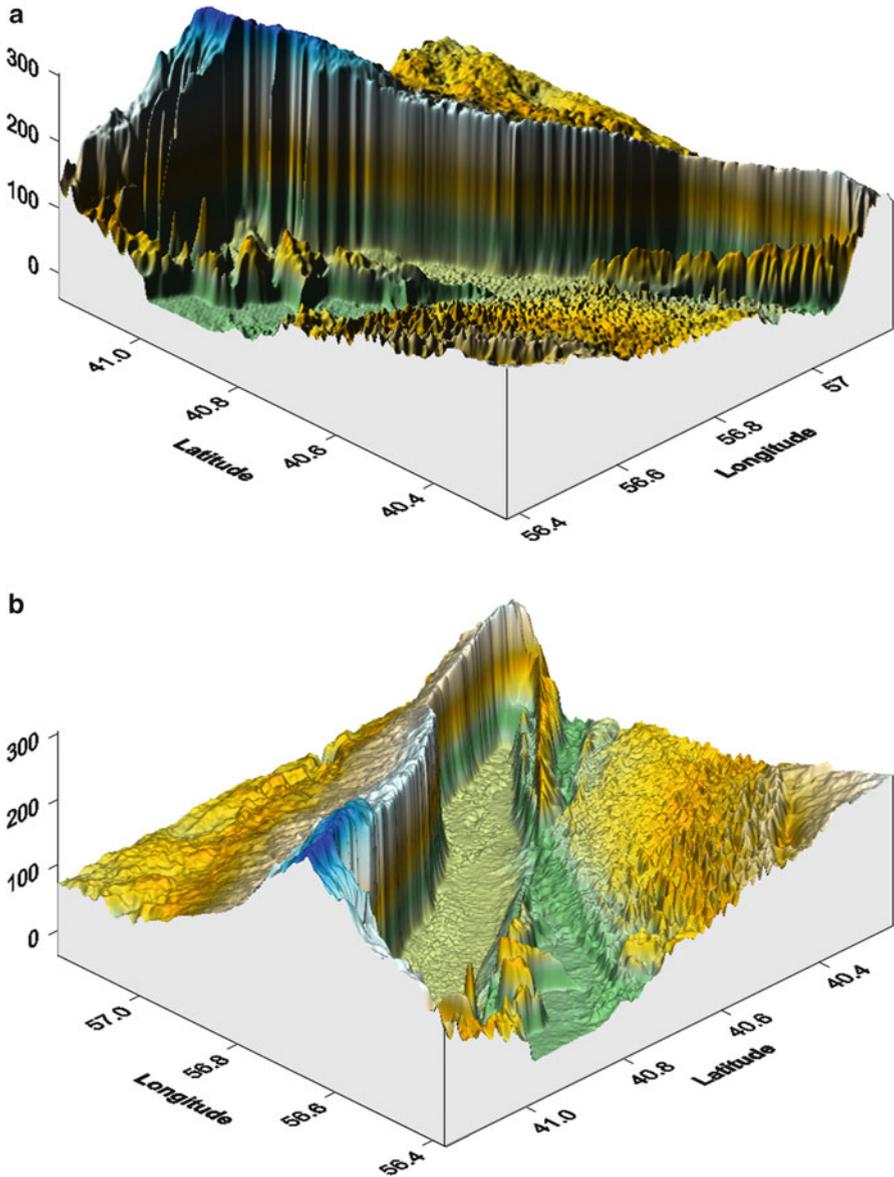
Fig. 4 Three-dimensional topography of the Karashor Depression: An airview from the southwest (**a**) and from the northwest (**b**)

point more than 300 m at the Kaplankyr Plateau closer to the northwestern end of the depression (Fig. 4a). The height of the chink (which looks like a chain of mountains) gradually decreases to the left and right, encircling the depression from both sides. The front southwestern side of the depression is partially open; therefore
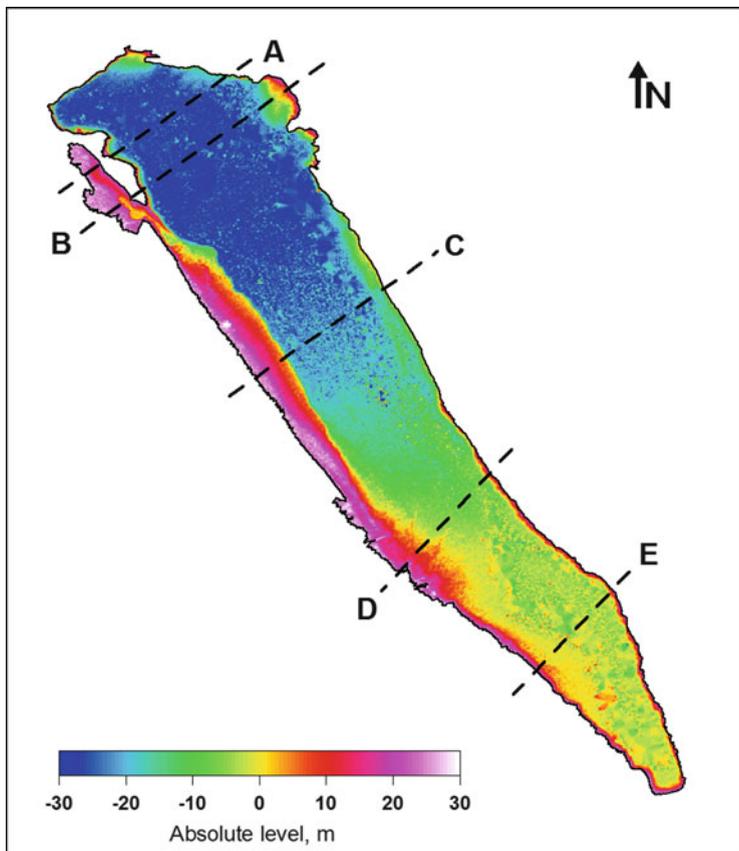
Fig. 5 Bottom topography of the Karashor Depression (absolute level in meters) and the location of cross sections A, B, C, D, and E

the canal will bring CDW to Altyn Asyr Lake via local gates somewhere in this place.

A bird's eye view on the depression from the northwestern corner is also very spectacular (Fig. 4b). It shows that the depression is deep, the bottom is wide and flat, and the walls of the depression are high and almost vertical on the left (northeastern) side and low on the right (southwestern) side of the depression. In the middle of the southwestern side there is a natural decrease in topography which will be used as a point for CDW delivery to the depression. It seems that the future Altyn Asyr Lake will have a fantastic landscape, and a magnificent view from any point will reward travelers and tourists. Also, the easiest accessible place at the coast of the lake will be located in the middle of its southwestern side, where the lake management infrastructure, probably, will be constructed.

Let's look at the vertical cross sections in different parts of the depression. The location of five sections A, B, C, D, and E is shown in Fig. 5. Sections A and B are

located in the widest northwestern part, C and D – in the middle part, and E in the southeastern narrowest part of the depression. Figure 6a–e shows vertical profiles of topography in the Karashor Depression and surrounding borders at different sections. The dashed line denotes the maximum allowed level of the future Altyn Asyr Lake, which was defined by the analysis of the closed contours at different levels of land topography with a step of 1 m (see Table 1). The last closed contour was at the level of +28 m, which gives the maximum allowed depth of the lake of 60 m. The first open contour was at the level of +29 m, which means that excess water will flow outside of the lake and flood the nearest areas located farther northwestward.

Figure 6a (Section A) shows a flat bottom, a depth of about 55 m, a width of about 20 km, an almost vertical wall 220 m high over the lake level on the right side of the depression axis, a future narrow peninsula, and a small and shallow bay close to the mainland on the left side (see also a plan view in Fig. 5). Figure 6b (Section B) shows more or less the same characteristics, but the wall is higher – 260 m. Figure 6c (Section C) shows that the wall height over the lake level will be 190 m, the depth in the middle of the lake – 50 m, and the width – 18 km. The left coast will be almost flat because the land will rise to 40 m gradually along a distance of 1 km from the shoreline. Section D (Fig. 6d) shows the lake width of about 15.3 km, the maximum depth less than 40 m, the eastern wall as high as 190 m, and the western coast to be flat – 30 m for 3 km distance from the shoreline. The southeasternmost Section E (Fig. 6e) crosses the lake with the depth of about 30 m, its width here is 13 km, the wall height is of 130 m, and left coast topography on the distance of 4 km is irregular with maximum heights of 80 m (see also Fig. 4a for a plan view).

The morphometric characteristics (depth, surface, volume) of Altyn Asyr Lake were calculated on the base of the Karashor Depression DEM with a step of 1 m abs. level (Table 1). This information is of vital importance for the Altyn Asyr Project, as well as for other scientific and practical purposes. The morphometric characteristics are given for the range of absolute levels between −30 m and +28 m, which is a maximum possible level of the lake. At this level mark the maximum depth of the lake will be about 60 m (mean depth – 37 m), surface – about 1,325 km^2, and volume – about 50 km^3. These values significantly differ from those suggested in the Altyn Asyr Project – 69 m, 1,915.8 km^2, and 132 km^3 [2]. The difference is explained by the fact that the Project values were obtained by a simple multiplication of the planned length (103 km), width (18.6 km), and depth (69 m) of the lake, which is not correct.

DEM of the Karashor Depression in the northwestern part of its bottom gives topography level values deeper than −30 m as well (down to −38 m), but the analysis of spatial distribution of these depths shows that these are small-scale separated ponds. A much greater number of the smallest "ponds" at levels below −32 m is probably related with horizontal and vertical errors of the SRTM database. From the other hand, if we divide the lake volume of 0.002 km^3 on its surface of 1.45 km^2 (characteristic values for −30 m abs. level) (see Table 1), we
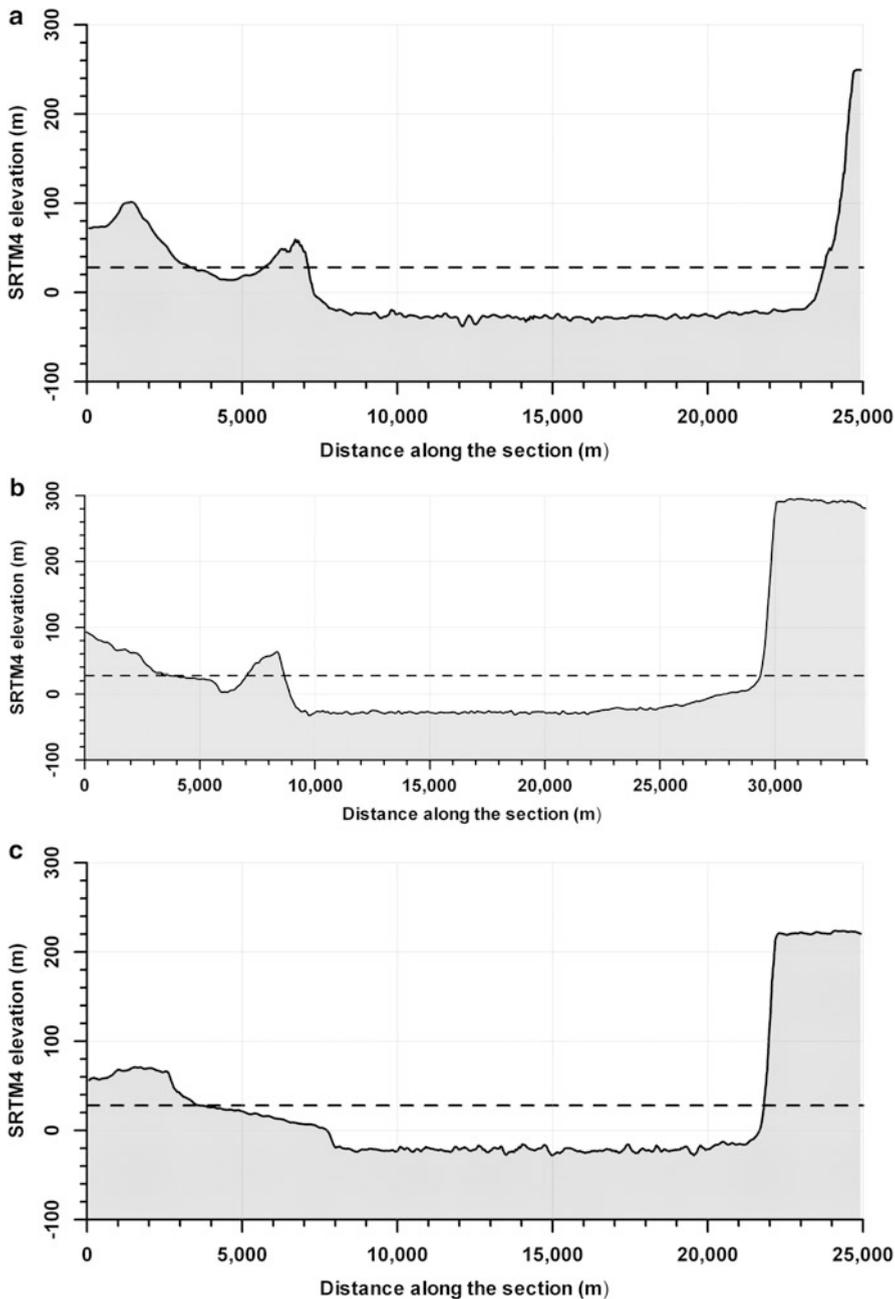
Fig. 6 (continued)
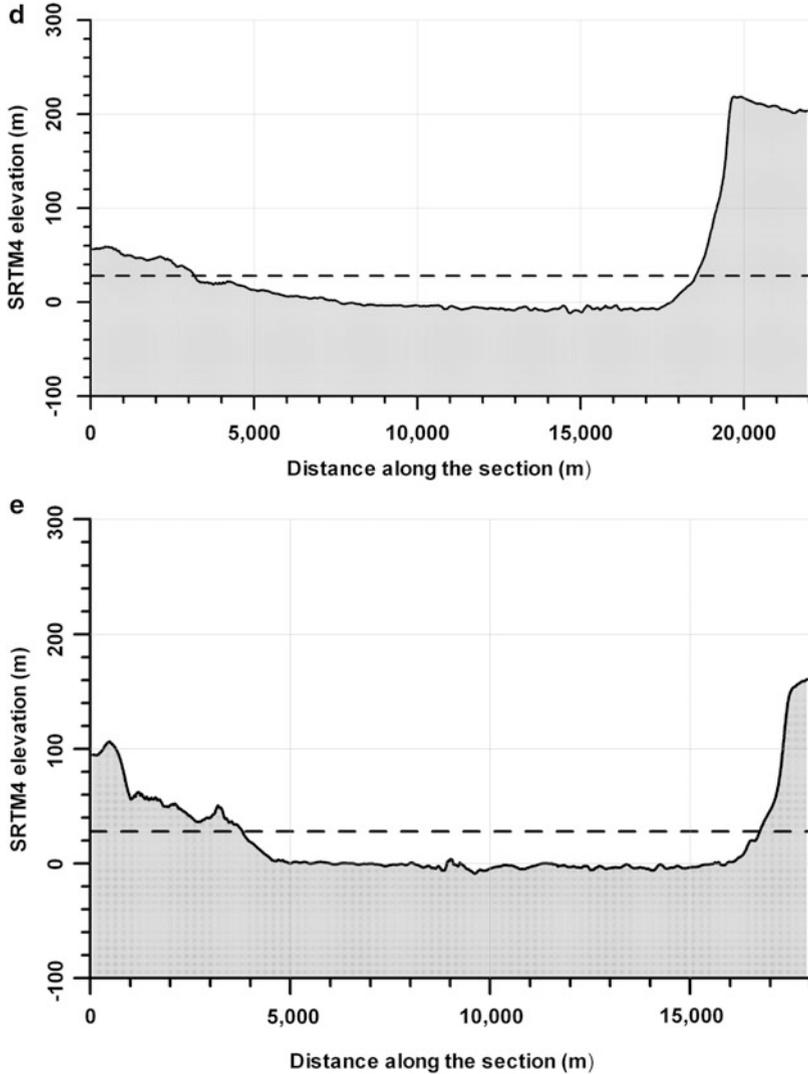
Fig. 6 Vertical profile of the topography across the Karashor Depression at sections A (**a**), B (**b**), C (**c**), D (**d**), and E (**e**). See Fig. 5 for location of sections. Vertical height is in meters of absolute level. The *dashed line* shows the maximum water level in Altyn Asyr Lake. *Grey* color shows land

will get 1.4 m as an averaged depth (assuming that the lake already represents a single water body). Thus, for simplicity we can suggest that the bottom of the lake is located at −32 m abs. level. This is the reason why we started the table with −30 m abs. level (2 m depth).

Table 1 Morphometric characteristics of Altyn Asyr Lake at different stages of its filling

Lake abs. level (m)	Lake surface (km^2)	Lake volume (km^3)	Lake depth (m)	Lake abs. level (m)	Lake surface (km^2)	Lake volume (km^3)	Lake depth (m)
−30	1.450	0.002	2	0	1,011.681	16.729	32
−29	3.062	0.007	3	1	1,042.332	17.754	33
−28	20.932	0.044	4	2	1,058.429	18.804	34
−27	220.655	0.361	5	3	1,070.937	19.870	35
−26	281.584	0.608	6	4	1,082.894	20.951	36
−25	318.386	0.886	7	5	1,094.182	22.045	37
−24	345.765	1.200	8	6	1,104.882	23.151	38
−23	376.518	1.559	9	7	1,115.116	24.269	39
−22	411.269	1.958	10	8	1,124.630	25.398	40
−21	446.782	2.389	11	9	1,136.451	26.550	41
−20	469.450	2.833	12	10	1,145.142	27.700	42
−19	494.174	3.312	13	11	1,153.819	28.861	43
−18	513.610	3.810	14	12	1,162.189	30.029	44
−17	532.538	4.333	15	13	1,169.939	31.203	45
−16	553.940	4.878	16	14	1,179.778	32.388	46
−15	575.246	5.445	17	15	1,189.221	33.583	47
−14	600.727	6.036	18	16	1,198.849	34.784	48
−13	616.974	6.645	19	17	1,208.674	35.996	49
−12	636.356	7.273	20	18	1,217.602	37.218	50
−11	655.206	7.925	21	19	1,226.217	38.449	51
−10	671.744	8.591	22	20	1,235.801	39.689	52
−9	691.232	9.276	23	21	1,246.285	40.940	53
−8	707.943	9.976	24	22	1,254.653	42.197	54
−7	721.580	10.689	25	23	1,263.599	43.463	55
−6	741.686	11.427	26	24	1,273.271	44.738	56
−5	756.948	12.178	27	25	1,286.912	46.027	57
−4	797.461	12.991	28	26	1,299.132	47.329	58
−3	860.029	13.861	29	27	1,308.265	48.641	59
−2	930.179	14.794	30	28	1,324.898	50.039	60
−1	979.590	15.743	31				

To illustrate these values we presented Table 1 in different graphical forms. In Fig. 7 we draw contours of the lake surface (shaded by black color) at different absolute (sea) levels, which correspond to different stages of the lake filling. In total there are 12 frames corresponding to the absolute levels between −30 m (2 m max depth) and +25 m (57 m max depth) with a step of 5 m. A contour of the maximal lake surface is shown in every frame for spatial comparison of the shapes. Figure 7 shows that the filling of the lake will start from the deepest part of the depression in the northwestern part, and the configuration of the lake will change significantly with an increase of the water level from −30 m to 0 m abs. level (max depth of 32 m). Then the surface of the lake will increase slowly and the lake configuration will not change significantly till it reaches the maximum level of +28 m abs. level.
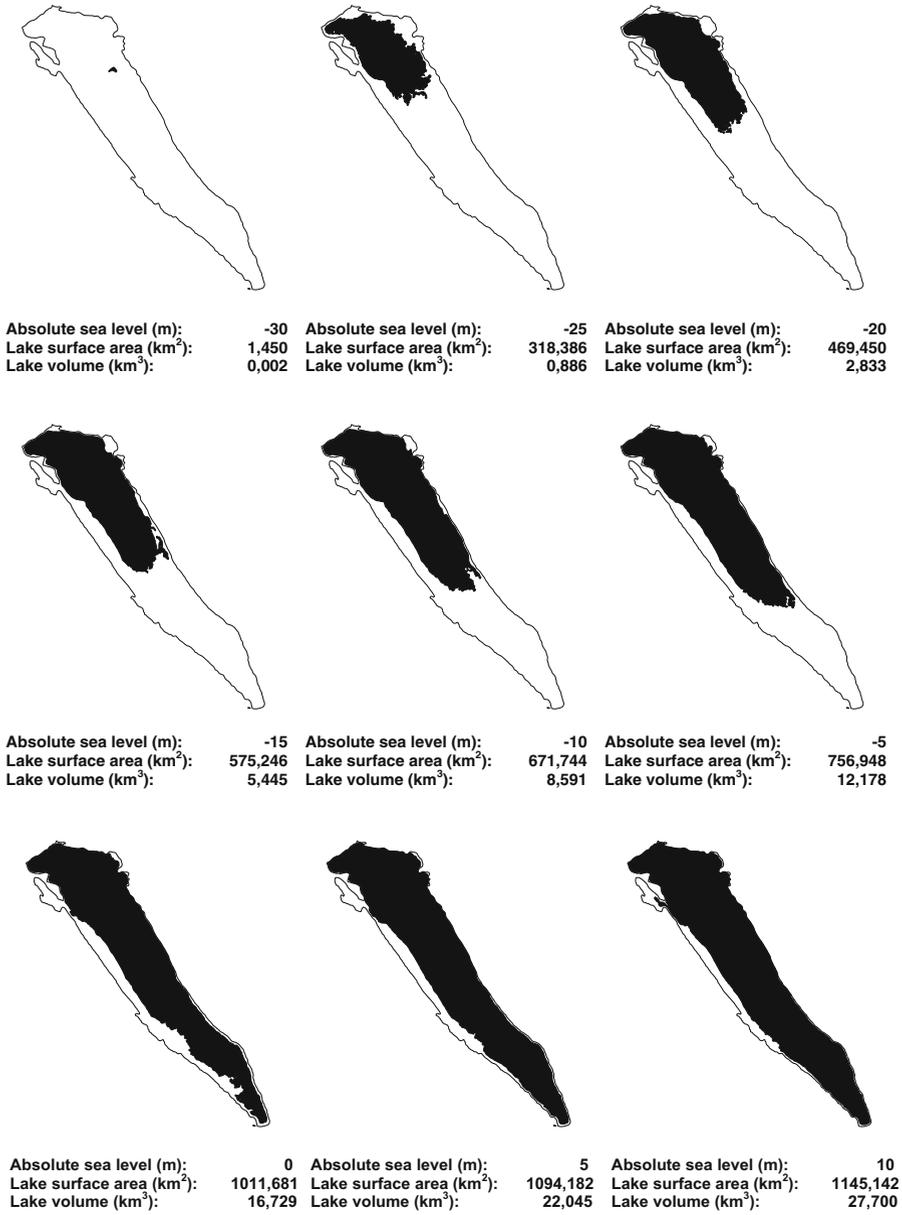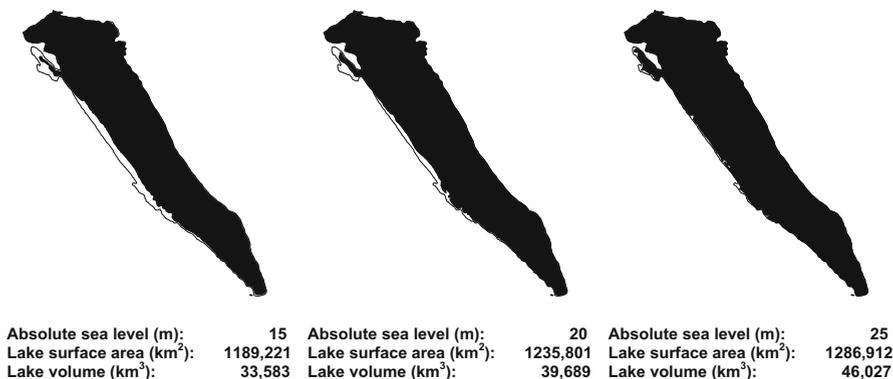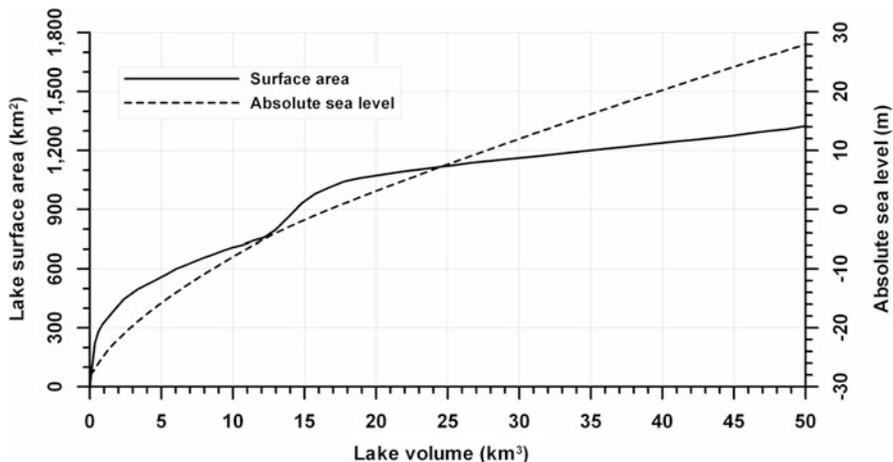
Absolute sea level (m):	-30	Absolute sea level (m):	-25	Absolute sea level (m):	-20
Lake surface area (km^2):	1,450	Lake surface area (km^2):	318,386	Lake surface area (km^2):	469,450
Lake volume (km^3):	0,002	Lake volume (km^3):	0,886	Lake volume (km^3):	2,833

Absolute sea level (m):	-15	Absolute sea level (m):	-10	Absolute sea level (m):	-5
Lake surface area (km^2):	575,246	Lake surface area (km^2):	671,744	Lake surface area (km^2):	756,948
Lake volume (km^3):	5,445	Lake volume (km^3):	8,591	Lake volume (km^3):	12,178

Absolute sea level (m):	0	Absolute sea level (m):	5	Absolute sea level (m):	10
Lake surface area (km^2):	1011,681	Lake surface area (km^2):	1094,182	Lake surface area (km^2):	1145,142
Lake volume (km^3):	16,729	Lake volume (km^3):	22,045	Lake volume (km^3):	27,700

Fig. 7 (continued)

Absolute sea level (m):	15	Absolute sea level (m):	20	Absolute sea level (m):	25
Lake surface area (km^2):	1189,221	Lake surface area (km^2):	1235,801	Lake surface area (km^2):	1286,912
Lake volume (km^3):	33,583	Lake volume (km^3):	39,689	Lake volume (km^3):	46,027

Fig. 7 Filling of Altyn Asyr Lake at different absolute (sea) levels. Surface of the lake is shaded by *black* color. Contour of the maximal lake surface is shown by a *solid line*. Every frame has indications of the absolute (sea) level, and the corresponding values of the lake surface and volume

Fig. 8 The Altyn Asyr Lake surface and absolute (sea) level vs. the lake volume

Figures 8, 9, and 10 present the relationship between the absolute (sea) level, surface, and volume of Altyn Asyr Lake. The lake surface and level as a function of the lake volume are given in Fig. 8, and the lake surface and volume as a function of the lake level – in Fig. 9. Figure 10 shows the increment of the lake surface and volume vs. the absolute lake level, i.e., a value of an increase of the lake surface and volume with a step-by-step increase of the lake level by 1 m. Figures 8, 9, and 10 show that the lake surface will raise quickly till the absolute level of about +2 m, and then it will increase slowly. The lake volume will increase almost monotonically with a raise of the level.
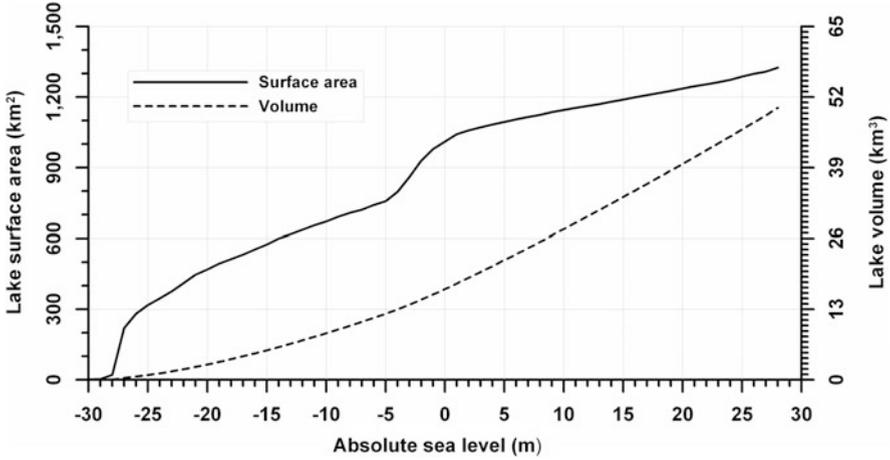
Fig. 9 The Altyn Asyr Lake surface and volume vs. the lake absolute (sea) level
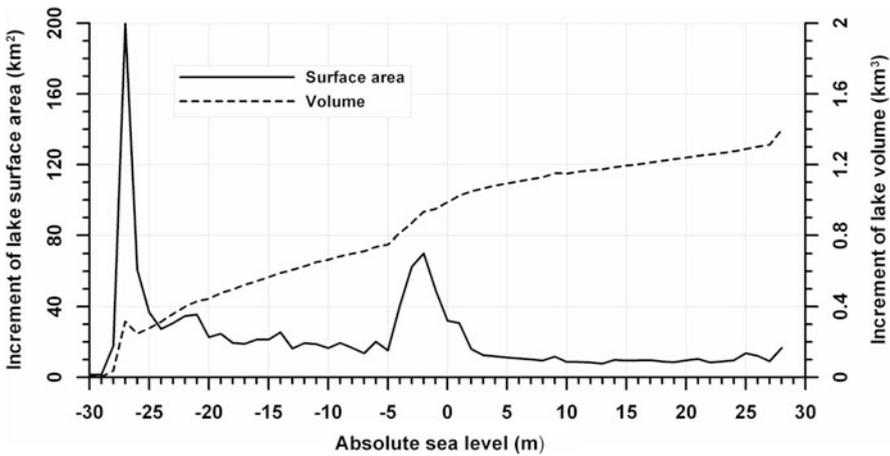

Fig. 10 The increment of the Altyn Asyr Lake surface and volume vs. the absolute lake level

Now, let's discuss two scenarios of the lake filling with the rates of CDW supply of 10 km^3/year, envisaged in the Project, and 5 km^3/year, which seems to be more realistic. Let's assume that the depression is a rigid box (no infiltration), the lake has no evaporation/precipitation, and we fill it with a rate of 10 km^3/year. In this case the lake volume will rise linearly and in 5 years the lake will be filled (Fig. 11). During the first two years (total volume of CDW of 20 km^3) the lake level will rise till 3 m abs. level (max depth of 35 m), and then it will rise slowly – 25 m during 3 years. If we add a strong evaporation of about 1–1.5 m/year, which is a characteristic feature for the other water bodies around – Kara-Bogaz-Gol Bay, Sarykamysh Lake, and the Aral Sea – we
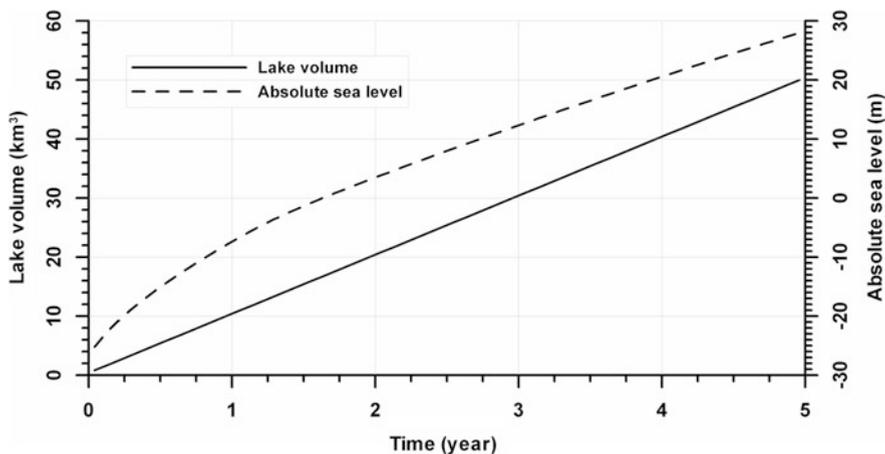
Fig. 11 The Altyn Asyr Lake volume and absolute (sea) level vs. time (years) of filling with a rate of 10 km^3/year

will have a loss of water of about 1 km^3 during the first year, 3 km^3 after 3 years, and 10 km^3 in total after 5 years (see Table 1 and Fig. 11). It means that one more year of water filling will be required, and the total time of the lake filling will increase till 6 years.

If the lake is filled with a rate of 5 km^3/year, in the ideal case 10 years will be required, but evaporation will "consume" more than 15 m of the water layer, which corresponds roughly to 20 km^3 of water. It means four additional years will be required, which in their turn will "consume" another 6 m of water or about 8 km^3, which will require additional 2 years, etc. Thus, the total time of the lake filling may be estimated as 17 years. These rough estimates showed that a decrease of water supply to the lake by a factor of 2 from the rate mentioned in the project will lead to a huge water loss for evaporation and increase of the total time of the lake filling by three times. Our calculations show that the lake being filled, only 2 km^3/year will be required to compensate yearly evaporation and keep Altyn Asyr Lake at a constant level (Table 1).

4   Conclusions

According to the Project, Altyn Asyr Lake will be 103 km long, 18.6 km wide, and 69 m deep. It will have a surface of about 1,915.8 km^2 and a volume of 132 km^3 [2, 3]. It is planned that the depression will receive annually 10 km^3 of CDW; thus it will be filled during about 15 years. These characteristics of the lake represent only some rough estimates, which are far from real values, knowledge of which is very important for calculation of the water budget of the lake, the amount of year-to-year

water supply required for filling the depression, and the forecast of the time of the lake filling. This is explained by the fact that the high-resolution DEM of the Karashor Depression was not constructed and used for the analysis of morphometric characteristics of the future lake.

In this chapter we have described the DEM of the Karashor Depression we constructed on the base of digital surface topography of the area with the spatial resolution of 90 m and the vertical resolution of 1 m, provided by the SRTM. The absolute (sea) level, surface, volume, and maximum depth of Altyn Asyr Lake were calculated with a step of 1 m. This information was given in a table and different graphical forms, which would be useful for scientific and practical purposes related to the Altyn Asyr Project. The results showed that the maximum depth of the lake will be about 60 m (mean depth – 37 m), surface – about 1,325 km^2, and volume – about 50 km^3. Two scenarios of the lake filling showed that a decrease of the rate from 10 to 5 km^3/year will increase the total time of the lake filling from about 6 to 17 years due to the enormous loss of water for evaporation. When the lake is filled out, only 2 km^3/year will be required to compensate yearly evaporation and keep Altyn Asyr Lake at a constant level. We hope that the obtained morphometric characteristics of the lake will help decision-makers in Turkmenistan to take correct decisions at the final stage of the Altyn Asyr Lake construction.

Our future research will include modelling of the water budget of Altyn Asyr Lake basing on the analysis of the potential water supply, precipitation, and evaporation from the changing lake surface, taking into account typical seasonal meteo conditions (air and water temperature, wind speed, and humidity). It will be done basing on the reanalysis meteo data, but in the future an establishment of weather and limnological station at the coast of the lake will require. In situ data will have a great importance for the project. All this will allow to provide a more accurate relationship between the amount of water supply to the lake and its level (surface and volume) at different stages of its filling. This will also allow a correct forecast of the time required to fill the lake by CDW.

Ten years after the SRTM (February 2000), in 2010 a new German space experiment was performed aimed to produce better DEM of Earth's land. TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) is a second, very similar spacecraft successfully launched on 21 June 2010 from Baikonur Cosmodrome in Kazakhstan [8]. Since October 2010, TerraSAR-X and TanDEM-X fly in a close formation at distances of 250–500 m and synchronously record data (Fig. 12). This unique twin-satellite structure allows the generation of global DEM of Earth's land surface of an unprecedented accuracy, coverage, and quality. It was planned that the data will be acquired and the DEM generated within 3 years after the launch. This DEM will have a vertical accuracy of 2 m (relative) and 10 m (absolute), and the horizontal resolution of 12 m [8]. The quality of this new product is shown in Fig. 13 in comparison with the SRTM DEM 90 and 30 m models.

Fig. 12 TerraSAR-X and
TanDEM-X satellite mission.
© Astrium GmbH
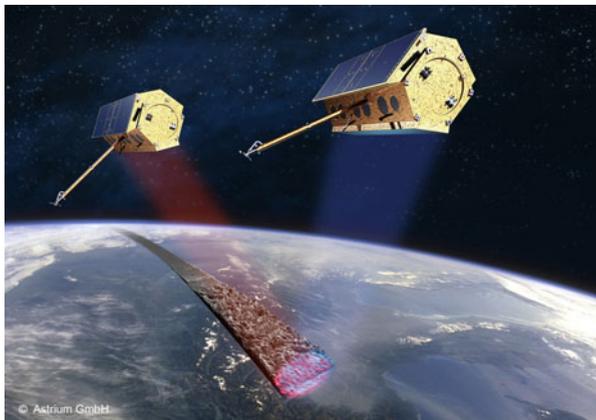
Fig. 13 Comparison of the
quality of the TanDEM-X,
SRTM DEM 90 m and 30 m
data sets for generation of
land topography in the Death
Valley. © DLR

SRTM 90m | SRTM 30m | TanDEM-X 12m
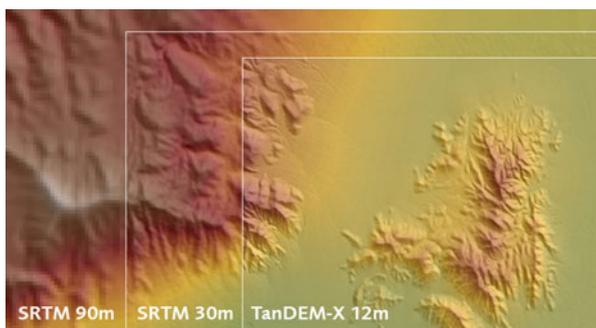
We hope that these data will be soon available to the scientific community, which, in particular, will improve the Karashor Depression DEM. Meanwhile, we already constructed the SRTM DEM (90 m) for the whole territory of Turkmenistan, which should be widely used for a broad spectrum of tasks in water management, agriculture, and other sectors of economy in the country.

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