

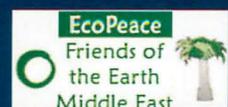


STATE OF ISRAEL  
MINISTRY OF NATIONAL INFRASTRUCTURES  
GEOLOGICAL SURVEY OF ISRAEL

# Red Sea-Dead Sea Conduit Geo-Environmental Study Along the Arava Valley



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STATE OF ISRAEL  
Ministry of National Infrastructures  
Geological Survey of Israel

## **Red Sea - Dead Sea Conduit**

### **Geo-Environmental Study Along the Arava Valley**

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## **Executive Summary**

The Arava (Araba) Valley extends over a 165-km long section of the Dead Sea rift valley, between the southern tip of the Dead Sea and the Gulf of Elat (Aqaba). It is between 5 and 15 km in width and is hemmed on both sides by mountain ranges built of Precambrian to Tertiary rocks. The eastern rim is precipitous with elevations reaching 1000 m (Edom Mts.) where crystalline rocks and sandstones are exposed. The hills to the west consist mainly of limestone, dolomite and marl, are lower (up to +500 m) and rise gradually westward toward the Negev Highlands. The Arava proper is a subsiding basin covered and underlain by a thick veneer of alluvial clastic sediments deposited since Neogene times.

The path of the proposed Red Sea – Dead Sea Conduit (RDC) along the Arava Valley will initiate a variety of design challenges due to numerous geo-environmental factors: immediate proximity to shallow groundwater resources; flash-flood risks to open/near surface sections of the conduit; a cluster of tectonic related features such as high seismicity, active faults, high amplification potential of the sediments and recent surface displacements. These will have to be thoroughly analyzed in the course of a substantial study.

Five possible alignments for the future water carrier were studied by the Harza JRV Group in 1997-8. These routes were examined from environmental, technical and economic points of view, and the eastern alternatives, passing along the Jordanian side of the Arava Valley, were recommended as the most favorable. These alignments will include sections which are very close to the surface or are planned as open canals, and will thus be vulnerable to flash floods both during construction and continuous operation. The maximum discharge for each watershed cutting these stretches of the conduit was calculated as a function of the watershed area, average precipitation, the lithological units exposed and the height of the conduit above the local valley. The computations demonstrate that all watersheds in the northern part present high risks at open/near surface parts of the conduit, those in the central Arava Valley are mainly categorized as medium-low risk, and those in the southern part are classified as presenting a high risk to the RDC.

Three main aquifers are utilized along the Arava Valley by Jordan and Israel. The most exploited of these is the shallow Arava Fill Aquifer which includes the Hazeva Aquifer. The two other deeper aquifers are the Judea Group Aquifer of Cenomanian – Turonian age; and the Lower Cretaceous Kurnub Group Aquifer. The water in the Arava Fill system is of low salinity and of prime importance both to agriculture and for the tourism industry. The water in this system derives from three sources: direct recharge from occasional flash floods,

limited to the shallow unconfined sub-aquifers only; lateral subsurface leakage from the “fossil” Kurnub and Judea aquifers along the rift margins; and seasonal rainwater precipitated over the Moav and Edom mountain ranges which is conveyed to the aquifer system through the alluvial fans developed along its eastern rift margins.

The vulnerability of these groundwater resources to continuous leaks or sudden spillovers from the RDC is a major concern. The first to be affected would be the many shallow wells operating along the Arava Valley in Jordan in immediate proximity to the proposed alignment of the RDC. The heterogeneity in water quality of the Arava aquifers will make the detection of such leaks challenging and an array of monitoring wells will be required, mostly along the eastern margins of the Arava Valley. The monitoring system should comprise at least few tens of wells at depths of up to 200-300 m, and designed on the basis of a comprehensive hydrogeological database of all information available throughout the region and on additional new data in areas of information gaps.

The knowledge gathered on earthquakes occurrence, high values of Horizontal Peak Ground Acceleration (PGA) and recent surface displacements along the Arava Valley and the Dead Sea rift, demonstrate the complexity of the RDC project in relation to the seismic activity of the region. Since faults along the Arava Valley are presumably active faults, a laborious study of potentially active faults should be carried out using all available methodologies, and summarized in a catalogue similar to the one available for Israel. The presence of numerous intersection points of any alternative alignment of the RDC with potential active faults, extensive outcrops of sediments with high amplification potential, and the possibility of abrupt surface displacements of 1-2 meters, call for a thorough study of these aspects at an early stage of the planning phase.

A comprehensive GIS database has been established during this study in relation to the infrastructure and geo-environmental aspects of the Arava Valley, which can be used as an aid for future planning stages, and will be updated accordingly.

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## **Introduction**

The renewed interest by the Hashemite Kingdom of Jordan and Israel in the construction of a conduit to pipe water from the Gulf of Elat (Aqaba) to the Dead Sea (termed “The Peace Conduit” or “Red-Dead Canal” - RDC), has focused public attention mainly on the future and fate of the Dead Sea, i.e., the potential impact on its limnology, geochemistry and biology. However, the construction of such a complex unit to transfer some 1.8 billion m<sup>3</sup>/year of water along an active segment of the Dead Sea Transform-Rift zone in immediate proximity to shallow and deeper groundwater resources should also be evaluated very cautiously.

This report addresses issues such as the vulnerability of the Arava Valley region to continuous leaks and/or accidental spill of seawater from the RDC; potential danger to the conduit from floods initiated within the drainage basin of the Arava Valley, and various aspects related to recent and sub-recent tectonic activity in the Arava Valley.

A comprehensive GIS database has been established during this study in relation to the infrastructure and environmental aspects of the Arava Valley, and will be used as a basis for future updates. The database includes various geological and lithological maps issued in Israel and Jordan, geomorphologic maps, well logs and associated information, Digital Terrain Models (DTM), maps of potentially active faults, and potential amplification of earthquake vibrations.

## **Geological Setting**

The Dead Sea, with a water level at 419 m below mean sea level, is the lowest point on the surface of the earth. The lake occupies a morpho-tectonic valley which formed along an intra-land transform – the Dead Sea transform. The latter extends some 1000 km from the Red Sea to the zone of plate convergence in southern Turkey. The Arava Valley (Fig. 1) is part of this system - an elongated depression of about 165 km, from the Dead Sea in the north to the Gulf of Elat (Aqaba) in the south. The area crossed by the transform has a normal continental crust, 30-35 km thick. The crust of the region was shaped and stabilized in the Late Proterozoic by the Pan African orogeny, and during most of the Phanerozoic the region was a relatively stable platform. The area is covered by an extensive veneer of sediments that accumulated during several depositional cycles separated by periods of erosion between the Cambrian and the Late Eocene. In the Early to Mid-Miocene (15-18 m.y.), a left-lateral movement began along the Dead Sea transform resulting in the ‘breakaway’ of Arabia from Africa, which became two independent plates. They continue to move apart along the Red Sea, where a new, approximately 1800 km long divergent plate boundary formed. North of the Red Sea, the Arabian-African plate motion was partitioned along two lines and most of the motion was taken up by the Dead Sea transform, while a fraction of the motion was transferred to the Suez rift which separates the Sinai sub-plate from the rest of Africa. The eastern Arabian plate

moved with time some 100 km northward in relation to the Israel-Sinai subplate in the west. A second stage of movement and rapid subsidence, which started some 5 m.y. ago, gave rise to an elongated topographic trough – the Dead Sea rift (DSR) valley, with secondary deeper basins such as the Hula Valley, the Dead Sea Valley, the Arava Valley and the Gulf of Elat (Aqaba). East of the DSR, the western margins of the Trans-Jordan plateau were uplifted, resulting in eastward tilting and shaping of the El-Azrak and El-Jafr basins (Begin and Zilberman, 1997). Along the Arava Valley, the fault trace is straight and sharp (Fig. 2), associated with very little relief except locally at small compressional or extensional dislocations. The fault pattern becomes more complex in the vicinity of the two pull-apart basins (Dead Sea and Gulf of Elat), where it is characterized by marginal normal faults and central sinistral strike-slip faults (Amit et al., 2002).

The Arava valley is 5-15 km wide, bordered by high mountains – the Negev Mountains in the west (~500 m high) and the Edom Mountain ridge (~1000 m) in the east. The topographic elevation along the valley's floor is variable: near Beer Menuha (215/470 new Israel grid) the altitude is some 230 m above msl, dropping towards the north to -419 m at the Dead Sea shore, and to mean sea level at the Gulf of Elat.

The sedimentary fill (Fig. 2) of the Arava Valley consists mainly of two formations: The Miocene Hazeva Formation and the Plio-Pleistocene Arava Formation. The Hazeva Formation is predominantly a continental sequence, composed of reddish sandstones, red and green shales and conglomerates. In places, lacustrine carbonate units composed of limestone and marl are present. Its maximum thickness is about 2000 m. The Arava Formation consists of weakly cemented conglomerates in a reddish sandstone matrix, locally with sand lenses. The pebbles vary in size, composition and sphericity according to their relative locations in paleo channels. The sequence is well stratified, commonly with imbrications and cross-bedding. At the southern tip of the Dead Sea, extensive outcrops of the Lisan Formation are present - yellow-white lacustrine sediments, that were deposited during periods of Lake Lisan highstands (paleo-Dead Sea lake) in the Late Pleistocene. The outcrops of the Lisan Formation extend as far as the Hazeva village (some 30 km south to the Dead Sea).

The alluvium in the Arava Valley consists mainly of conglomerates fed from the ephemeral streams incised in the rift flanks. Locally, dune fields cap the fans. The fans are relatively flat and their lateral merging has formed a continuous piedmont with little relief. The alluvial surfaces in the Arava are generally subdivided into three groups, depending on their relative position, degree of desert pavement and weathering (Grossman and Gerson, 1987).

### Possible Alignments of the “Peace Conduit”

Five alternative alignments for the future water carrier were studied by the Harza JRV Group (1998; Fig. 3). These routes were examined from environmental, technical and economic points of view, and the eastern alternatives, passing along the Jordanian side of the Arava Valley, were recommended as the most favorable. These alignments will include sections which are very close to the surface or are planned as open canals (Fig. 4), and thus will be vulnerable to flash floods, both during construction and along its continuous operation (see pp. 15-23).

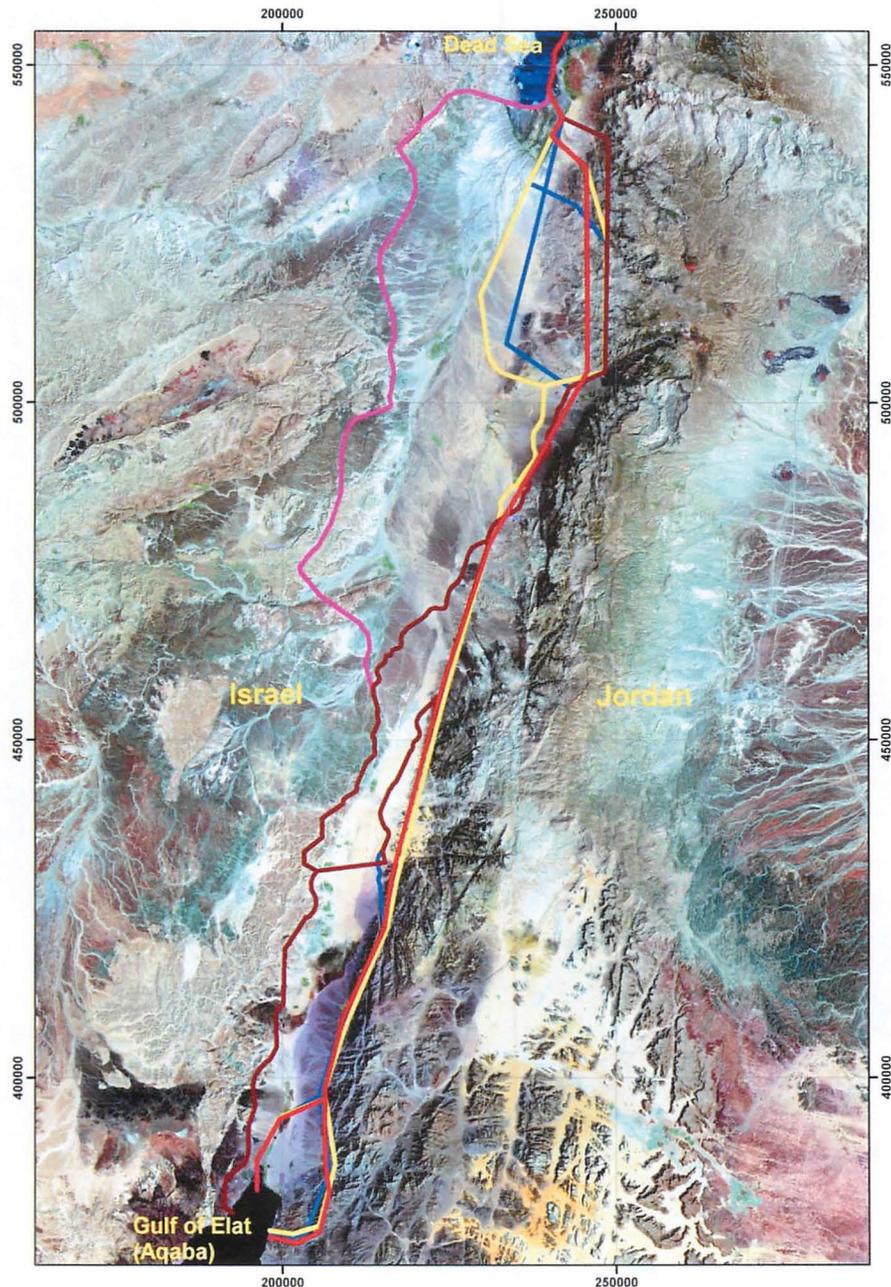


Figure 3: Possible alignments for the “Peace Conduit”

## **Groundwater Resources along the Arava Valley**

The Arava (Araba) Valley extends over a 165-km long section of the Dead Sea rift Valley, between the southern tip of the Dead Sea and the Gulf of Elat (Aqaba). It is between 5 and 15 km in width and is hemmed in on both sides by mountain ranges built of Precambrian to Tertiary rocks. The eastern rim is precipitous with elevations reaching 1000 m (Edom Mts.) where crystalline rocks and sandstones are exposed. The hills to the west consist mainly of limestone, dolomite and marl, are lower (up to +500 m) and rise gradually westward toward the Negev Highlands. The Arava proper is a subsiding basin covered and underlain by a thick veneer of alluvial clastic sediments deposited since Neogene times.

During the hottest months of the summer common temperatures are 34°-40°C with peaks as high as 45°C; during the coldest months temperatures drop and are usually around 14°-16°C only. The area experiences very low precipitation with an annual average of less than 50 mm, and high potential evaporation (up to 5,000 mm/year). On the eastern Moav and Edom Mts. however, precipitation, which occasionally includes also snow, is much higher and reaches up to 250 mm/year.

The Arava forms a regional drainage basin to which both surface water and groundwater flow, and through which the water is drained to the final drainage basins. The thickness of the Arava fill sediments, between the bordering faults, reaches a few thousand meters, becoming thinner at the topographic high near Beer Menuha. This topographic divide also regulates the flow regime of groundwater along the Arava - towards the Dead Sea north of Beer Menuha and south towards the Gulf of Elat. Surface water is exclusively in the form of flash floods, which develop sporadically and may reach high volumes in short spells. Groundwater include regional aquifers which drain across the Rift margins into the local alluvial aquifers that in turn are directly recharged through flash floods or via alluvial fans developed along the margins of the valley. The morphotectonic setting of the region dictates a hydrogeological regime through which deep confined aquifers merge and mix with shallow aquifers and local brines and therefore, groundwater of varying quality is exploited throughout the valley and along its margins. The most fresh water are used for direct irrigation, and after some minor treatment also for domestic consumption. Brackish water encountered mostly in the southern part, are desalinated and supplied to the city of Elat.

Four aquifers are exploited along the margins of the Arava vally. Two aquifers are in Cretaceous rocks and the other two are in Neogene and Quaternary strata located in the rift proper (jointly named the Arava Fill aquifer; see Figures 5 and 6). The Lower Cretaceous Kurnub Group (upper part of the Nubian Sandstone sequence) is composed of sandstones and clays and contains water that is mostly “fossil” and not

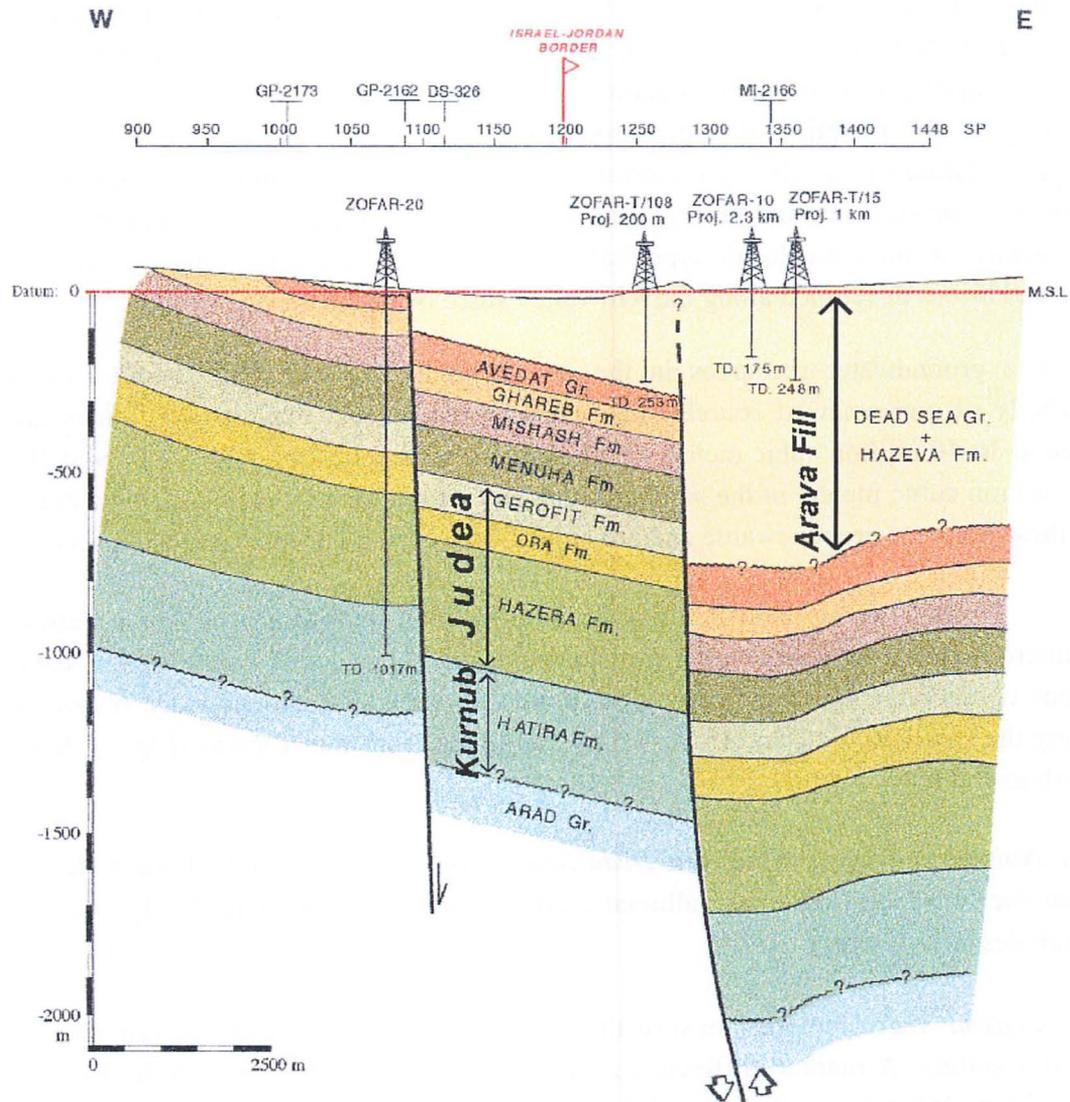


Figure 6: Geological cross section in the Zofar area, central Arava valley. (compiled by L. Fleischer, Geophysical Institute of Israel; see Fleisher et al., 1997 )

The water in this system derive from three sources:

1. direct recharge from occasional flash floods in the ARV proper which is limited to the shallow unconfined sub-aquifers only.
2. lateral subsurface leakage from the “fossil” Kurnub and Judea aquifers along the rift margins.
3. seasonal rainwater precipitated over the Moav and Edom mountain ranges, which is conveyed to the alluvial aquiferial system in the ARV through the alluvial fans developed along its eastern rift margins.

these data and the Digital Terrain Model of the area, the thickness of the unsaturated zone has been calculated and presented in Figure 9.

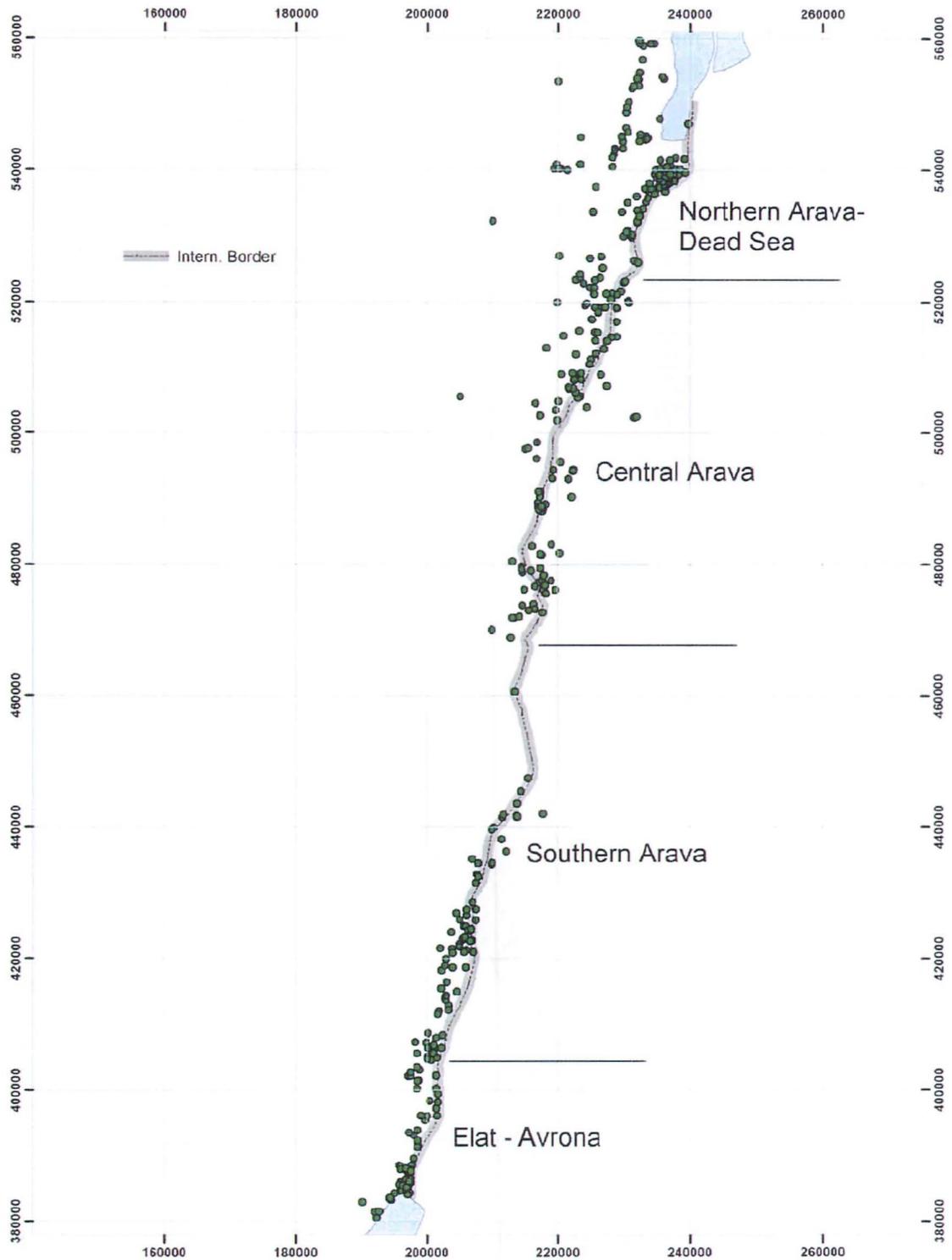


Figure 7: Israeli water wells along the Arava Valley and the operational subdivision of the region.

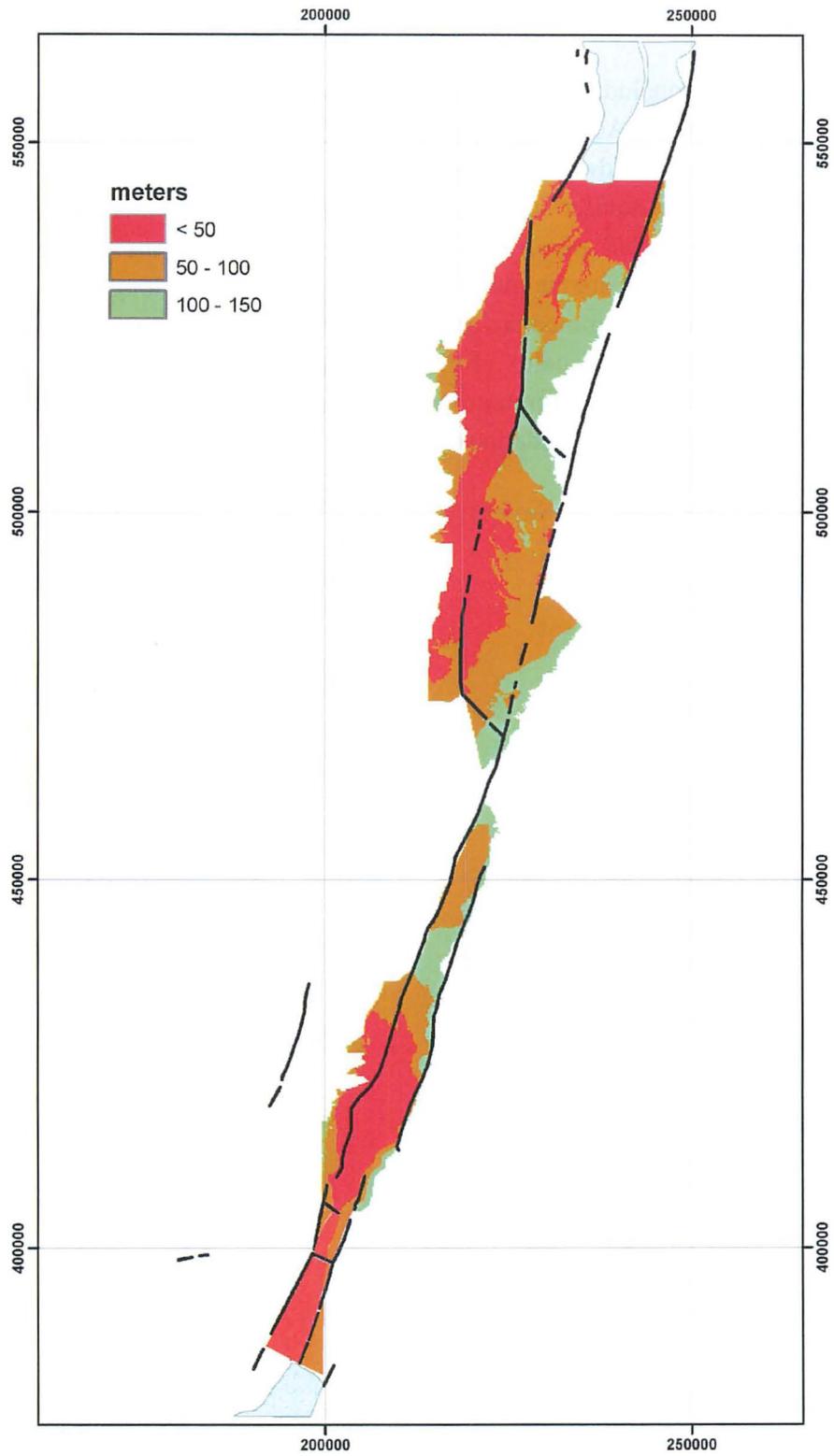


Figure 9: Thickness (in m) of the unsaturated zone along the Arava Valley.

## Vulnerability of the RDC to Flash Floods

The proposed eastern alignments of the conduit include sections which are very close to the surface or are planned as open canals (Figure 10), and these parts of the conduit will be vulnerable to flash floods, both during construction and along its continuous operation.

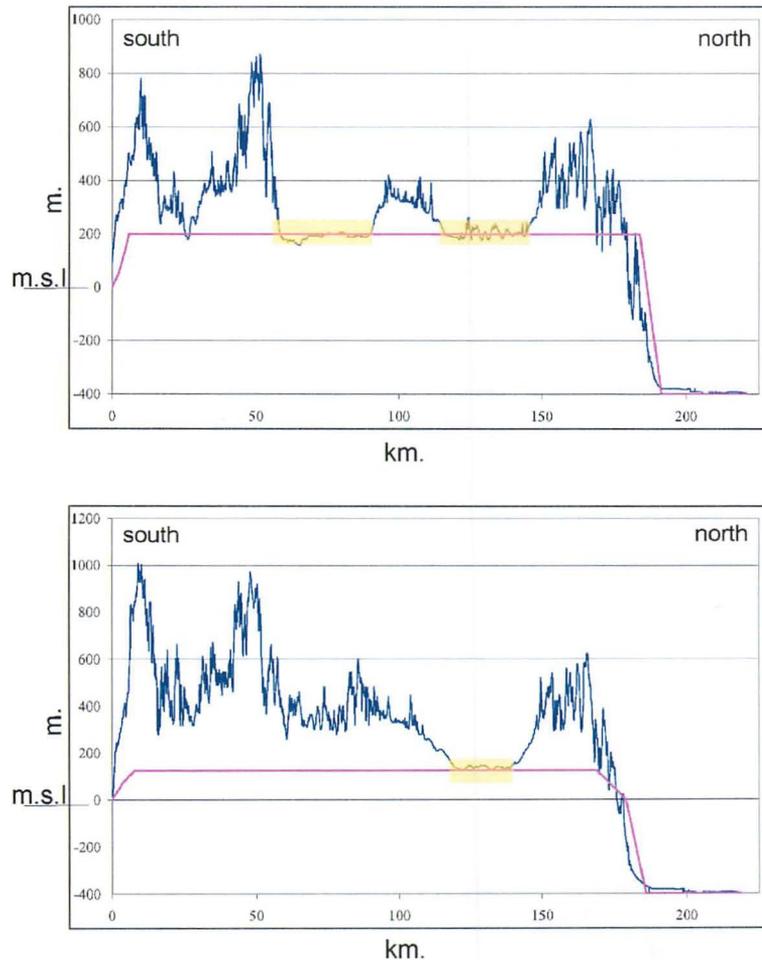


Figure 10: Topographical cross sections along the eastern alignments, showing (in Yellow) locations of open / near surface stretches of the RDC.

In order to evaluate the potential hazard from flash-floods to the open/near-surface sections of the proposed canal, a physiographic analysis of the Arava basin was carried out, based on two Digital Terrain Models (DTM): (1) the 25X25m grid model prepared by the Geological Survey of Israel (GSI), and (2) the NASA Shuttle Radar Topography Mission (SRTM) 90X90m grid. The two models were merged into

Flow Accumulation algorithms were added as a GIS layer (Fig. 12). The junction points between the open/near-surface sections of the proposed eastern alignments (Fig. 4) and the watershed layer were identified, and the surface area of the relevant watersheds was calculated (Fig. 13).

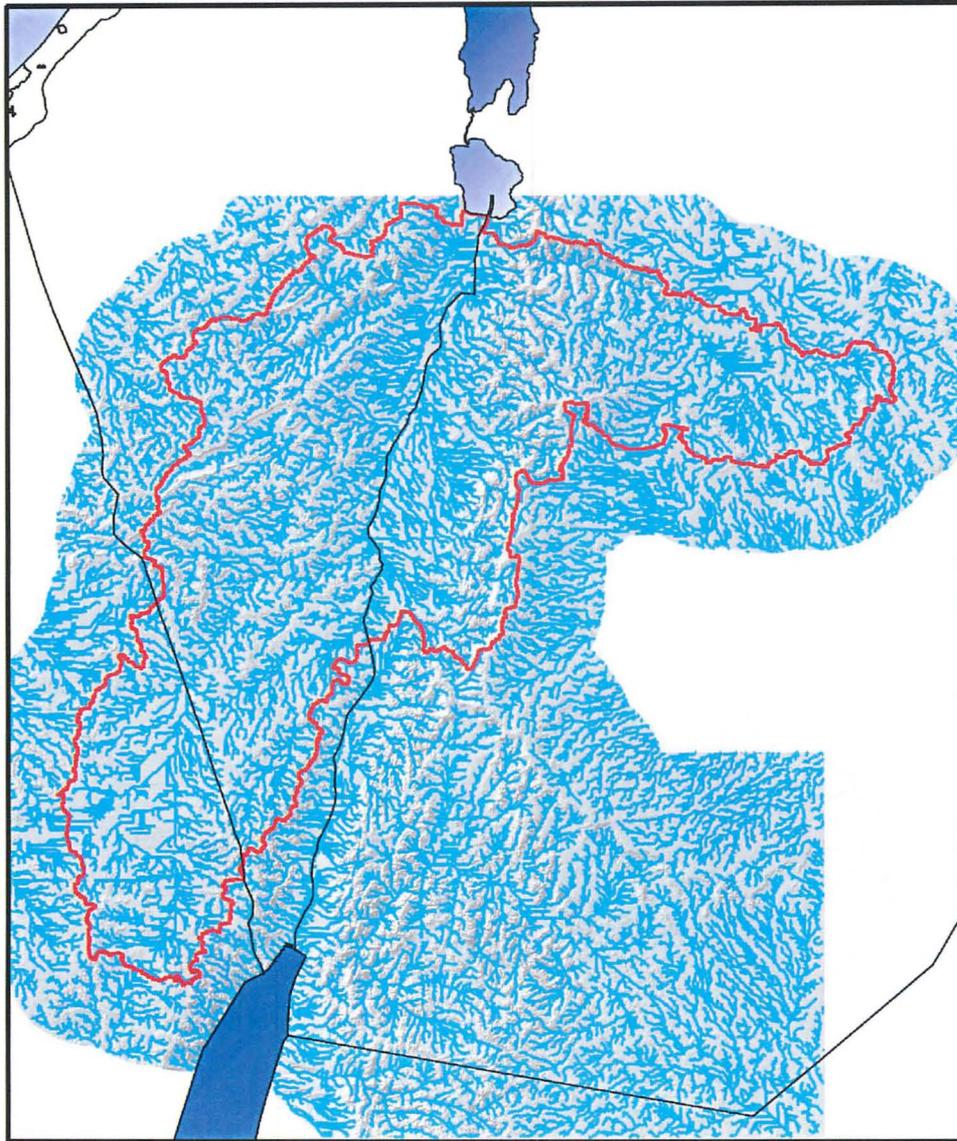


Figure 12: Drainage pattern of the Arava region. In red – Catchment area of the Dead Sea.

Based on a routines developed by Calvo and Ben Zvi (2004) and Yanivitz et al. (1996), the volumes of flash floods for every watershed were calculated according to the following parameters (Fig. 14): area, elevation distribution, slope, exposed rock units and the average total rainfall (Fig. 15) on each watershed. The distribution of rain for each watershed (rainfall for each pixel of the GIS model) and the average rain thickness were calculated from a joint rainfall map based on data mainly from Jordanian weather stations (Fig. 16). The maximum discharge for each watershed was calculated as a function of the watershed area, the lithological units exposed and the height of the conduit above the local stream. The potential risk to the conduit as a result of these maximum discharges was evaluated and categorized into high, medium and low risk. A summarizing map delineating the potential vulnerability of the conduit to floods initiated within the drainage basin of the Arava Valley is presented in Figure 17.

As can be inferred from this map, watersheds in the northern part all present high risks at open/near surface parts of the conduit, those in the central Arava Valley are mainly categorized as medium-low risk, and those in the southern part are classified as presenting a high risk to the RDC.

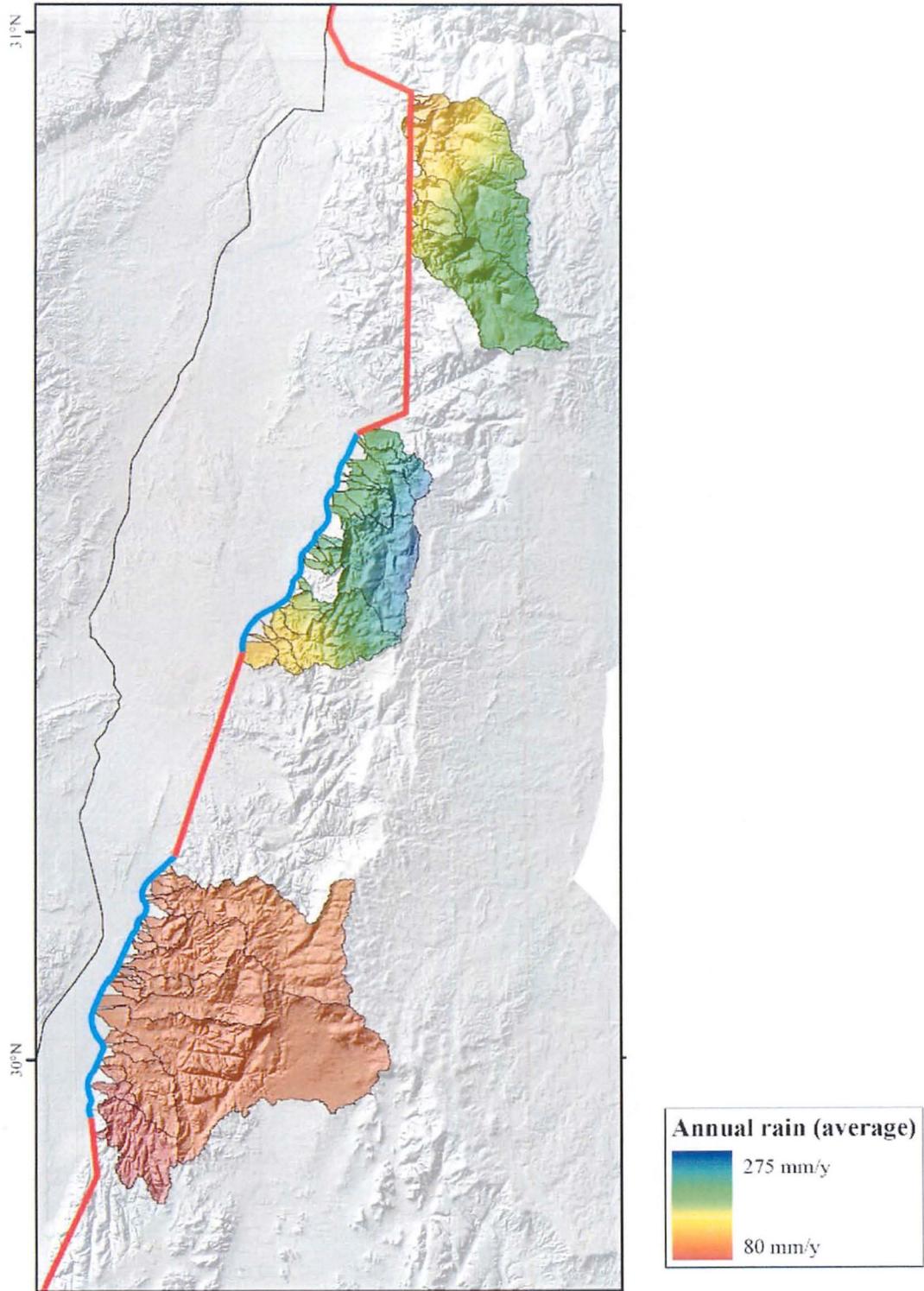


Figure 15: Annual average rainfall in the computed watersheds.

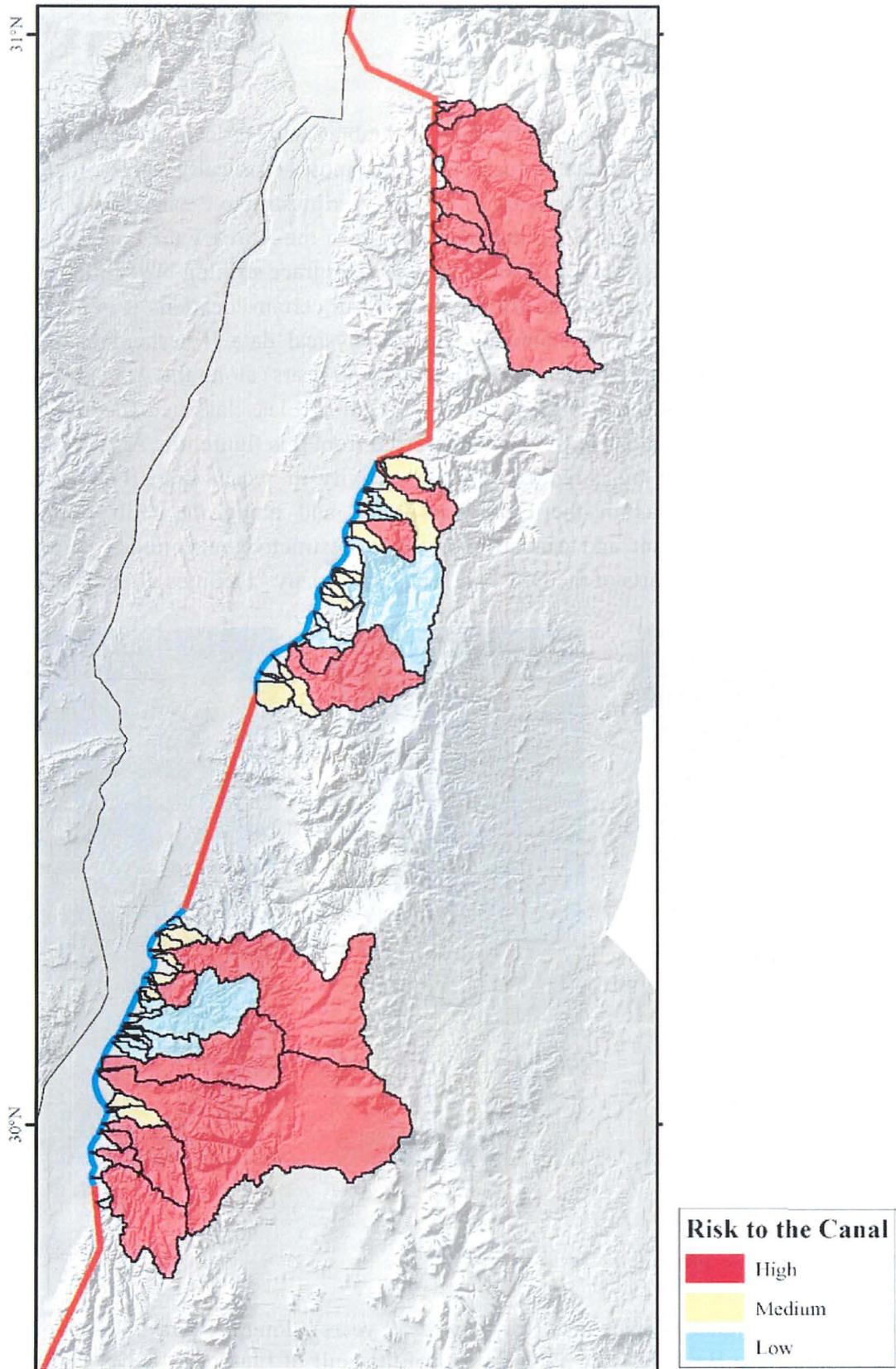


Figure 17: Potential risk from floods to the open / near surface sections of the RDC.

points of the conduit, i.e. – pumping stations, desalination plant, power plant etc., as demonstrated in the Elat area (Wust-Bloch, 1997) during the 22.11.1995 Nuweiba earthquake ( $M_w$  7.2). Nevertheless, based on paleoseismic analysis of sediments in the Avrona Playa, a pull-apart basin along the Arava, Amit et al. (1999) bring evidence for at least six  $M > 6$  earthquakes have affected this area in the last 14,000 years, giving a recurrence interval for such events of approximately 2000 yr. In a different study, on the Elat fault segment, Amit et al. (2002) suggest that a decrease in earthquake magnitude in time and lack of microseismicity for tenth of years, emphasize the possibility that the area might be a site of major earthquakes in the near future.

The seismic response and the slip rate on the DSF system in the Arava has been studied in detail on the Israeli side (Amit et al., 1999; 2002; Bowman, 1995; Freund et al., 1968; Garfunkel et al., 1981) and, to a lesser extent, on the Jordanian side (Klinger et al., 2000). The slip rate on faults along the Arava valley can be constrained from dated geomorphic features which were displaced by the faults, and from numerous observations, suggesting an average rate of  $5 \pm 3$  mm/year. This slip rate is consistent with other constraints on the kinematics of the Arabian plate. However, these observations generally do not shed light on the question of whether the movement along the faults is a continuous creep or occurred as sudden displacements related to earthquakes. Amit et al. (2002) concluded from a study in the Elat region (southern Arava Valley), that during the late Pleistocene,  $M_{6.7}$ - $M_7$  earthquakes displaced the surface by 1-1.5 m, and their average recurrence interval was  $2800 \pm 700$  years. In the Holocene, more frequent earthquakes (recurrence  $1200 \pm 300$  years) were of smaller magnitudes ( $M_{5.9}$ - $M_{6.7}$ ), and displaced the surface by 0.2-1.3 m.

Based on historic evidence for the last 2000 years and an extrapolation of instrumental data of the last 100 years, Begin (2005) suggested that the mean recurrence interval of  $M_w \geq 6.2$  earthquakes in the Jordan valley is 400 years, and that of  $M_w \geq 7$  is 3000 years. For the Dead Sea basin the recurrence interval for earthquakes of magnitude  $M_w \geq 7-7.3$  is  $\sim 10,000$  years, supported by the geological record for the last 40,000 years and instrumental data. Based on the assessment of the recurrence intervals, Begin (2005) suggested that the best estimate for the 50 year probability of occurrence for a destructive earthquake ( $M_w > 7$ ) is 1.7%.

Figure 19 combines a number of tectonic-related elements along the Arava Valley: locations of earthquakes and their magnitude (taken from the catalogue of the Geophysical Institute of Israel); mapped faults (based on Sneh et al., 1998); intersection points of faults and the proposed eastern alignment of the conduit; potentially active faults and potential amplification of earthquake vibrations.

A preliminary version of a fault catalogue identifying those which are “potentially active” was prepared by Bartov et al. (2002) for the entire area of Israel.

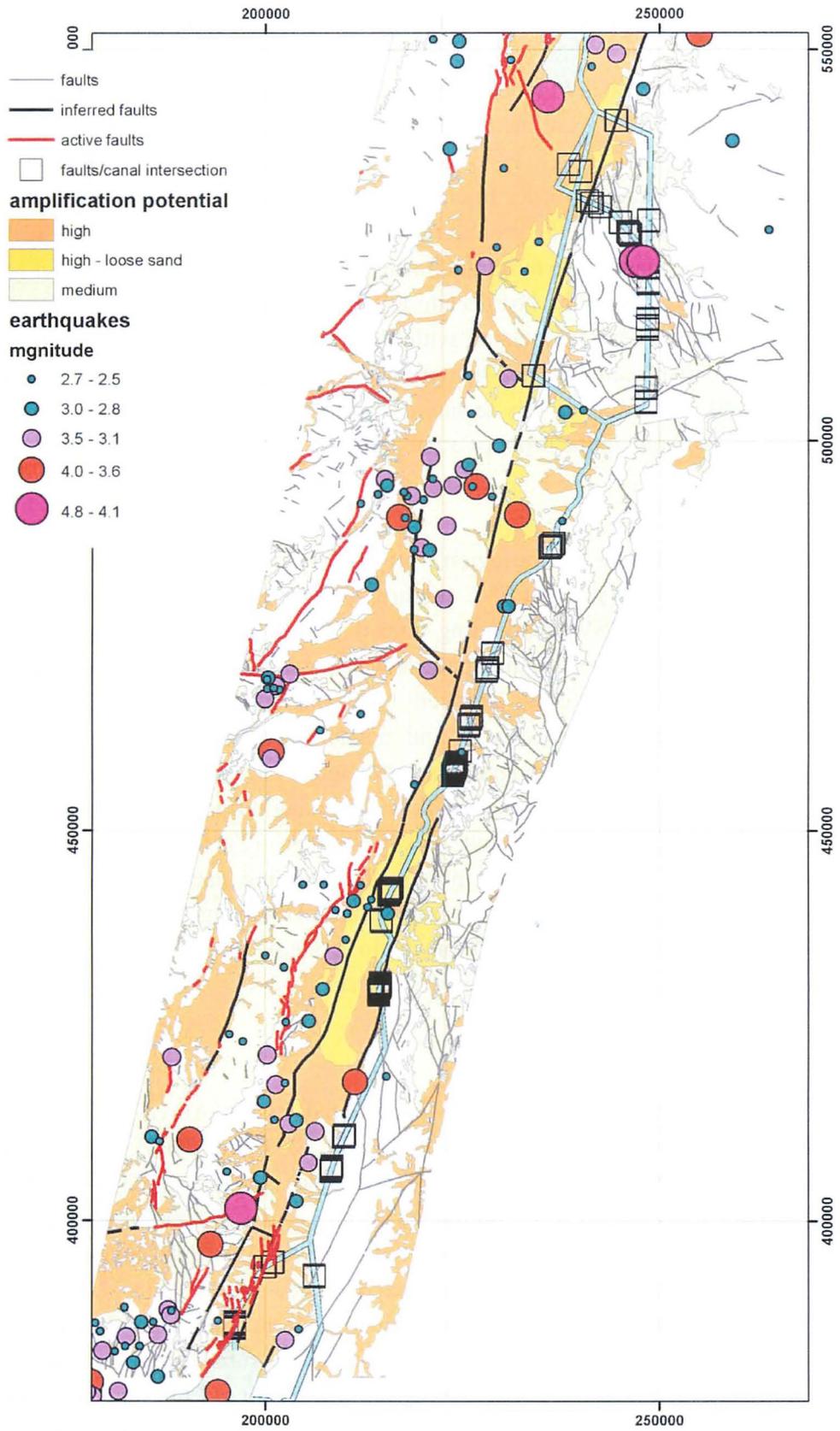


Figure 19: Tectonic-related elements along the Arava valley. The eastern alignment of the RDC is marked in blue.

(Avrona S; Figure 21b). In these three sub-zones, deformation rates were higher between March and November 1995 (before the M=7.2 Nuweiba earthquake) and decreased gradually later on (Figure 22). All the subsidence features described above are associated with left-stepping fault segments and the uplifts occur along right-stepping faults (Figure 21). They are thus interpreted as the result of slip along segmented faults (Finzi, 2005). These features clearly demonstrate that the Arava Valley floor is tectonically active.

Figures 23-25 show the descending and the two ascending interferograms along the entire course of the canal. The profiles above each interferogram show the relationships between topography, in blue, and displacement rates (calculated by dividing the absolute observed displacements by the time interval of the interferogram), in purple. Figure 26 shows selected zoomed intervals. In order to examine whether the observed changes along the canal course also indicate recent movements, some possible errors or artifacts were sorted out: phase changes due to atmospheric stratification (Hanssen, 2001), and random atmospheric noise due to turbulence or variations in the water contents in the troposphere.

Along the conduit course near the Gulf of Elat (Figure 26a,b), both descending and ascending track interferograms show poor correlation with topography in the northern side of the section, and some correlation in the south. In general, the displacement pattern is similar in the two interferograms. These may indicate some possible deformation and deserve further analysis with higher resolution and comparison to additional interferograms. The region along the margins of the central Arava Valley zoomed in Figure 26c, d, e shows a smooth topographic profile and an undulating displacement pattern of about 3 mm/yr in (c) and (e) and 1 mm/yr in (d). The lack of correlation with topography excludes the atmospheric stratification artifact but does not rule out the random atmospheric effect. In the case where the LOS changes are due to pure vertical displacement, both ascending and descending track interferograms would show the same rate and the same sense, which is not the case here. On the other hand, E-W displacements would show in an opposite manner in the descending and ascending interferograms, because of their opposite look directions (see above). One may notice that there are some parts in this section where the displacement sense is opposite in the two tracks, particularly when comparing track 78 and track 343. This might indicate displacements with an E-W component.

### *Summary*

There is clear evidence for active tectonics and vertical displacements along the Arava Valley west of the proposed eastern alignment of the RDC. There are also a few indications for displacements along the course of the conduit, but none are conclusive so far. The presentation of observed displacements in rate values (mm/yr) may be somewhat ambiguous, because it averages information of more than 4 years, and thus cannot distinguish between single and ongoing deformation events. Furthermore, because of the large amount of data, it was not processed in the highest

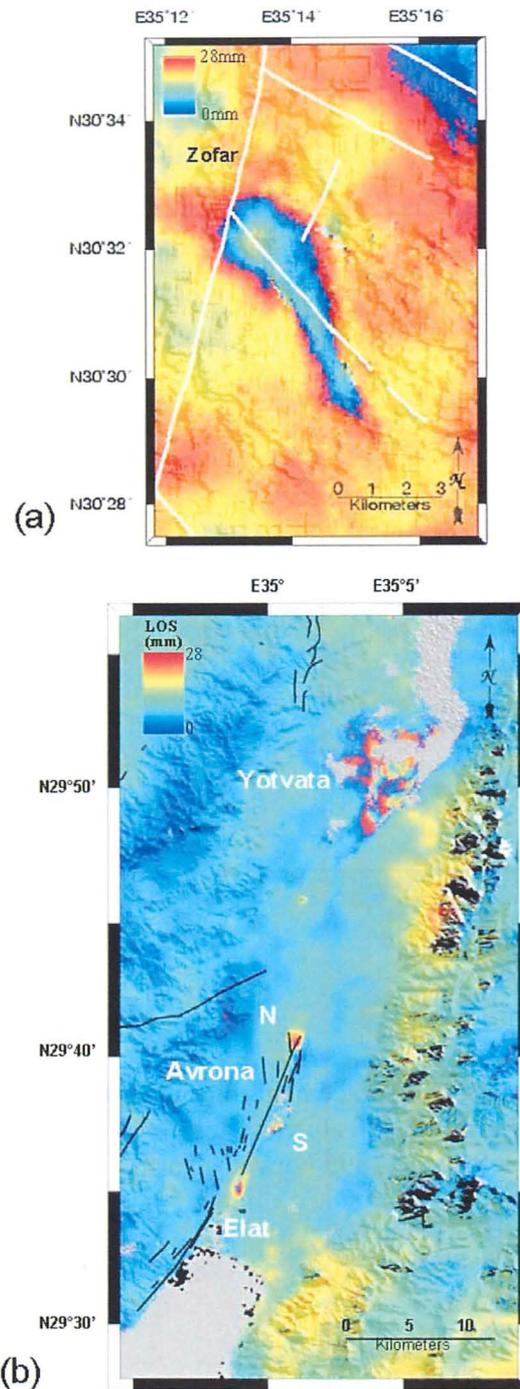


Figure 21: (a) Zofar interferogram for the period 950519\_990807 (yymmdd). Subsurface faults are marked by white lines (from Bartov et al., 2002). (b) Southern Arava interferogram for the period 950329\_951129 (yymmdd). Potentially active faults are marked by black lines (from Bartov et al., 2002).

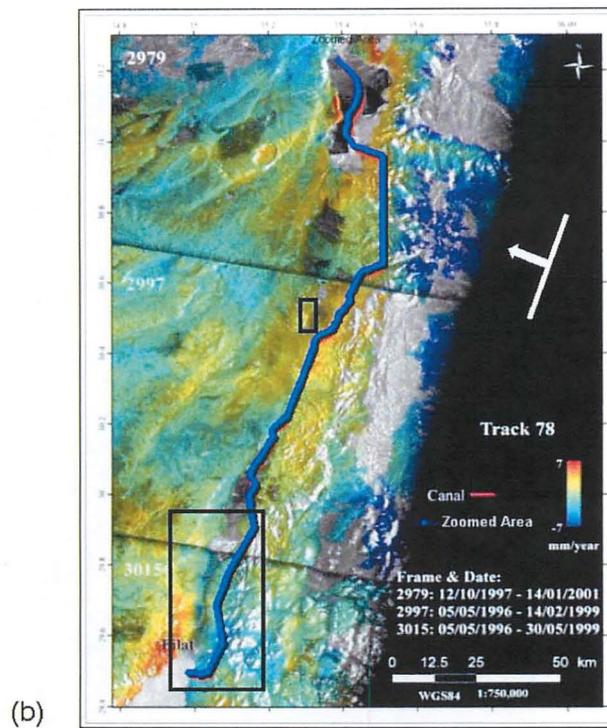
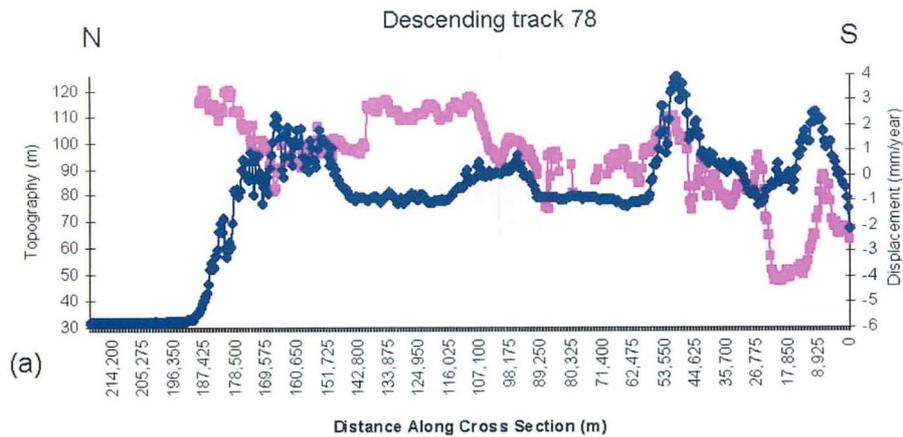


Figure 23: (a) Topographic (blue) and displacement rate (purple) profiles along the course of the proposed canal as measured in the merged 1996 to 2001 interferograms along descending track 78. (b) Merged interferogram with the canal course in red, and the zoomed area (in this case the entire length) in blue. White line marks the flight direction from NNE to SSW; white arrow shows the satellite look direction. Black rectangles mark the areas of tectonic deformation described above and shown in Figure 21.

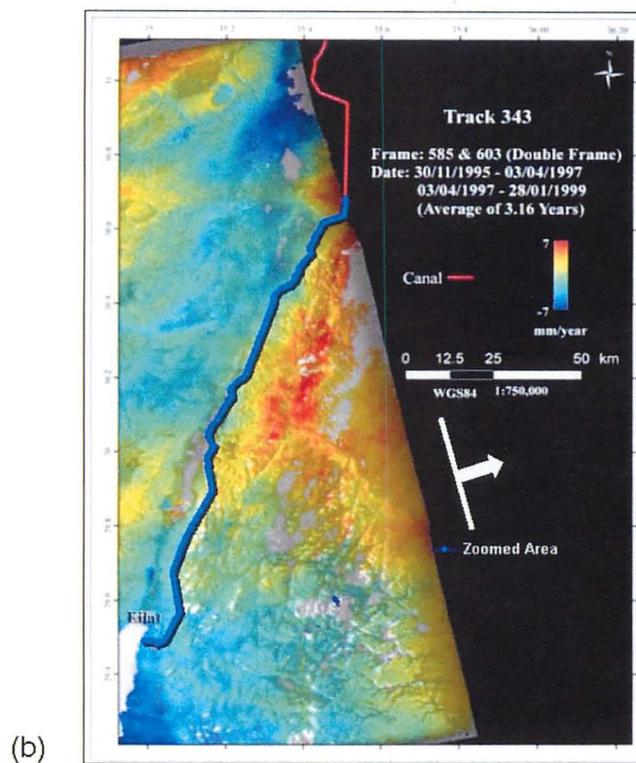
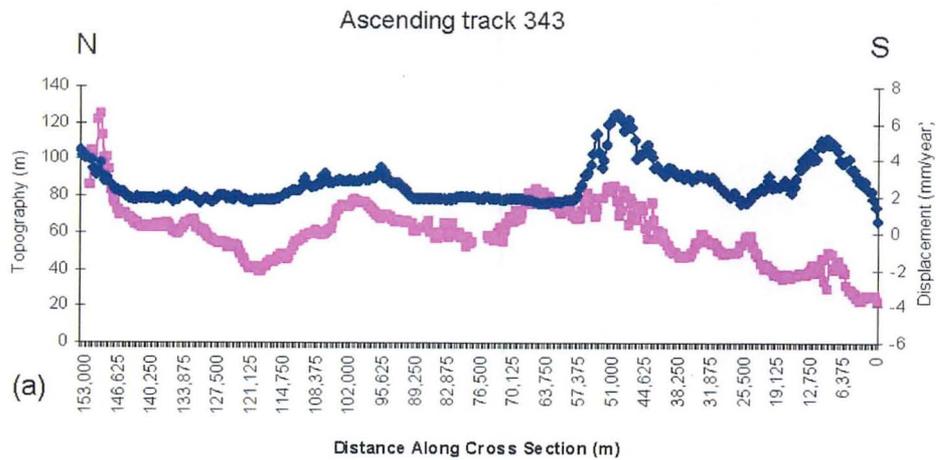


Figure 25: (a) Topographic (blue) and displacement rate (purple) profiles along the course of the proposed canal as measured in the merged 1995 to 1999 interferograms along ascending track 343. (b) Merged interferogram with the canal course in red, and the zoomed area in blue. White line marks the flight direction from NNE to SSW; white arrow shows the satellite look direction.

## Summary and Recommendations

The path of the proposed Red Sea – Dead Sea Conduit along the Arava Valley places a variety of design challenges due to numerous geo-environmental conditions: immediate proximity to shallow groundwater resources (Fig. 9); flash-flood risks to open/near surface sections of the conduit (Fig. 17); a cluster of tectonic related features, such as seismicity, active faults, high amplification potential (Fig. 19); and recent surface displacements (Fig. 22). These will have to be thoroughly analyzed in the course of a substantial study.

Once a final alignment for the RDC is chosen, a comprehensive study of its route should be carried out, of the issues discussed in this report:

- (a) The vulnerability of the groundwater resources to leaks from the RDC is a major concern; a systematic hydrogeological survey of these resources and their vulnerability should be based on a comprehensive database of all the data available throughout the region and on additional new data in areas of information gaps. Provided that the conduit will follow the current eastern alignment, an array of monitoring wells will be required, mostly along the eastern margins of the Arava Valley. The array will have to be based on at least few tenths of wells, up to depths of 200-300m, due to the heterogeneity in water quality and the possibility of sea water percolation at different horizons. A trained staff will have to monitor and process the data continuously, examining chemical criteria to allow early detection of leaks (i.e.: marine salinity vs. calcium chloride salinity in the groundwater).
- (b) Flash-flood hazard to the near surface/open sections of the final alignment of the RDC should be evaluated , on a basis of an accurate Digital Terrain Model.
- (c) A detailed study of potentially active faults along the final alignment should be carried out using all available methodologies, and summarized in a catalogue similar to the one available for Israel. Since almost every fault along the Arava Valley is suspected to be an active fault, this study and the relations of the faults to the RDC alignment are highly important.
- (d) Detailed InSAR observations along the final alignment should be carried out in order to locate areas in which recent surface displacements take place.
- (e) The seismicity and amplification potential along the RDC should be studied in detail.

A thorough study of the above mentioned parameters will allow for the best possible choice of the future site of the Red Sea – Dead Sea Conduit.

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