Compare water supply and water demand—A model for a better understanding of water management in ancient times by the example of Assyrian settlements along the lower Ḫabūr River*

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Abstract
The understanding of water management can be key to the understanding of cultures. The collaboration between archaeology and water management gives rise to new and interesting insights into the function and use of hydraulic structures and water management in ancient civilizations. In this article the concept was introduced of how water supply and water demand can be compared to check especially how many people could exist in an area. This concept was developed and tested by the situation of Assyrian settlements along the Ḫabūr River with a part of the available archaeology data. Further discussions between experts on water management and archaeology could improve this concept. Displaying water management is an essential contribution to the understanding of the canal system along the Lower Ḫabūr River and its importance for the local population. Extensive research into the processing and incorporation of all available data can further refine the route of the canal. The developed concept is also an idea for other archaeology projects in arid and semi-arid regions to check if the water supply is enough for the estimated number of people.

KEYWORDS
Assyria, Ḫabūr River, Syria, water demand, water supply

Résumé
La compréhension de la gestion de l’eau peut être essentielle à la compréhension des cultures. La collaboration entre l’archéologie et la gestion de l’eau donne lieu à des perspectives nouvelles et intéressantes sur la fonction et l’utilisation des structures hydrauliques et la gestion de l’eau dans les civilisations anciennes. Dans cet article, un concept a été introduit pour comparer l’approvisionnement en eau et la demande en eau—un modèle pour une meilleure compréhension de la gestion de l’eau dans les temps anciens par l’exemple des établissements assyriens le long de la rivière Ḫabūr inférieure.

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l’approvisionnement en eau et la demande en eau afin de vérifier en particulier combien de personnes pourraient exister dans une zone. Ce concept a été développé et testé par la situation des colonies assyriennes le long de la rivière Ḫābūr avec une partie des données archéologiques disponibles. D’autres discussions entre experts de la gestion de l’eau et de l’archéologie pourraient améliorer ce concept. La gestion de l’eau, l’affichage est une contribution essentielle à la compréhension du système de canaux le long de la rivière Lower Ḫābūr et de son importance pour la population locale. Des recherches approfondies sur le traitement et l’incorporation de toutes les données disponibles peuvent affiner davantage le tracé du canal. Le concept développé est également une idée pour d’autres projets d’archéologie dans les régions arides et semi-arides pour vérifier si l’approvisionnement en eau est suffisant pour le nombre estimé de personnes.

**Mots clés**
approvisionnement en eau, demande en eau, Syrie, fleuve Ḫābūr, Assyrie

## 1 | INTRODUCTION

In arid and semi-arid regions, the supply of water is limited for people, animals and agriculture, setting the maximum means of subsistence for a population in the present as well as in antiquity. The most important factor is the amount of water available for agriculture. With less than 300 mm rainfall per annum, rain-fed agriculture is risky. Other important factors are the yearly variations of the total and the available amount of water during the growing season. If this is not satisfactory, additional sources are needed and temporary or local water transfer becomes necessary.

In areas where humans did not introduce sustainable water management, people generally left the area temporarily or permanently due to insufficiently available water resources. The understanding of water management can therefore be key to the understanding of cultures. The collaboration between archaeology and water management gives rise to new and interesting insights into the function and use of hydraulic structures and water management in ancient civilizations. This particularly applies to the irrigation of agricultural surfaces necessary to provide the population with sustenance. Such a collaboration was experienced during the excavation season of 2009 at Tall Šē amad within the scope of a collaborative exploration. The civil war in Syria has unfortunately prevented further and more intensive on-site studies, so that the potential was studied based on available data and recommendations for future action developed. The results of the study and the reflections and discussions pertaining to the relation between archaeology and water management are presented in the present article. The results show that further intensive research has significant potential for gaining deeper insights, contributing to a better understanding, particularly of matters pertaining to settlement and irrigation agriculture. The rapid developments in the field of geographic information systems (GIS) and the availability and quality of digital data allow for analyses with reasonable effort which were unthinkable 10–15 years ago. However, this paper does not draw on currently available data but rather on the drastically improved accessibility of older data. The availability of older satellite images and the digitization of maps and aerial imagery allow for the processing of larger areas, a virtually insurmountable task with analogue methods. As it currently stands, the processing and reanalysis of the accessible data will provide a significant increase in knowledge pertaining to ancient irrigation systems on the Lower Ḫābūr River. The assumptions thus developed will be the subject of verification on-site when the particular region is accessible again for archaeological research. Research with GIS can clearly demarcate the potential areas worthy of archaeological exploration. However, the methods presented here can also be applied to different regions and projects. The focus in this article is to introduce the method to compare the water demand with the existing water resources in a historical context. For the chosen example of the Lower Ḫābūr River in Assyrian times, more and newer archaeological information is available such as Kühne (2018b) and Dornauer (2016). The discussions with the archaeologists about different data and different possibilities is not been finished until now and also
additional research on the different topics including more and newer information was not done until now. But results and ideas could also be interesting for other projects. With a more detailed study in the future the idea presented in this paper could be improved. Especially for the estimated population more and deeper investigations are necessary.

2 POSSIBILITIES OF HYDRAULICS AND WATER MANAGEMENT

Hydraulic and hydrological calculations in archaeological projects have the advantage that the physical behaviour of water remains unchanged over time. Based on the archaeological record, the hydraulic performance capacity of piping or canals can be calculated and the amounts of transported water estimated. Reflections on building and construction principles can be applied in combination with building technologies and materials used to reconstruct potential routes, also in areas where no archaeological investigation has been carried out to date. These considerations can be used to support or also reject theories relating to populations and the use and operation of hydraulic devices. However, hydraulic calculations of performance capacity only provide a maximum-capacity scenario. A maximum load is achieved only a few times a year for short periods. Further hydrological considerations are necessary to determine whether the required water amounts were actually at the disposal of populations during the year. Sinter deposits can provide us with clues regarding the utilization of canal sections and the period during which they were used. The river area that needs to be included in the research spreads out over the catchment. This in turn means that information needs to be collected on the entire drainage area for this research.

In the context of this paper, this aspect has been considered only marginally, as resources were lacking to create a precipitation–runoff model. However, expansive precipitation data have been analysed (Figure 1), and these modern data can also be applied for historical considerations under the assumption that the climate of the Middle East has not changed significantly over the past 5000 years as pollen analyses by Gremmen and Bottema (1991) have demonstrated.

Analysis of the data shows the alternating succession of dry and wet years. However, it also demonstrates that the validity of the average annual precipitation amounts is insignificant pertaining to the importance of irrigation and to the reliability of population supply. This shows that a further water management perspective, for example over the course of the year, is sensible. For the investigation of these problems, a parameter of yearly water management has to be introduced. Water management is an overarching concept relating to the management of water resources with the goal of aligning water supply with human water demand. In arid and semi-arid regions, the amount of available water directly correlates with the number of people that can be supplied with water in a region. Permanent transport of drinking and service water in containers to supply people is only feasible for individual outposts with lower staffing. Transporting water in piping systems and through canals is more realistic, also over longer distances. The largest share of water that people need is necessary to produce food.

A flow chart (Figure 2) has been developed during this research, considering archaeological projects, which depicts how water supply and demand can be estimated and compared. The depicted approach has been tested in the model case of the Lower Ḫabûr River. The proceedings following the flowchart in Figure 2 will be described in the subsequent paragraphs using this specific case.

**FIGURE 1** Annual precipitation at the measuring stations Deir Ezzor, Hassaka and Kamishli from 1956 to 1975 as percentages of the perennial average precipitation amounts (climate data from: National Oceanic and Atmospheric Administration (NOAA) (2014) as applied by Hoppe, 2014) [Colour figure can be viewed at wileyonlinelibrary.com]
3 | SYSTEMATIC APPROACH TO ESTIMATE SUPPLY RELIABILITY

In the context of the present study, the question should also be answered to what extent the Eastern Ḥabur Canal was able to secure a nutritional and water supply for the number of population estimated for this area. To answer this question, the approach depicted in Figure 2 was developed and applied. With this approach, it could be established that this canal potentially provided water to an estimated 14,000 people along the eastern part of the Lower Ḥabur River, with sufficient irrigation water to sustain them in dry years as well. How the population was estimated will be explained later. The approach is based on an estimation of water demand and supply for historical situations and a subsequent comparison to test whether the water supply of the people was guaranteed and sustainable. A supply and demand comparison offers three different scenarios. In the first, the water supply suffices, covering the water demand of the population. This means that no water is stored, as enough water is available at all times. In this case, it should be tested whether all data used are plausible and if all potential unfavourable circumstances—such as dry years—have been considered. With a natural water supply, it is assumed that this water resource regularly regenerates. A second possibility is that the natural water resources approximately meet water demands. It should then be estimated whether the risks associated with, for example, particularly dry years, a growing population or similar
The annual average water demand in the Lower Ḥābir valley (Hoppe, 2014: 24)

| Water Demand            | Population [P] | Drinking and service water | Trade | Animals | Agriculture on 8 000 ha |
|-------------------------|----------------|---------------------------|-------|---------|------------------------|
|                         |                | 4.4 m^3 F_year           | 3.7 m^3 F_year | 3.7 m^3 F_year | 3.7 m^3 F_year | 1 900 m^3 F_year    |
| Tall Schech Hamad       | 7 000          | 30 800                    | 25 900 | 25 900  | 25 900                  | 13 300 000          |
| Tall Tnenir             | 1 000          | 4 400                     | 3 700  | 3 700   | 3 700                   | 1 900 000           |
| Tall Taban              | 300            | 1 320                     | 1 100  | 1 100   | 1 100                   | 570 000             |
| Tall Agaga              | 500            | 2 200                     | 1 850  | 1 850   | 1 850                   | 800 000             |
| Tall Fadgami            | 1 000          | 4 400                     | 3 700  | 3 700   | 3 700                   | 1 900 000           |
| Tall Brik               | 300            | 1 320                     | 1 100  | 1 100   | 1 100                   | 570 000             |
| Tall Abu Hamda          | 300            | 1 320                     | 1 100  | 1 100   | 1 100                   | 570 000             |
| Other locations         | 3 500          | 15 400                    | 13 000 | 13 000  | 13 000                  | 6 650 000           |
| Sum                     | Around 14 000  | 61 200                    | 51 500 | 51 500  | 51 500                  | 26 600 000          |
| Share [%]               | 0.23           | 0.19                      | 0.19   | 0.19    | 99.20                   |

situations were acceptable or if precautions were taken to counteract such scenarios, for example through the storage of food or alternative supply possibilities. In a third scenario, water demand at least temporarily exceeds available water resources. In this case, it should be examined how the deficiency was compensated for. If there is enough available water during the year and only temporary shortages occur, a possible solution can be the storage of water (temporary transfer), for example using dams, in reservoirs or also in groundwater. If there is a general shortage of available water to cover demand, as in the case of the Lower Ḥābir River without supra-regional irrigation canals, water needs to be supplied from outside the affected region (eventually also as virtual water in the form of food). If no structures for temporary or spatial transfer of water have been identified or if the capacity of these installations is insufficient, all data need to be re-examined, additionally questioning previous estimations of population sizes if necessary. Alternatively, a search can be started for additional water resources or relevant buildings or structures. If the available water resources, including spatial or temporary transfer, are plausible and sufficient to cover the demand, the assumed population sizes can be accepted from a water management perspective.

### 4 | ESTIMATED WATER DEMAND

The first fragments of the supra-regional Eastern Ḥābir Canal parallel to the Lower Ḥābir River were discovered in 1982 and were dated to the Middle and neo-Assyrian era. Ergenzinger and Kühne (1991) provide the first extensive description of the canal and the current state of knowledge at the time. Kühne (2016) complements these considerations with current findings from translations of preserved Middle Assyrian texts (thirteenth century BC).

The population in the Lower Ḥābir region is estimated to have been 24 000 in the Late Assyrian period (Morandi Bonacossi, 2008) and that of the regional centre Tall Seh Hamad as 7000 people (Kühne, 1991). The population for the eastern side of the Lower Ḥābir River was estimated as 14 000 inhabitants by the population density of 150 inhabitants per hectare (Morandi Bonacossi, 2008) and 75% of the area of the cities. For the western side 10 000 inhabitants were estimated, to have in total 24 000 people for the Lower Ḥābir region. This raises the question as to how these people were provided with supplies and whether this was possible with regional resources or to what extent supply from outside the region was necessary. External supply, in turn, raises the question as to how the food products were transported. Research on the various identified canal sections in the digital terrain model shows that this was a hydraulically coherent system, allowing for the transportation of irrigation water and goods over this route. The consistent size of the canal supports the assumption that it was used as a transport route. If it were merely used for irrigation purposes, a gradual reduction of the canal cross-section size could be expected. The question as to how the canal was generally used and operated can only be answered after further intensive research.

The vast body of knowledge and data that has been gathered over the decades within the scope of the Lower Ḥābir Archaeological Project, led by Professor Kühne, can be used to estimate water demand. The water demand per person, including domestic animals as well as for trade, was estimated by the author considering the
various quality demands (drinking or service water). The grain demand was estimated based on data on monthly barley rations paid to workers as wages in arbe (Tell Chuera, around 300 km north-west of Tall Šē amad) (Kühne, 1999). The determined amounts still do not cover current calorie intake requirements, but it can also be assumed that people did not eat these barley rations exclusively. Information from Röllig (2008) and Reculeau (2011) was used to estimate the potential grain yields on irrigated fields. This information is related to middle Assyrian times (thirteenth century BC); it will also be used for the neo-Assyrian period. Soil parameters to estimate the demand for irrigation water were taken from Smettan (2008). The demand for irrigation water could subsequently be estimated and checked for plausibility in a comparison with other sources using FAO Cropwat 8.0 software. The result is shown in Table I, clearly displaying that most water was needed for irrigation, with 99% of the water demand used to produce food. A part of this demand could be covered by natural precipitation during the growing season. It is assumed in further considerations that seeds were sown once a year in October/November, during the rainy season, and that crops were harvested at the end of April/May (growing period of 165 days). Only the area between the Eastern Ḫabur Canal and the Lower Ḫabur River is accessible for agricultural use and irrigation for topographical reasons. For the area around Tall Šē amad, Smettan (2008) has determined that about 700 ha could be used for agriculture in the region. This amounts to around 78% of the total land area. For the entire Ḫabur valley, it is assumed that 70% of the surface between the canal and the Ḫabur

![Map of the Ḫabur River catchment](image-url)
River could be used for agriculture. This would amount to around 16 500 ha. As the Assyrians only tilled their fields every second year (Altaweel, 2008; Wirth, 1971), this means that around 8000 ha yr\(^{-1}\) were available. Assuming that the available fields were adequately irrigated, these estimations show that, under these boundary conditions, enough food would be available for around 14 000 people—also in drier years. This is in accordance with the assumed population size of 14 000 for the eastern side of the Ḫabur valley. Furthermore, it is assumed that around 10 000 people lived on the western side, where another supra-regional canal was accessible. It can be surmised that the conditions on the eastern and western sides were largely similar. This shows that the supra-regional canals provided adequate water to feed a population of around 24 000 people. Without them the amount of land that could be irrigated would be drastically reduced, no longer sustaining the regional population.

5 ESTIMATED WATER SUPPLY AND CAPACITY OF THE CANAL

As far as the discharges of the year-round aquiferous rivers are concerned, an average of 40 m\(^3\) s\(^{-1}\) was determined for the Upper Ḫabur River (Wirth, 1971). The combined discharge of the more than 10 sources of the Ḫabur River was also determined to be 40 m\(^3\) s\(^{-1}\) by Sprenger (1990). For the Lower Ḫabur River, after the confluence with the Gaag River, an average discharge of 52 m\(^3\) s\(^{-1}\), a minimum discharge of 36 m\(^3\) s\(^{-1}\) and a high-water discharge of around 300 m\(^3\) s\(^{-1}\) was defined (Sprenger, 1990). No secure sources can be found for the Gaag River, but Wikipedia (2017) lists it as 8–12 m\(^3\) s\(^{-1}\). However, these discharges are influenced by a modern dam and therefore cannot be equated to those of the Assyrian era. The catchment areas of the Gaag and Ḫabur rivers are approximately the same size at the mouth of the Gaag River (Figure 3). The drainage rates are not consistent over large areas. Therefore, the discharges do not equally correlate to the catchment areas. It does, however, provide a good indication. This aspect needs further investigation, also taking into account the discharge of the irrigation water into the eastern supra-regional canal.

The groundwater lies at a depth of around 4–5 m underneath the site. In the steppe, however, it is partially at a low depth of 2 m. However, the water is saline (5.3 mS cm\(^{-1}\)) and bitter and therefore only of limited use for irrigation or drinking purposes. It was probably used before the canal was constructed, as well as for contingencies.

Examinations within the scope of this study have resulted in the identification of an additional water demand of 140 mm, already taking into account the precipitation from October to May with a growing period of 165 days. The estimated average water demand ranges from 10 mm at Hassaka (demand 220, precipitation 210) to 270 mm at Deir-Ezzor (demand 400 mm, precipitation 130 mm) and thus increases significantly as the Ḫabur River flows further downstream.

A total water loss of 50% is assumed for the canal and irrigation system. This is a common order of magnitude for earth canals and is also used in modern calculations. The hydraulic examination of the canal demonstrated an average performance capacity of around 4 m\(^3\) s\(^{-1}\), providing around 187 000 m\(^3\) day\(^{-1}\) of water. This was sufficient to provide the estimated cultivated area with sufficient water during the growing period, also in drier years. It is also realistic that these amounts of water could alternatively have been tapped from the Ḫabur or Gaag rivers. The structural effort for tapping this water depends on the height relations and the ratios between the discharges at the tapping point. The question as to where the water was tapped will be considered separately later on, taking into account the respective advantages and disadvantages.

The expositions so far show that the canal was of central importance to the development of the Lower Ḫabur region. According to the current state of research, the Assyrians had the technological capacities to erect all the structures necessary for such a canal. Bagg (2000) has described Assyrian hydraulic structures from the seventeenth until the fourteenth century BC in detail, particularly by analysing the original cuneiform sources. He shows that the Assyrians realized the clear advantages of

**FIGURE 4** Dam wall at al-Gila, view from the north-west (picture trustees of the British museum, from Bagg, 2000) [Colour figure can be viewed at wileyonlinelibrary.com]
flood irrigation through water drainage from a canal against lifting water from springs or streams and, in turn, used this preferred method wherever possible. They were also capable of performing the necessary survey work for large projects, such as canals, with the necessary high level of precision. This was the case especially for the gradient (at the Ḥābūr River, averaging 0.5 per mille (1 per 1000), and at the same time they used the natural topography optimally. They also mastered large organizational challenges—workers, building materials, supply and transport—posed by the construction of the canal. It became clear that the Assyrians had knowledge of the various structures necessary for operation of the canal, canal bridges and tunnels and could erect these structures as well.

The natural water levels fluctuate strongly as a function of the discharge. Transverse structures in the natural body of water are necessary to lead a certain amount of water into the canal under these circumstances. Baggi (2000) presents various types of channel heads (outlet locations from the stream). A similar structure must have been present for the Ḥābūr canals. However, the author has no information that such structures are substantiated by archaeological findings as yet. The Eastern Ḥābūr Canal must have been of such importance for the supply of water and food that it is certain that no efforts were spared to provide the canal with sufficient amounts of water. The barrage construction in the stream may have been either a dam or a masonry dam, such as at al-Gila (Figure 4), or also a weir (Figure 5). The upstream water level, and with that the amount of water drained into the canal, could be regulated through various openings or spillways. This construction in the stream needs to be of such stability that it also withstands floods, contrary to constructions in the canal system itself, which are generally not subject to occasional flooding. A further weir in the canal can reduce water amounts in the canal or even temporarily close it for maintenance work, for example. In this case, moveable locks are required. Under favourable topographical conditions, one weir in the inlet area of the canal suffices to regulate the outflow. Further structures similar to those in the inlet area are likely further down the canal, guaranteeing even distribution of the water, especially at the junctions to the various settlements. In addition to the irrigation season, particularly in the summer when there is only little water available in the streams, such regulating structures are also necessary to allow for ships to navigate the canal, guaranteeing high enough water levels with little discharge.

An important question is where the water for the canal came from. From a topographical perspective, drainage from the Ġaġaġ River at Tell Bab, or from the Ḥābūr River at Tell Kerma North is possible. Both routes carry with them technical difficulties and plenty of unanswered questions. These unanswered questions are considered below from a purely water management and technical perspective.

Drainage from the Ġaġaġ River constitutes the problem of overcoming the watershed between the Ġaġaġ and Ḥābūr rivers. The exact height difference could not be determined due to differences in the geographic coordinates of the different maps; it will be up to 20 m at several points and more than 10 m over longer distances. To overcome this watershed, either a sufficiently deep cut in the terrain or tunnels needed to be realized; these cuts would have had a maximum depth of 20 m and are still visible today (Kühne, 2018a).

The Assyrians were also capable of constructing canal tunnels. However, as shown by Baggi (2000), the dimension of the tunnel was smaller than the cross-section of the canal. Therefore, multiple tunnels would have been constructed adjacent to each other to provide the canal with sufficient water, making it impossible to navigate ships. Transhipment and transportation of goods by land would need to have been made at least for the length of the tunnel. In this case, an appropriate infrastructure would have been necessary at the beginning and end of the tunnel.

Diverting the water from the Ḥābūr River offered a greater water supply, as the Ġaġaġ River already discharged into the Ḥābūr River, allowing the water from both catchment areas to be used. It would be likely that a dam in the Ḥābūr River was constructed to allow for constant discharge into the canal. A dam in the Ḥābūr River would certainly have been larger, as in the Ġaġaġ River. Moreover, the Wadi Hammar would have to be traversed closer to the confluence with the Ḥābūr River, in turn necessitating a larger structure.

**FIGURE 5** Weir in Shushtar, Iran, from downstream (Röttcher, 2014) [Colour figure can be viewed at wileyonlinelibrary.com]
An advantage of this route is its shorter length and no watershed needed to be overcome. Depending on the height ratios, the canal would have to be led over a dam for a longer distance in order to limit height losses. Here also the author has no information about archaeological evidence for such a dam or other noticeable structures in the landscape; this aspect needs more detailed discussion with different archaeologists. Also, no noticeable structures can be found in the landscape.

Diverting water for the Eastern Ḫabûr Canal from the Gaḡaḡ River brings with it the advantage that the shipping route to the Assyrian heartland is significantly shortened. This leads to the questions if and under which circumstances—and for what ship sizes—navigation on the Ḫabûr and Gaḡaḡ rivers was possible. Supra-regional navigation on the highly meandering Lower Ḫabûr River, with its mainly boggy floodplain, can be excluded. When used for navigation, canals have the advantage that the cross-section of the canal remains the same size—which would certainly not have been the case if the canal were solely used for irrigation. In any case, the canal is an efficient shipping route and was certainly used as such.

Remains of a weir system in the Gaḡaḡ River are also lacking, as well as conforming transformations in the landscape and leftovers of a tunnel. The point of discharge for the eastern irrigation canal could be explored using a high-resolution digital elevation model and georeferenced maps to avoid further collection of on-site data.

Elaborate and coordinated irrigation management would have been necessary to operate the canal for irrigation. In this way, individual canal sections could be provided with water relative to demand, thus using the available water resources optimally. This applies to the main canal as well as to the fields irrigated by the canal outlets. For the Shaddade Canal on the west side and the Maraza Agaga Canal on the east, the structure of the local irrigation systems from the Assyrian age has been researched and presented by Sprenger (1990). Communicating information in a fast and timely manner when controlling the water flow in the main canal would have been a special challenge, due to its large length of around 200 km and flow velocity of 0.5–0.75 m s\(^{-1}\) (1.8–2.7 km h\(^{-1}\)). Therefore, it can be assumed that an irrigation calendar, with a set schedule for the irrigation of individual areas, was used. In this case, only deviations needed to be communicated.

As previously mentioned, weirs or other obstructing features would have been necessary for optimal control of the water flow in the main canal and for distribution for irrigation or navigation during the dry season. It can be assumed that stones used for these structures would have been used for other purposes later on and that the wood has rotted or been burned by now.

To analyse the canal route, three types of elevation data were used in the scope of the Shuttle Radar Topography Mission (SRTM) research project. Digitized aerial imagery could be used for some regions. Images of the CORONA reconnaissance satellites were used for other regions. However, the various data sources did show significant position deviations (of up to around 100 m). The results of these observations show that a continuous canal route was feasible and plausible and that its construction could be realized (Figure 6). It would have been possible to build the canal with a relatively consistent gradient of around 0.5 per mille (per thousand).

**FIGURE 6** Longitudinal cut of the Eastern Ḫabûr Canal (Hoppe, 2014) (green line is average slope of 0.5 per mille (per thousand)) [Colour figure can be viewed at wileyonlinelibrary.com]
This would have offered operational advantages, as it does not lead to varying degrees of erosion or sedimentation in the different canal sections. The digitization of further aerial imagery and the use of a digital terrain model with higher resolution could lead to a better understanding of the exact position of the canal route and the various potential effluents. An optimally visualized canal route in those areas where no structures are recognizable could also reduce the depth of necessary terrain cuts. The defined cut depths of more than 10 m in Figure 6 are partially the result of positional disparities between the digital maps and the terrain model. After these corrections are completed, the transported soil masses and the building effort necessary for construction of the canal can be estimated. For the considerations presented here, it can assumed that the option of digging in the terrain was preferred over leading the canal over a dam, as the densification of soil material and waterproofing against seepage play a particularly important role with dam sections. Insufficient soil compression and sealing in dam sections present long-term structural weaknesses. The question as to how the laterally discharging Wadis River could have been traversed can also be researched with more precision using more detailed digital map data.

6 Conclusion

Water management is presented in this article, displaying its essential contribution to understanding of the canal system along the Lower Ḫabur River and its importance for the local population. Extensive research into the processing and incorporation of all available data can further refine the route of the canal. Such data can also provide information on the origin of the irrigation water, the crossing of the Wadis, and water distribution within the studied region. By combining these insights with archaeological findings, a comprehensive image can be formed about the function and use of the supra-regional canal and irrigation system. The presented systematic comparison between water resources and demand can also be elaborated upon and tested in further research projects. Further discussion from an archaeological and water management perspective about the data sources used and about the validity of the results is also desirable.

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