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# **Economic Feasibility Study of Canal Plastic Lining in the Aral Sea Basin**

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Additional information is available at the end of the chapter

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## **1. Introduction**

The Aral Sea Basin (ASB) in Central Asia centuries ago was part of the Great Silk Road that brought Chinese silk, bronze ware, cosmetics, paint, rice, and tea to the West, and glassware, dried fruits, vegetables, cotton, horses, and semi-precious stones to the East [5]. However, the ASB was a place not only for trade but also a cradle for cultures, ideas and agricultural development, a place where impressive irrigation and drainage networks have been established to support the flourishing of the oasis.

Since the ancient days agriculture in the ASB region has been possible only with irrigation but viable for millions of farm families to make a living and to have access to sufficient drinking water and healthy food. Since the 1960s, about 8 million ha of land, including natural forest and desert areas, were transferred to irrigated agricultural production in the ASB. The required ca. 96 km<sup>3</sup> of irrigation water was conveyed through 323 000 km of channels [6]. In the past four decades, between 80 to 95% of water from the Amudarya and the Syrdarya rivers – the main feeding rivers of the Aral Sea – with annual flows of around 75 km<sup>3</sup> and 34 km<sup>3</sup> respectively, has been used for irrigation purposes for production of cotton, rice and other crops. However, the present management of irrigated cropland is becoming increasingly unsustainable with a widespread land and water resources degradation, which further threaten the ecological and economic sustainability as well as food security and health of the population in the ASB region.

The case study region Khorezm is located between 60.05 and 61.39 N and 41.13 and 42.02 E in the northwest of Uzbekistan and ASB. Khorezm is a living habitat to over 1.7 million people (as of 2011). Roughly 260 000 ha of the region are used for irrigation purposes. Agriculture in

Khorezm is possible with irrigation only to compensate the difference between the low precipitation (annually 100 mm) and high evaporation rates (up to 1400-1600 mm) resulting from the continental climate. Irrigated agriculture in Khorezm contributes to more than 50% of the regional income, provides more than 98% of hard cash revenues, and employs more than 60% of the economically active population [7].

The probability of adequate water supply has been decreasing over the past years [1]. Seasonal variations in river runoff also decrease water availability during the vegetation period [1]. The mentioned water scarcity has been aggravated by external factors, such as river runoff reduction due to climate change and the growing water demand in upstream countries [2], yet also by internal factors, including the expansion of the production of water intensive crops such as cotton and rice and the poor condition of the irrigation and drainage infrastructure causing high water losses [3].

Low conveyance and irrigation efficiencies are thus the main causes of irrigation water losses in the ASB and Khorezm. Water is mainly conveyed by unlined (earthen) irrigation canals [3]. The loss of irrigation water due to seepage and evaporation out of the irrigation canals has raised groundwater levels, thereby causing water-logging of the soil, increased salt concentrations (via evaporative concentration), and lowered crop yields [8]. Additionally, the quality of drinking water, which is often pumped from groundwater, has been negatively affected by increasing salt concentrations.

It is expected that climate change and increasing water use in upstream regions of the basin will change the quantity and temporal behavior of the water resources available in Khorezm for the worse [4]. This underlines the need for improving irrigation efficiency and adequacy of water management in Khorezm, which presently are notoriously low [3]. The enormous water losses in the irrigation system and the shallow ground water table with outcoming negative consequences call for urgent solutions to improve water supply and to increase water use efficiency. Improving irrigation efficiency is urgently needed to (i) reduce the currently enormous waste of water, (ii) contribute to overcoming the underutilization of agricultural yield potentials, and (iii) lower adverse impacts on the soil and groundwater resources [4].

## **2. Current situation of water use in Khorezm**

The Amudarya river is a muddy river and used to bring large amount of sediments with irrigation water. These sediments covered the beds of earthen irrigation channels thus lowering infiltration of water and seepage losses. However, after the construction of the Tuyamuyun water reservoir, which main function is to store water, water discharged from the reservoir to the channels became 10-20 times less muddy. As a result, the channels do not receive sediments for bed covering and infiltration of water in the channels is high, the ground water table in the vicinity of the channels is rising, causing secondary soil salinization processes.

Irrigation water management is supported by and conducted with a larger number of dams, pumping stations also for water lifting, canals (lined but mainly earthen), intake structures,

flumes and subsurface and vertical drains. The larger infrastructures used to be regularly maintained and operated in contrast to the smaller structures such as pumping stations and intakes from channels as well as the drains, which are insufficiently maintained [3].

Irrigation distribution network comprised of hundreds interfarm canals in Khorezm is characterized by the excessive length – each ha of irrigated agricultural land is serviced by 37.5 meters of irrigation channels. Irrigation water is conveyed to the farm fields through around 2 445 km of channels, of which only 233 (or less than 10%) have concrete lining.

Around 90% of the channels in the Khorezm region have been constructed without any lining measures and are considered earthen canals. Furthermore, the current layout and status of the irrigation and drainage infrastructure also hinder appropriate operation. The present situation is characterized by a large number of small size irrigation fields and a large number of water users with diversified requirements. On the contrary, the irrigation and drainage network has been constructed to serve large production units (kolkhozes and sovkhozes) with high uniformity [2]. With this regards the delivery performance ratio<sup>1</sup> of irrigation water in Khorezm is low and enormous amount of water is lost during conveyance from the water source to the field. As a result, the fields and crops do not get the required amount of irrigation water, which influences yields, income, and food provision of the farming population. Furthermore, the estimated poor irrigation efficiency (30-33%), and high drainage ratio (55%), indicate inefficient water management at irrigation network level and especially at field level. Furthermore, the widespread occurrence of deteriorated hydraulic structures and lowered discharge capacity of the canals are consequences of a low maintenance intensity [9, 3]. Loss of irrigation water is not unique to Khorezm; worldwide, 40-75% of irrigation water is lost due to evaporation and seepage [10, 11]. As global water supplies come under increased pressure due to population growth and climate change, measures to balance agriculture and the hydrologic system are critical.

### 3. Water saving technologies

Many measures to increase water use efficiency at different levels have been developed so far, varying from measures for improving conveyance and distribution efficiency to measures for increasing irrigation efficiency at field level. Since irrigated agriculture is the dominant livelihood form in the study region, crop production should be ensured under conditions of reduced water supply, which would necessitate upgrading irrigation networks and management practices and improving water application at field level. The present lack of maintenance of the irrigation infrastructure engraves the on-going deterioration as evidenced by the ever-growing number of silted up and damaged canals, broken gates, outdated pumps, lack of spare parts, and so on. Hence, an improvement of the irrigation infrastructure bears high potential to decrease overall water losses, although it recently was postulated that rehabilitating and

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<sup>1</sup> The relation between actual and intended amount of water directed to a scheme or part of a scheme is the most important indicator to assess the operational performance of water distribution

renovating the irrigation systems by, for instance, concrete lining of channels could reduce irrigation water losses, but would require extraordinary high investments [12].

Given the present economic and ecological situation, it is necessary to consider not only high returns to investments, as predominantly has been emphasized in the past, but also their relevance for environmental sustainability, while considering also the financial viability of the technical measures for improving conveyance, irrigation, and management efficiencies. At field level water use reduction can be achieved by implementing improved irrigation technologies and water-wise options such as laser guided land leveling, drip or sprinkler irrigation and other through which water use efficiency at field level could be increased but where the costs of technologies showed an inverse relationship [13].

At channel level there also exist various methods for reducing water loss due to seepage and infiltration including: reinforced and unreinforced concrete; geomembranes; flocculant polymers; compacted soils and clays; mud; and plastic liners [14]. These methods have their advantages and disadvantages, but have the common explicit objective to reduce water loss, to lower groundwater level and improve water quality. None of these methods have been examined for their efficiency in the irrigated systems in Central Asia and ASB. In our study we selected the plastic lining to decrease water loss and lower groundwater levels due to appropriateness for the soil type and climate, low cost, local availability of resources, and low maintenance needs, which would potentially be to the benefit of farmers.

## **4. Plastic lining of channel beds for reducing infiltration**

Seepage of irrigation water in the earthen canals can be reduced by placing a plastic liner on the canal bed prior to irrigation season. Lining of canals is a well-tested remediation method for minimizing seepage loss from canals.

### **4.1. About the technology**

In 2009-2012 researchers from Urgench State University in Khorezm together with one of the Water Consumers Associations in Khorezm have tested the technology of plastic lining on one of the small interfarm earthen channels in the region.

The selected channel, 2.6 km long, provided irrigation water to 400 ha of farm land and had the discharge capacity of 1.5-2 m<sup>3</sup> per second. The average performance ratio hardly reached 0.49, meaning that 51% of water in the channel was lost due to seepage and infiltration.

When applying the technology an area slightly larger than the banks and bottom of the canal was cleaned and excavated of soil. Prior to excavation works the channel was checked for elevation with the use of special leveling laser tools as to ensure gravity flow of water after plastic lining. Approximately 10 to 15 cm of sand was placed as a base on the cleaned bottom of the channel (refer to the photos). The plastic was laid on top of the sand. The plastic was then covered by up to 0.5 m layer of compacted soil to keep the plastic in place, and prevent exposure to the sun.





**Figure 1.** Appearance of the channel prior to plastic lining



**Figure 2.** Cleaning the bottom and the banks of the channel



**Figure 3.** Lining of plastic



**Figure 4.** Covering of plastic with compacted soil

Specifications of the plastic liner included 100  $\mu\text{m}$  thickness, 7 m wide, and elasticity of 250%. Such plastic is locally available and is usually and widely used by the rural population to cover the temporary greenhouses for year round production of vegetables and green vegetables. The





**Figure 5.** Gravity flow of water in the plastic lined channel

plastic laid at the bottom of the channel can last up to 50 years given the proper coverage by compacted soil and non-exposure to the UV sun rays.

Concurrent with application of plastic liner, fields irrigated from the selected channel were lazer leveled to improve gravity flow. The combination of enhanced gravity flow and water saved resulted in less use of mechanized pumps.

#### **4.2. Pros and cons of the technology**

The major achievement of the technology was that average performance ratio in the lined channel increased from 50 to 89% during the growing season. Overall the findings illustrate that plastic lining was effective at reducing water loss due to seepage, groundwater levels decreased in the plastic-lined canal. This was the intended effect of the plastic liner. However, though the plastic lining remained effective at reducing water seepage, as seen in the consistently lower groundwater level, it could not counteract movement of groundwater from nearby areas. High hydraulic conductivity values allowed groundwater from nearby irrigation to seep into the area around the canal thus increasing groundwater levels, which is a common, annually observed phenomena in the entire region [8]. The reasons may include the absence or low efficiency of particular crops contributing biodrainage potential in the irrigated area [15].

Reduced seepage or infiltration of irrigation water allowed saving enormous amount of water (over 10 million m<sup>3</sup> during one irrigation season for the total length of 2.6 km), which was used to irrigate additional cropping areas amounting to about 500 ha in the tail end of the channel. Thus, the results showed that given the same amount of water in the channel and given



virtually no seepage losses farmers can irrigated twice as large cropping areas, can get additional revenues from additional cropping areas, but also from higher yields (i.e. cotton yield was at least 15% higher compared to other fields) caused by the timely delivery of irrigation water and lower ground water level.

Another major achievement was the gravity flow of water in the lined channel due to leveling measures. Gravity flow allowed the farmers to stop using pumps for delivering water both to the tail end of the channel and to the fields with higher elevation levels compared to the channel. Thus, the farmers could save enormous financial resources for electricity or diesel, not talking about the benefits to the environment.

Water shortage often happens during the peak irrigation season negatively affecting crop yields. Plastic-lined channels hold potential to be used also as decentralized water reservoirs for tackling the problem of temporarily unreliable water supplies. Filling the reservoirs (lined channels) during periods of oversupply of irrigation water could make the farmers more independent from the water supply by the network.

Along with all the evident benefits of plastic lining as an efficient water saving option, there are some obstacles for further dissemination in the region. This is in the first place the financial aspect or high costs of plastic lining (over 15 thousand USD per 1 km of channel). Farmers in the ASB are predominantly not rich and could not afford adopting this option individually. Broad adoption of this technology would require the joint efforts of many farmers using the same channel for irrigating their fields. However, interested in this water saving technology are farmers in the tail end of the channel, whereas farmers in the head of the channel receive water in any case and do not usually want to cooperate and to invest in the technology to the benefit of other farmers. Thus not farmers, but higher level structures, such as Water Consumers Associations, local governments, etc. and decision makers should become the major driving force for disseminating water saving technologies in the environmentally degraded ASB region.

#### **4.3. Cost benefit analysis**

Any innovation, any technology to be accepted and adopted by local farmers and decision makers on higher level should be financially analyzed to show the costs, the benefits and payoff period of the required investments. Economists from Urgench State University have conducted cost benefit analysis of the plastic lining technology both per 1 km of interfarm channel (rather small channel with 5-7 m width) and for the whole Khorezm region.

The technology of plastic lining required 15.3 thousand USD per 1 km of channel length (Table 1). Since it was possible to save around 4 million m<sup>3</sup> of irrigation water per 1 km of channel and given the cost of water delivery of around 0.002 USD per m<sup>3</sup> the farmers could save around 9.5 thousand USD on water delivery. Furthermore, due to gravity flow in the lined channel, the farmers could save around 3 thousand USD on energy costs for pumps and around 0.5 thousand USD on pumps maintenance.

The timely and in required amount delivery of water to the fields resulted in an increase in particular of cotton yields of up to 0.4 tons per ha. Cotton was used in analysis since it is the

main cash crop cultivated in the region. If we assume that at least half of the cropping area supplied by the channel is covered with cotton, then additional income from increased cotton yield could reach 35.6 thousand USD (Table 1).

The efficiency or profitability of plastic lining technology can be analyzed from two perspectives: (1) on farmers' level (without the consideration of benefits from water delivery costs saving) and (2) on Water Consumers Association level (without the consideration of benefits from increased cotton yields). The farmers thus could receive up to 39 thousand USD of net benefit in the first year if accounted for cotton or 3.6 thousand USD not accounting for cotton revenues. The payoff period for farmers would be 0.4 years with cotton revenues, but more than 4 years without cotton revenues. The payoff period for the Water Consumers Association would be slightly over 1 year.

| Indicators                         |   | Per 1 km of channel |
|------------------------------------|---|---------------------|
| 1                                  | PL costs, USD                                     | 15 324,4            |
| 2                                  | Additional irrigated area, ha                     | 276,3               |
| 3                                  | Total irrigated area, ha                          | 476,3               |
| 4                                  | Canal efficiency, %                               | 89                  |
| 5                                  | Increase in canal efficiency, %                   | 39                  |
| 6                                  | Water saving, m <sup>3</sup>                      | 4 019 593,8         |
| 7                                  | Saved water delivery costs, USD                   | 9 570,5             |
| 8                                  | Energy for pump, KVt                              | 60 000,0            |
| 9                                  | Energy saving, USD                                | 3 205,7             |
| 10                                 | Maintanance costs for pump, USD                   | 476,2               |
| 11                                 | Increased yield, t/ha                             | 0,39                |
| 12                                 | Extra-yield income of cotton, USD                 | 35 622              |
| <i>Farmers</i>                     |   |                     |
| 13                                 | Total benefits from PL, USD (9+10+12)             | 39 304              |
| 14                                 | Total benefits from PL without cotton, USD (9+10) | 3 682               |
| 15                                 | Net benefits from PL, USD (13-1)                  | 23 979,3            |
| 16                                 | Net benefits from PL without cotton (14-1)        | -11 642,5           |
| 17                                 | Cost recovery, in years (1/13)                    | 0,4                 |
| 18                                 | Cost recovery without cotton, in years (1/14)     | 4,2                 |
| <i>Water Consumers Association</i> |   |                     |
| 19                                 | Total benefits from PL, USD (7+9+10)              | 13 252              |
| 20                                 | Net benefits from PL (19-1)                       | -2 072,0            |
| 21                                 | Cost recovery, in years (19/1)                    | 1,2                 |

PL=plastic lining

**Table 1.** Cost benefit analysis of plastic lining on 1 km of channel

#### 4.4. Economic feasibility of plastic lining for the whole region

Irrigation channels in the Khorezm region were laid on soil of various types from loamy to sandy, which determines the varying delivery performance ratio (or seepage amounts) of channels across the region. The technology of plastic lining could be applied to all the in-farm and interfarm channels in the region, but due to high investment costs, it would make sense to line in the first place channels with beds (bottoms) laid on sand loamy, light loamy and sandy soils, i.e. where most infiltration of irrigation water occurs. According the GIS lab of Urgench State University, there are 1 080 km of such channels in the Khorezm region. Furthermore, if only in-farm and interfarm, small channels are selected, then plastic lining should be applied to only 557 km of channels (Table 2).

Table 2 presents the results of economic feasibility of applying plastic lining in the whole region. The analysis was conducted according to 4 scenarios: scenario 1 covers all irrigation channels; scenario 2 covers interfarm and in-farm channels laid on all soil types; scenario 3 presents calculations for interfarm and in-farm channels laid on light loamy, sandy loamy and sandy soils; and finally scenario 4 covers 40% of the channels from scenario 3 since this amount of channels has the specified width of 5-7 meters. Scenario 4 can be considered the real and first hand to do scenario in the region in order to urgently prevent high water loss due to seepage in the irrigation channels.

Current water loss from all channels in the Khorezm region due to seepage reaches 2.2 km<sup>3</sup> of valuable irrigation water, or about 920 thousand m<sup>3</sup> of irrigation water per 1 km of channel length. Based on rough calculations after plastic lining of all the channels, water loss would amount to 0.5 km<sup>3</sup> of water or 202 thousand m<sup>3</sup> of water per 1 km of channel (Table 2). Thus, water saving potential as a result of plastic lining measures in the framework of the real scenario 4 stands at 0.4 km<sup>3</sup> of irrigation water or about 9% of total annual water intake from the Amudarya river for irrigation purposes of the Khorezm region. This saved water instead of being infiltrated to the groundwater and thus lost, alternatively could be used to irrigate more than 22 thousand ha of agricultural lands in the region.

According to scenario 4 the region would need to invest around 8.5 million USD (Table 2), whereas the benefits in the first year after plastic lining would reach 6.5 million USD including:

- Saving on water delivery – 952 thousand USD
- Saving on energy (pumps) – up to 1.8 million USD
- Saving on pumps maintenance costs – 265 thousand USD
- Additional revenue from increased cotton yields – 3.6 million USD

If taking into account additional revenue from increased cotton yields, the payoff period for plastic lining in the whole region will come due in slightly over 1 year, or 2.8 years without cotton revenues.



| Indicator   | for all canals | Interfarm and in-farm channels on all soil types | Interfarm and in-farm channels on light loamy, sandy soils | 40% of interfarm and in-farm channels (5-7 m wide) (real scenario) |
|---|----------------|--|--|--|
| Canal length, km                                    | 2 445          | 2 029  | 1 080  | 557  |
| Total intake, km <sup>3</sup>                       | 5              | 5  | 5  | 5  |
| Conveyance losses, %                                | 50             | 50   | 50   | 50   |
| Conveyance losses, km <sup>3</sup>                  | 2,25           | 1,87   | 0,99   | 0,51   |
| Conveyance losses per 1 km, m <sup>3</sup>          | 920 328,21     | 920 328,21                                       | 920 328,21   | 920 328,21   |
| Efficiency in canals prior to PL                    | 0,39           | 0,39   | 0,39   | 0,39   |
| Efficiency in canals after PL                       | 0,89           | 0,89   | 0,89   | 0,89   |
| Conveyance losses after PL, %                       | 11             | 11   | 11   | 11   |
| Conveyance losses after PL, m <sup>3</sup>          | 0,50           | 0,41   | 0,22   | 0,11   |
| Conveyance losses after PL per 1 km, m <sup>3</sup> | 202 472,21     | 202 472,21                                       | 202 472,21   | 202 472,21   |
| Water saving, km <sup>3</sup> after PL              | 1,76           | 1,46   | 0,78   | 0,40   |
| Water saving, in % to total water intake            | 39             | 32   | 17   | 9  |
| Cost of PL, USD                                     | 37 464 705     | 31 086 253                                       | 16 547 203   | 8 538 512  |
| Saved water delivery costs, USD                     | 4 178 571      | 3 467 160  | 1 845 568  | 952 331  |
| Energy consumption for pumps, KVt                   | 146 686 800    | 121 713 035                                      | 64 787 813   | 33 431 119   |
| Energy saving after PL, USD                         | 7 837 266      | 6 502 954  | 3 461 520  | 1 786 177  |
| Cost savings for maintenance of pumps, USD          | 1 164 181      | 965 976  | 514 189  | 265 326  |
| Average area under cotton, ha                       | 105 000        | 87 124   | 46 376   | 23 930   |
| Increase in yield (15%), tons per ha                | 0,39           | 0,39   | 0,39   | 0,39   |
| Increase in income from cotton, USD                 | 15 707 250     | 13 033 055                                       | 6 937 491  | 3 579 810  |
| Total benefits from PL, USD                         | 28 887 269     | 23 969 145                                       | 12 758 769   | 6 583 644  |
| Total benefits without cotton revenues, USD         | 13 180 019     | 10 936 090                                       | 5 821 278  | 3 003 834  |
| Net benefits from PL, USD                           | -8 577 436     | -7 117 108                                       | -3 788 435   | -1 954 868   |
| Net benefits without cotton revenues, USD           | -24 284 686    | -20 150 163                                      | -10 725 926  | -5 534 678   |
| Cost recovery, years                                | 1,30           | 1,30   | 1,30   | 1,30   |
| Cost recovery without cotton revenues, years        | 2,84           | 2,84   | 2,84   | 2,84   |

**Table 2.** Economic feasibility of plastic lining technology for the whole Khorezm region

## 5. Discussion and conclusions

Plastic lining was studied as a first step towards addressing in general counterbalancing lower crop yields in Khorezm due to raised groundwater tables causing soil salinisation. Soil salinization and near-surface groundwater levels are a global problem. As global water supplies come under increased pressure due to population growth and climate change, measures to balance agriculture and the hydrologic system are critical. This study contributes by providing a better understanding of the promises and limitations of a lined canal for addressing increased groundwater levels and salinity resulting from intensely irrigated

agriculture. Research impacts will allow Uzbek stakeholders, such as land managers and policy officials, to better address regional water resource issues (supply and quality), as well as potential soil improvement options.

Furthermore, combining the introduction of water-saving measures as plastic lining with decentralized reservoirs would create a win-win situation by tackling both shortcomings that affect the water productivity, i.e., unreliable water supplies and irrigation timing. This should go hand in hand with raising the willingness of farmers to introduce and invest in water-saving technologies.

The results showed that plastic lining of channel beds as water saving technology is a viable, efficient and rather acceptably moderate-cost option for preventing water loss and lowering ground water in the region. However the question comes on the source for required investments. The farmers in the region do not possess enough farm capital to uptake this option themselves. Thus decision makers on higher level, such as Water Consumers Association, local governments or even environmental funds should take the leading role in disseminating this technology throughout the region.

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