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Meeting the demands of the construction industry – The economic case for re-using sediment from the Tuyamuyun Hydropower Complex

A Water Energy Food Nexus Solution

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Disclaimer

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Executive Summary

Background

The Tuyamuyun Hydro Complex (THC) is a system of four interconnected reservoirs and a series of canals on the lower Amu Darya River, bordering Uzbekistan and Turkmenistan. Its primary purpose is to provide water for irrigation schemes in Uzbekistan and Turkmenistan. The complex also provides water for industrial and municipal uses and has a 150 MW power station (Olsson et al., 2008).

Reservoirs, including the THC, are typically built with a design life of fifty years (OECD 2017) – the time it takes to pay-off capital equipment costs. As a result, sedimentation volume is estimated over this period, and the lowest dam outlets are set above the dead storage, so as to not infringe on active storage during that period. Without consideration to sediment management costs, this kind of design defers future sediment management to another generation than those that built the dam (Randle and Boyd 2018).

The construction of the THC was completed 40 years ago in 1983 and today and the sediment management problem is very real. With 1.5 billion m^3 of sediments trapped in the main channel (Ruslovoe) reservoir, the total storage loss is estimated at 63% of total initial storage volume. Projections in Ikramova (2021) suggest that the channel reservoir will be entirely lost by 2040 with no further action, whilst the hydropower facility will likely cease to operate much earlier (Giri 2022, personal communication)

There are significant costs associated with lack of sediment management and sediment build-up, including reduced storage capacity, which will eventually lead to the reduced reliability of water and power supply, and shortened the life time of the dam; wear and tear and damage to turbines by the abrasive properties of sand and gravel; increased dam safety risks from sediment loads against the dam, abrasion of outlets and spillways, and loss of functioning outlets as well as upstream channel aggradation, which can lead to increased flood risk, waterlogging and soil salination (with an increased ground water table elevation) (Palmieri et al., 2001; OECD 2017; Randle et al., 2017)

There are consequently significant benefits associated with the active pursuit of sediment management. Sustainable sediment management focus on improving the sediment balance across reservoirs by:

1) Reducing sediment yield from the watershed e.g., through landscape restoration;
2) Keeping the sediment going – e.g. by routing sediment-laden flows around or through the reservoir, through diversion, bypass, density current venting, sluicing, and managing flood events such that sediment moves out of the gates; and
3) Removing sediment following deposition, through flushing, or with various dredging options. Successful sediment management will typically combine multiple strategies (Morris 2020).

The third option, is often seen as the option of last resort, because the costs to remove sediments when they are already deposited, are considerably higher than preventing from getting into the reservoir to begin with or keeping them moving through the reservoir (Randle and Boyd 2018). However, the sedimentation level may get so critical that the other measures (1 and 2) are no longer sufficient.

In the case of the Tuyamuyun, physical sediment removal is necessary. According to the technical assessment by Giri (2022), possible storage recovery efforts include capital dredging in the channel reservoir with a target removal of up to 500 million m^3 of sediment over just a few years. Alternatively, there are structural solutions, such as the construction and/or extension of the off-channel reservoir(s), and renovation/reconstruction of the structures (e.g., dam heightening, replacement) (Giri 2022). However, without complementary measures to reduce sediment inflow, keep the sediment going, or remove sediments, these latter structural measures would simply defer the problem of sedimentation to the future. In either case, before any of these options - capital dredging, building of an off-channel reservoir or dam heightening - are selected, comprehensive feasibility and impact assessment must be carried out.

Aside from the need to recover large-scale storage capacity, in the medium term, maintenance dredging is urgently needed in the short term, to not deteriorate the functioning of the hydropower plant, off-channel reservoirs and endanger the mechanical structures. An annual dredging volume of 1-2 million m^3 is recommended for the first years Giri (2022a) to be carried out near the hydropower and canal intakes, spillways, and the intakes of the off-channel reservoirs. Parts of the upstream reservoir reach should also be dredged at regular intervals to reduce sediment inflow from the upstream. The volume dredged can be increased with time, gained experience and production rate efficiency.

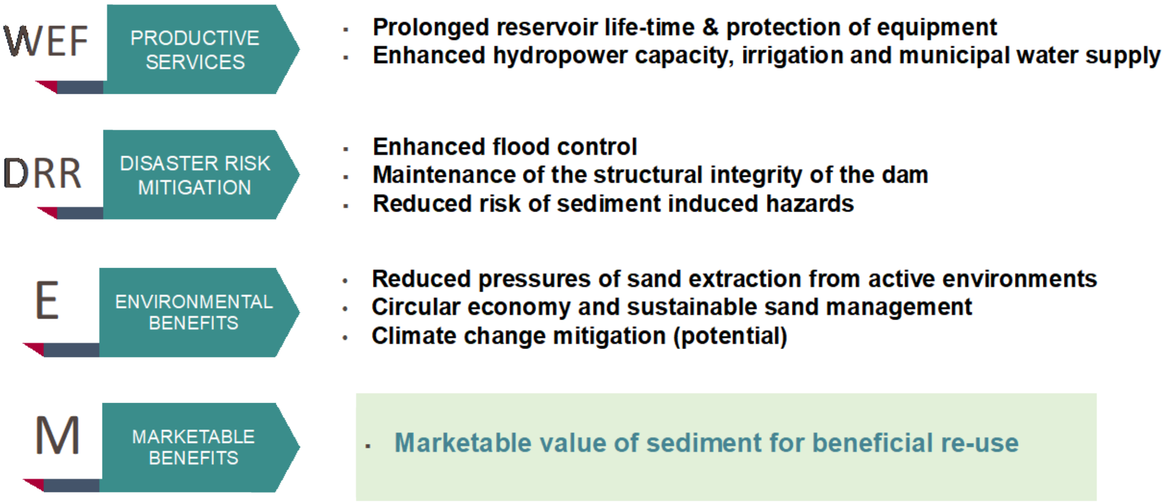
Objective

From an economic perspective, sediments in reservoirs be considered as resources that are ‘out of place’. Whilst effectively reducing the life-span of dams, they are needed to maintain downstream river ecology and morphology system (UNEP 2022a). Moreover, sediment can have many productive uses. Sand and gravel for example are used to make concrete and asphalt, and are therefore essential for building roads, bridges, hospitals, infrastructure and housing. As such, they are essential resources to economic development.

Another significant benefit of sediment re-use is the potential to provide a sustainable source of sand. With a projected 300% increase in sand use from 2020 to 2060 across low-and-middle-income regions, a global supply crisis of sand is looming (Zhong et al., 2022). Sand is often extracted from dynamic environments, such as rivers, estuaries and beaches where they play an important role in the ecosystems. In the THC however, sand is hindering the proper functioning of the reservoir and reducing its life-span. Thus, any extraction of sand from the THC, will not only help protect the essential services provided by the THC, but also reduce pressures on sand extraction from environmentally problematic areas (Figure E1).

Whilst there are multiple benefits associated with the recovery of storage capacity of the THC and the beneficial re-use of sediment (figure E1), this report is concerned with the marketable value of sediment re-use within the Uzbek construction industry.

Figure E1: Benefits of sustainable sediment management and re-use of sediment from reservoirs



Method of assessment

To assess the economic case for using dredged sediments from the THC, a profit and loss (P&L) account has been established. A P&L account is a financial statement that shows how much profit or loss can be generated from a business. The P&L statement elaborated for this assessment summarises the revenues, costs, and expenses that are expected to be incurred during the first five years of the maintenance dredging phase. Revenue from the sale of sediment features as the top-line and subtracts the cost of goods sold (COGS), operating expenses (OPEX) and interest expenses, when these are known. COGS is the total cost related to the sale of products – including in this case, the sediment processing costs and transportation costs. OPEX includes expenditures that are not directly tied to the sale of products. For example, maintenance dredging and disposal of sediments, which are inevitable expenses (independent of whether sediment is re-used or not) to mitigate risks and guarantee the continuous functioning of the hydropower complex in the short term. The difference between the revenues and costs, is net profit, known as the bottom line.

Data and information to inform the P&L account have been derived from various sources, including expert interviews, discussions with technology providers (e.g. Royal IHC in Giri 2022a), literature reviews and other research undertaken as part of the WEF Nexus project.

The marketable benefits of sediment extraction

Sediment in reservoirs typically include, clay, silt, sand, gravel, cobble, boulders. Sixteen sediment samples have been taken within various locations of the channel reservoir (Shirokova Y. I. 2022). They demonstrate a varying composition of sediment with some samples showing a high sand content, and others, high silt and clay contents. This is according to expectations. As sedimentation of a reservoir progresses, coarser sediment (gravel and sand) typically deposits in the upstream ends of the reservoir pool, whilst silt and clay deposits closer to the outlets (Randle and Boyd 2018).

The sediment samples do not allow to assess the true composition of sediment in the THC however, with a sediment layer with up to 15 meters of thickness, that have aged more than 40 years. Moreover, the content of the sediment will depend on where dredging efforts are concentrated. For the purpose of assessing the economic value of the sediment, it is therefore conservatively assumed that 20% of what is dredged during a maintenance dredging phase qualify as sand, and another 20% as clay-sand[1]. There are readily available markets for both of these. As such, with annual dredging volume of 1 million m^3 in the first year, rising to 2 million m^3 of sediment by the 4th and 5th year, it is assumed that 200,000 m^3 to 400,000 m^3 of sediment is re-used for the construction industry[2].

These volumes can easily be absorbed on local markets, with a minimum annual demand of 20 million m^3 of sand in Uzbekistan and Turkmenistan combined. The city of Urgench is located within 100 km of the Tuyamuyun and has 20 construction firms alone. Moreover, the construction industry is growing at a compound rate of >4% in Uzbekistan, pointing to rising demand over time. At prevailing market prices for sand ($10.3 per m^3) and clay-sand ($6 per m^3), projected sales revenues from sediment re-use are in the order of $3.3 to $6.6 million.

Dredging costs are estimated at $2 per m^3 of sediment dredged. Sediment furthermore needs to be placed in a physically contained area(s), in a so-called confined disposal facility. No estimates have yet been made, of the costs of constructing a CDF for dredged sediment from

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[1] Clay-sand has a high content of clay particles (more than 30%), loam soil (10-30%), sandy soil (3 to 10%) (Pesok.uz 2022)

[2] Once dredging starts, it is possible that higher proportions of sand and clay-sand can be recovered, but only additional sampling or experience can tell that.

the Tuyamuyun. We therefore draw on comprehensive estimates from the Slufter Confined Disposal Facility (CDF) at the port of Rotterdam in the Netherlands, which includes compartments for clay ripening, sand separation and cleaning of contaminated sediment (R.M. van Swam, not dated). If 40% of the sediment from the THC is re-used a 5 million m^3 facility is required for storing sediment during a 5-year maintenance dredging phase. Resulting dredging and disposal costs are in the order of $2.2 to $4.2 million per annum, assuming a CDF construction cost of $1.2 per m^3 storage capacity and yearly O&M cost of $0.06 per m^3 deposited.

Finally, total processing of sand and transportation costs amount to $1 to $ 2 million, with sand and clay-sand processing costs of $0.6 per m^3 and transportation costs of $0.02 per m^3 per km and assuming that sand and clay-sand is transported to the nearest major city of Urgench (100 km from the THC).

Table E1: Profit and loss account of a 5-year sediment re-use campaign (in US$ 2022)

+	**Sales revenue** $ 3.3 to $ 6.6 million
-	**Processing and transportation costs (COGS)** - $ 1 to - $ 2 million
=	**Gross profit** (sales revenues minus processing and transport costs) $ 2.3 to $ 4.7 million
-	**Dredging and disposal costs (OPEX and capitalized expenses)** - $ 2.2 to - $ 4.2 million
=	**Net profit** - $ 62,000 to $ 276,000 thousand
→	**Recovery of dredging and disposal costs*** 97 – 106%

* = Gross profit/total dredging and disposal costs

Subtracting the sediment processing and transportation of sand from sales revenues, a gross profit of $2.3 to $4.7 million is generated. Subtracting further the inevitable dredging and sediment disposal costs, the net profit is in the order of -$62,000 in the first year to $276,000 per year as dredging volumes reach 2 million m^3 (and 40% of sediment is re-used). Table E1, shows the simplified profit and loss account for the first five years of the maintenance dredging and sediment re-use campaign.

The results demonstrate that gross profits from the sale of sediment for construction materials (after deducting processing and transportation costs) are of a sufficient magnitude to cover the inevitable dredging costs, as well as the annualized construction, operation and maintenance costs of the CDF. In the absence of sediment re-use, sediment disposal costs are likely to be even higher, than those estimated here, due to higher volumes of sand that are not re-used. Moreover, gravel is excluded in this analysis due to insufficient information on the quantities of gravel that may be dredged. However, gravel, is also valuable for the construction industry, and may offer yet another source of revenue. If the marketable volumes of sediment (gravel, sand and clay-sand) are greater than those estimated here, the bottom-line from beneficial sediment re-use will be even higher.

The figures presented here (dredging costs, quantities of sediment to be dredges, the cost of constructing disposal facilities, etc.) are preliminary and should be fine-tuned with potential service providers and further experience. Moreover, as highlighted in Giri (2022) a detailed design, as well as a social and environmental impact assessment, shall be made specifying the tentative sediment volume to be removed, as well as appropriate dredging technology, to ensure for safe and efficient sediment removal during both a maintenance dredging and later, capital dredging phase.

The need to use hydrological resources from the THC efficiently

Finally, the latter part of this assessment shows that the pursuit of Water, Energy and Food security, requires efficient use of water from the THC. Uzbekistan is the biggest agricultural water consumer in Central Asia and the Karshi Steppe of Kashkadarya region alone, uses nearly 5.0 billion m^3 of irrigation water within a hydrological year. A large share of this water comes from the THC.

Our analysis however shows that the use of typical furrow irrigation schemes in cotton production, leads to losses for society. The costs of providing and pumping this water (>$2 per m^3) are higher than the benefits provided ($0.35 per m^3 of water), when assessed in terms of the value of the incremental cotton yield. There is thus a mis-allocation of scarce financial and hydrological resources. Moreover, excessive use of water has led to waterlogging and salinization, which affect 50% of irrigated area in Uzbekistan (Hamidov 2022). The use of drip-irrigation, climate smart farming practices, integrating cover crops, tree crops, mulching and reduce tillage, will be key to transitioning towards a climate resilient farming in Central Asia (DeLaune et al., 2020; Djumaboev et al., 2019).

Conclusion

Whilst it makes good economic sense to re-use sediment, it also makes environmental sense. There are significant negative impacts from sand extraction within active sand bodies, which can tip the natural balance and result in critical social, economic, and environmental impacts (UNEP 2022b). Sustainable extraction of sand therefore requires careful risk mitigation and management of sand, as recognized in a new UN resolution[3] (UNEA 2022). Sediment re-use is also in alignment with circular economy principles and evolving legislation. The EU waste management hierarchy for example, require that re-use solutions of dredged sediments always prevail over disposal options (European Directive 48 2008/98/CE).

In conclusion, as part of the first efforts to safeguard the THC, the maintenance dredging phase will serve as an excellent pilot for a potentially much larger sediment re-use programme. There is an imminent global supply crisis of sand, whilst reservoirs around the world are reaching their economic life-time due to sediment build-up. The THC project could be amongst the first of its kind to properly demonstrate the value of reservoirs as a source of sand that have been sustainable excavated, whilst safeguarding food, water and energy security and promoting a circular economy in central Asia.

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[3] Resolution titled: 'Environmental aspects of minerals and metals management (UNEA 2022).

1. Introduction

1.1 Background on the loss of reservoir capacity, globally and at the THC

Water storage in reservoirs is one of the primary mechanisms for coping with the variability of water supply and demand. Globally, water from reservoirs supplies an estimated 30–40% of irrigated areas (World Commission on Dams, 2000), contributes 20% of global electricity generation in the form of hydropower (Demirbas, 2009), and serves a number of other beneficial purposes including flood control, recreation, and navigation (Wisser et al., 2013).

Recent studies showcase the expected growth of demand for freshwater resources for all sectors of production (UNESCO 2012). At the same time, sedimentation is steadily depleting reservoir capacity worldwide, with an estimated loss of reservoir storage capacity ranging between 0.5 to 1%, per annum relative to install capacity (Palmieri et al., 2003, Mahmood 1987, Basson 2009). Moreover, the construction of new dams appears increasingly difficult both for environmental and social problems (Begarani et al., 2020). The Tuyamuyun Hydro Complex (THC) in Central Asia is no exception to this global trend, with a critical mass of sediment build-up that is now threatening Water Energy and Food security in the region.

The Tuyamuyun Hydro Complex (THC) is a system of four interconnected reservoirs and a series of canals on the lower Amu Darya River, bordering Uzbekistan and Turkmenistan. Its primary purpose is to provide water for irrigation in Xorazm, Karakalpakstan and Daşoguz regions of Uzbekistan, Turkmenistan and as far north as Kazakhstan (Evered 2008). Tuyamuyun hydroelectric complex is owned and managed by the Republic of Uzbekistan (Ministry of Water Resources of Uzbekistan) in accordance with the interstate legal agreements. The facility controls the downstream flow of the Amy Darya River and allocates water to an estimated 779,300 ha in Uzbekistan and 425,000 ha of irrigated lands in Turkmenistan. It also provides an estimated electricity generation of 450 million kW/h per year in Uzbekistan and drinking water to Khoresm Region and Karakalpakstan (CAREC 2021).

The main dam (THC Main Dam) is located on the Amu Darya, straddling the border of Uzbekistan and Turkmenistan. It creates the Channel Reservoir, which is the center-piece of the complex. Water from the Channel Reservoir can be fed into the adjacent Kaparas and Sultansanjar Reservoirs for later use. It was constructed between 1969 and 1983. When first completed, all four reservoirs had a capacity of about 7.8 billion m^3 but due to silt built-up, this had been reduced to about 6.7 billion m^3 in 2001 (Evered 2008).

More recent measurement of the channel reservoir, shows further significant storage loss, since it was commissioned. Today, the total storage loss is estimated to about 1.48 billion m^3, i.e., 63% of total initial storage volume of 2.34 billion m^3. Projections in Ikramova (2021) suggest that the channel reservoir will be entirely lost by 2040. The dead storage was fully lost already by 2008. At that time, when a large amount of deposited sediment was still in the upstream reach, the severity of the problem could have been avoided. But such efforts were not made. Now it is too late (Giri 2022).

Currently, the sediment layer in the THC is adversely affecting the **functionality and safety of the structures**, namely the hydropower production and canal operation, irrigation structures, as well as the safe flood passage, increasing the risk of floor and sediment hazards and downstream disasters.

A comprehensive feasibility and impact assessment must be carried out before the selection of any of these measures. It therefore remains to be decided, which is the best way forward to recover storage capacity of the Tuyamuyun Hydropower Complex. For this reason, no attempt is made in this assessment to value sediment re-use under a large-scale capital drainage scheme.

1.2 The case for sustainable sediment management

Cost benefit analysis (CBA) is the main socio-economical tool used to justify the construction of dams (Dasgupta and Pearce 1972). Under positive discounting, CBA render all benefits and costs that occur more than several decades into a project negligible. In a CBA, the economic design life of a reservoir is typically 50 years – the time it takes to pay-off capital equipment costs. As a result, sedimentation volume is estimated over 50 years, and the lowest dam outlets are set above the dead storage, so as to not carry those sediment downstream during that period. This kind of design defers future sediment management to another generation than those that built the dam (Randle and Boyd 2018).

In the absence of sediment management therefore, sedimentation shortens the economic life of dams, relative to their true potential. Moreover, new “costs” are generated, which are not taken into account in traditional economic analysis (even today, for dams that are currently under construction). Costs of sedimentation include: Wear and tear and damage to turbines, loss of structural integrity, increased flood risk, upstream channel aggradation and downstream degradation caused by the upstream withdrawal and holding back of sediment; infrastructure and costs for dam retrofitting with sediment management facilities, or sediment disposal and dam eventual dam decommissioning, including conveyer belts and trucking, the construction of roads, sediment dewatering, confined disposal facilities, tailing dams etc. These may also be referred to as so-called eternity costs – reflecting the permanent cost for future generations to take care of silted reservoirs, when there are no more profits from THC, but expenses are required every year on safety measures, maintenance and sediment disposal. Therefore, neither sustainable reservoir life spans nor intergenerational equity can be achieved through conventional cost-benefit analyses (CBAs) (George et al., 2017).

Sustainable sediment management seeks to achieve a balance between sediment inflow and outflow, restoring sediment delivery to the downstream channel, maximizing long-term storage, hydropower and other benefits, while minimizing environmental harm (Morris 2020). Management strategies focus on improving the sediment balance across reservoirs by; 1) reducing sediment yield from the watershed e.g., through landscape restoration 2) keeping the sediment going – e.g. by routing sediment-laden flows around or through the reservoir, through diversion, bypass, density current venting, sluicing, and managing flood events such that sediment moves out of the gates; and 3) removing sediment following deposition, through flushing, or with various dredging options. Successful management will typically combine multiple strategies (Morris 2020). Dredging is often seen as the option of last resort in sustainable sediment management when the level of sedimentation has got so critical that other measures will not suffice (Randle 2018).

The technical assessment by Giri (2022) has highlighted that the problems at Tuyamuyun Hydropower Complex (THC) calls for imminent and urgent sediment removal and disposal. This 1st-category problem is related to the deposition of a large layer of sediment near the hydropower headworks (intakes and spillways). The sediment layer is adversely affecting the functionality and safety of the structures, namely the hydropower production and canal operation, irrigation structures, as well as the safe flood passage, increasing the risk of floor and sediment hazards and downstream disasters.

To address the problem first hand Giri (2022) has proposed a technical concept that details a comprehensive sediment management program. The concept includes four main components: (1) sediment removal in the Channel reservoir and canals (i.e. major operation & maintenance measures) in conjunction with sluicing and flushing (i.e.; supplementary measures); (2) erosion and sediment inflow management in the Tuyamuyun catchment, the river, tributaries, and the channel reservoir (3) a commercial pilot campaign for potential options of beneficial reuse of removed sediment and (4) establishment of monitoring, information, forecasting and early warning systems for water, sediment (quality, quantity and reuse) and reservoir morphology (i.e. non-structural adaptive measures).

This report is concerned with component one and three. By building on the proposed sediment dredging measures in component one, a profit and loss (P&L) statement is made, of the revenues, costs and profits to be earned from removing and re-using sediment for the construction industry. Before doing so, the next section summarizes the recommendations from Giri (2022) and provides an overview of the full range of both direct and indirect costs and benefits associated with improved sediment management of the THC. Chapter 2 investigates the characteristics of the sediment of the THC, the potential market for construction materials from the THC, and the various the costs associated with sediment management, ~~as part of a financial feasibility assessment of sediment re-use~~. Chapter 3 compiles all the elements of the P&L account, to assess the business case for sediment re-use. Chapter 4 discuss the promising role of public-private partnerships in financing a sediment re-use campaign and the case for using water resources from the THC optimally, such that the benefits of preserving the THC more than outweigh the costs of doing so. Chapter 5 concludes.

1.3 The case for imminent sediment removal of the THC channel reservoir

Sediment removal in the channel reservoir and canals, is inevitable for the channel reservoir to not deteriorate the functioning of the hydropower plant, off-channel reservoirs and avoid endangering the civil/mechanical structures. Accordingly, maintenance dredging should be carried out near the hydropower and canal intakes, spillways, and the intakes of the off-channel reservoirs. Some parts of the upstream reservoir reach should also be dredged at regular intervals, to reduce the inflow from the upstream. A detailed design, and social and environmental impact assessment, shall be made for this specifying the tentative sediment volume to be removed, as well as appropriate dredging technology, to ensure for safe and efficient sediment removal.

Giri (2022) recommends considering 1-2 million m^3 of annual dredging volume for first years that can be increased with time, gained experience and production rate efficiency. These measures should be in place as part of a holistic sediment management plan and executed regularly in perpetuity during the whole reservoir life in complement with other recurrent (sluicing and flushing) and non-structural measures, see figure 3.1 in Giri (2022).

These urgent measures do not require a very large financial investment, compared to the losses that the THC has been suffering from for last few years (according to Giri 2022). In a later and second phase, it is important to address the storage loss of the channel reservoir, which is almost 1.5 billion m^3 due to significant sedimentation. Addressing this problem requires large-scale storage recovery efforts or alternative structural solutions, including:

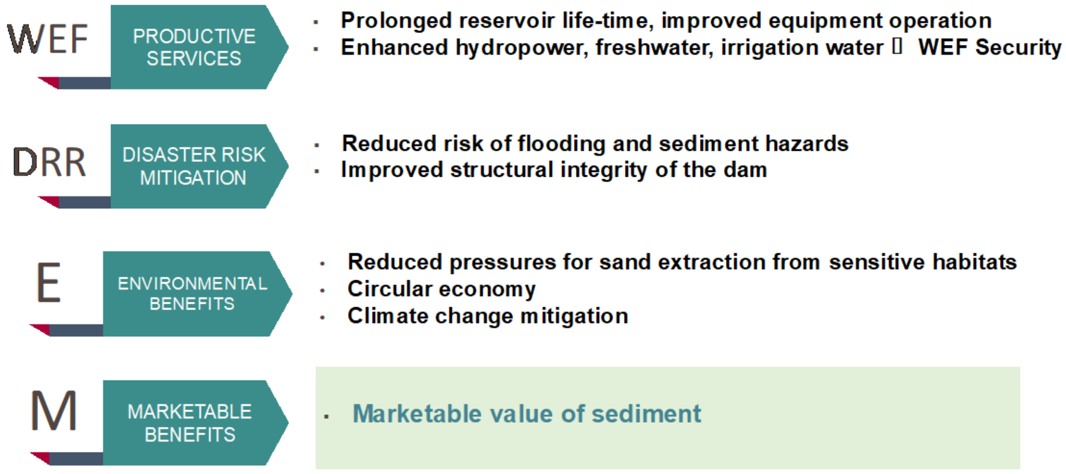
- Option 1 - capital dredging in the Channel reservoir with beneficial reuse of sediment with a target remove up to 500 million m^3 of sediment in a shortest possible period
- Option 2 - the construction and/or extension of the off-channel reservoir(s), and
- Option 3 - renovation/reconstruction of the structures (e.g., dam heightening, replacement).

A comprehensive feasibility and impact assessment must be carried out before the selection of any of these measures. It therefore remains to be decided, which is the best way forward to recover storage capacity of the Tuyamuyun Hydropower Complex. For this reason, no attempt is made in this assessment to value sediment re-use under a large-scale capital drainage scheme.

1.4 Overview of benefits of removing and re-using sediments

There are costs, but also multiple benefits, both direct and indirect of dredging and re-using sediment from THC. These are summarized in table 1 and discussed in the following sections.

Figure 1: Benefits from sustainable sediment management



A detailed design and social and environmental impact assessment, shall be made for this specifying the tentative sediment volume to be removed, as well as appropriate dredging technology, to ensure for safe and efficient sediment removal.

1.4.1 Benefits to the THC

The very significant storage loss of the THC is leading to a water stress that is affecting the livelihood of more than 5 million people that benefit from the THC in Uzbekistan and Turkmenistan. The benefit from reducing sedimentation can be assessed in terms of the benefits of maintaining reservoir storage, energy production and discharge capability for irrigation and drinking water relative to the business as usual (BAU) situation of the eventual loss of the THC as a productive resource.

There are also a range of costs and risks associated with unabated sediment accumulation. Sediment creates a wide range of environmental impacts (such as CH4 production from anoxic sediments), increases loads on the dam and gates and damages mechanical turbines and other mechanical equipment. Damage to equipment happens through erosion of the oxide coating on the blades, leading to surface irregularities and more serious material damage. Sustained erosion can lead to extended shutdown time for maintenance or replacement. Moreover, recent studies have highlighted the synergic effect of cavitation erosion and sediment erosion, showing that the combined effect of cavitation and sand erosion on turbines is stronger than the individual effects (Thapa, 2015).

In terms of risks to structural integrity, it is unclear whether the THC was designed for the immense additional load once more sediment reaches the dam axis. Sedimentation will put significant additional pressure towards the upstream face of the dam. If not designed for this, the danger of a collapse of the hydropower complex is real (Detering 2022; Giri 2022). Careful and high-level comprehensive planning of maintenance and capital dredging phase will help mitigate these risks.

1.4.2 Environment benefits associated with beneficial use of sediments

Sediment in reservoirs typically include, clay, silt, sand, gravel, cobble, boulders (Randle and Boyd 2018). From an economic perspective, they may be considered as resources that are ‘out of place’. Whilst effectively reducing the life-span of dams, they can have many productive uses. Sand and gravel especially, are essential for building the roads, bridges, hospitals, and infrastructure that are key to human development. ‘Sand is thus the unrecognised hero of our development’ (Sheila Aggarwal-Khan in UNEP 2022b).

Moreover, according to the European Directive 48 2008/98/CE, sediments extracted from reservoirs become waste. Following the EU waste management hierarchy, beneficial reuse solutions should always prevail over disposal options.

As such, a number of factors have pushed for sediment re-use. On the one hand, the loss of reservoir capacity, but also the loss of capacity of confided disposal facilities, built to store and handle dredged sediment (Miller et al., 1998) In some cases, re-use of dredged sediment is mandatory because of lack of storage facilities and sites. On the other hand, the evolution of national and european legislations in the field of reservoir water and sediment management has also led to a significant body of scientific research on possible re-uses of sediment (Molino et al., 2014). Possible uses of dredged silt, clay, sand and/or gravels include:

Silt-clay sediment for soil amendment (De Vincenzo et al, 2007; Sheehan et al., 2010; Fourvel et al., 2018); beach nourishment and protection from erosion (Miller et al., 1998; Bagarani et al., 2020); sediment for road or pavement construction (Dubois et al., 2009); raw material for traditional ceramic bricks manufacturing and production (Central Asian Institute for Environmental Research); clay sediment for the production of Portland cement (Valenti et al., 2003; Van Bunderen et al., 2019, Safhi et al, 2020); fine sediments as clinker raw material (Faure et al.) and the replacement of conventional aggregates and sand for the manufacture of mortar or concrete (Agostini et al., 2007; Bedaa et al, 2022; De Vincenzo et al., 2019, Messina et al., 2017, Bagarani et al., 2020; Limera., 2011; Junakova et al., 2014; Ozer-Erdogan 2016)

These latter studies demonstrate various beneficial uses of dredged sediments as raw materials in construction, including concrete, road construction, cement production and brick manufacturing. Specifically, in regards to brick construction, assessments done by the central Asian Institute for Ecological Research, 2022, have shown that high quality bricks can be produced from sediment from the THC (see figure 1).

Figure 1: The ready sample product (bricks), made using the samples of the Channel reservoir sediment (Asian Institute for Ecological Research, 2022)

Moreover, concrete is one of the most consumed materials in the world. Natural deposits that are used for concrete (sand, aggregates, limestone, etc) are becoming increasingly scarce while demand continue to grow. In response to an imminent global supply crisis there calls for moving towards a circular economy for sand, including banning the landfilling of mineral waste and encouraging sand to be reused in public procurement contracts (UNEP 2022b).

To meet the challenge of reducing the depletion of raw materials in conjunction with the booming construction industry in Uzbekistan, the potential to re-use sediment for construction is an obvious low hanging fruit and is the focus of this assessment.

Whilst there are different options for managing the storage loss of the THC channel reservoir, it is not clear yet what quantities of sediment will be dredged in the medium to long-term. The most imminent and pertinent use of sediment is therefore that which will be recovered under a maintenance dredging phase, which remain significant quantities (1-2 million m^3 per year) nevertheless.

1.4.2.1 Re-using fine sized sediments for bricks and in cement mixtures

Coarse sediments, sands and gravels are easily reused in concrete and for the construction industry. For finer sediments (silts and clays), it is a bit harder as they typically require costly thermal treatment process aimed at eliminating the organic fraction and certain pollutants before they can be used for construction materials (Beddaa et al., 2022).

However, as mentioned above, analysis by the Central Asian Institute for Environmental Research LLP, shows the finer sediments can be used in brick construction. Moreover, as finer sediments typically contain silica, alumina, calcia and iron oxide as main chemical constituents, they are useful candidates as for replacing raw materials in portland cement clinker (Van Bunderen et al. 2019). Encouragingly, new research, provide evidence that it may also be possible <u>to use raw untreated fine sediments</u> – in the order of 10% - as a replacement for cement in concrete production without adverse impacts on concrete properties using portland cement[4] (Beddaa et al., 2022).

Since the production of cement is associated with a significant carbon footprint[5] (7% of world's GHG emission), reduced dosage of cement in the construction industry, could reduce GHG emissions substantially. In a case-study of sediment from French reservoirs, Beddaa et al, (2022) shows that when fine sediments (<63 mu) are incorporated in concrete mixtures as a filler, by substituting of 10% cement with fine sediments, the carbon footprint of concrete is reduced by almost 10%.

Raw sediment characteristics vary by location and therefore the opportunity use of fine sediment from THC as a replacement for cement should be subject to further analysis (e.g. by the Central Asian institute for Ecologial Research). However, cement clinker characteristics can still be controlled by adjusting raw mix proportions, maintaining a rather high sediment content in the mix. The incorporation of sediments as an addition to cement is therefore technically promising, whilst allowing to reduce environmental costs of concrete production. Moreover, large quantities of sediment could potentially be re-used, which makes the cement industry as well as the brick construction industry, a relevant option for dredged material valorization.

In this feasibility assessment, no consideration is taken to the re-use value of fine sediments – as it is too early days to make any conclusions – but sediment re-use of fine materials from the THC, should be seriously considered to fully embrace a circular economy and allowing to reap maximum societal benefits from dredging.

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[4] Portland cement type CEM I 52.5 from Calcia plant, which mainly contains clinker (91.3 wt %), gypsum (4.9 wt %) and limestone (3.8 wt %).

[5] The emission factors of cement type CEM I is 866 kg CO_2 eq/t, against 2.3 kg CO_2/t for natural aggregates.

1.4.3 The strategic value of sand and the indirect ecosystem services benefits from sediment re-use

Globally, sand bodies form an integral part of the landscape and ecological system, contributing to biodiversity and the living environment. Until recently the natural balance of continual erosion and deposition of sand was assured, since sand was extracted at relatively low levels from *both inactive and active* sand bodies. However, the rapid growth in demand for sand resources and the localised build-up of sediment caused by infrastructure, including hydropower dams, have increased the threat to these systems (UNEP 2022b).

Where sand bodies are subject to modern erosional and depositional processes, they can be considered active and dynamic. Extraction of sediments in dynamic environments, like rivers, lakes, estuaries, rivers, deltas, and coasts is particularly problematic. In rivers for example, sand delivers nutrients to surrounding ecosystems, protects water sources, reduces riverbank erosion and controls river flows (regulation of floods and droughts) (Apitz 2012). In channel ecosystems, fish and invertebrates breed in riverbed and riverbank material, essential to sustaining healthy reproduction rates, which provide protein and food stocks for communities (Gopal 2020). Therefore, extraction from active sand bodies, that results in changing rates of sand transport, can threaten communities and livelihoods – not just at the point where extraction is occurring, but also downstream in the affected system[6].

Sand should therefore be recognized as a strategic resource, for which its extraction and use needs to be rethought (UNEP 2022a). Sand is also essential for economic development – but it is being used faster than it can be naturally replenished. Responsible management is crucial and re-use of sediment from Tuyamuyun may contribute to this. With this in mind, the next chapter is concerned with potential economic benefit that can be enjoyed from a successful sediment re-use campaign serving the construction industry in Uzbekistan and how these compare to the inevitable dredging and disposal costs.

NATURE

Sand mining is destroying Asia's rivers

Uncontrolled and mostly illegal extraction of sand and rocks from riverbeds for construction is killing rivers across South Asia and China, and must be tightly controlled

Figure 2: Example of headlines raising attention to troublesome sand extraction (Credit: the third pole 2022)

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[6] Moreover, these environments are typically governed by areas of policy and law (such as environmental legal regimes, water resources policy and management, coastal zone management, infrastructure, urban and land use planning, fisheries management, and biodiversity policy) which often do not address sand extraction governance and management adequately, if at all. Concession and permitting systems can be highly complex and difficult to comply with and and enforcement difficult to implement and under-resourced.

2. Financial feasibility analysis of sediment re-use for construction

2.1 Sediment from the Tuyamuyun

Sediment in reservoirs typically include, clay, silt, sand, gravel, cobble, boulders (Randle 2018). The composition of deposited in the THC is analysed and reported in Giri (2022) and shown in table 2. Sixteen samples taken at different points within the reservoir. They show that sediments from the Tuyamuyun are composed of sand, silt, clay, in various proportions. The samples furthermore reveal that they do not contain harmful (toxic) substances and include useful trace elements such as iron, copper, boron, magnesium, zinc, manganese, cobalt, molybdenum (according to an analysis by Shirokova Y. I. 2022). The sediments will therefore be able to comply with strict environmental standards in their final uses, whether domestic or international, without need for prior treatment[7].

Table 2: Sediment composition from 16 soils samples taken within the THC (from Shirokova Y. I. 2022) – Grey coloured: sand content of 29% or higher. Yellow, clay content 18% or higher.

No. p / p	Sample code (place of sampling)	Assessment according to Kaczynski	The content of fractions (mm) according to the US triangle, in%			FAO name	
			Sand, 0.05-2.0	Silt, 0.002-0.05	Clay, < 0.002		
1	**PK-23 "Uz"**	**The sand is loose**	**91**	**8**	**0**	**S**	**Sand**
2	TMGU Ave. coast of Uzb	Connected sand	29	69	3	ZL	Silt Loam
3	№130®515 m Ave. Bank Ruslovaya ST-1	sandy loam	34	61	5	ZL	Silt Loam
4	№130®515 m Ave. Bank Ruslovaya ST-1	sandy loam	39	56	5	ZL	Silt Loam
5	PK-25 "Uz"	Medium loam	9	73	18	ZL	Silt Loam
6	Military unit of TMGU Uzbek	Medium loam	12	71	17	ZL	Silt Loam
7	ST 22 Uzb	Medium loam	5	79	17	ZL	Silt Loam
8	TMGU Ave. beregTMGU	sandy loam	19	76	5	ZL	Silt Loam
9	Etc. Bank No. 130 Run-of-river dam	light loam	9	81	10	Z	Silt
10	Etc. Ruslovaya bank №130	light loam	7	81	12	ZL	Silt Loam
11	ST 2® 436m Pr Bank Ruslova	Connected sand	33	63	3	ZL	Silt Loam
12	Sulton Sanzhar Ave. Ruslovaya bank	Clay medium	3	66	31	ZCL	Silty Clay Loam
13	Military unit of TMGU Uzbek	Medium loam	9	75	17	ZL	Silt Loam
14	ST 2® 237m Pr Bank Ruslova	Medium loam	9	79	13	ZL	Silt Loam
15	Pr shore® 65 Run-of-river ST 5	Clay medium	1	65	34	ZCL	Silty Clay Loam
16	ST 2® 436m Pr Bank Ruslova	Sandy loam	27	69	4	ZL	Silt Loam

Silts are fine-grained soils that do not include clay minerals that tend to have larger particle sizes than clays. Clay is a type of fine-grained natural soil material containing clay minerals. Clay is used in many modern industrial processes, such as paper making, cement production,

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[7] https://www.carmeuse.com/eu-en/sediment-treatment-reuse

and chemical filtering. Between one-half and two-thirds of the world's population live or work in buildings made with clay, often baked into brick, as an essential part of its load-bearing structure. Clay is the defining ingredient of loam, which is one of the oldest building materials on Earth (Grim 2016). Mixtures of sand, silt and less than 40% clay are called loam (Olive et al., 1989). According to the $A, textural classification triangle, the only soil that is not predominantly sand, silt, or clay is called "loam" (see figure 3).

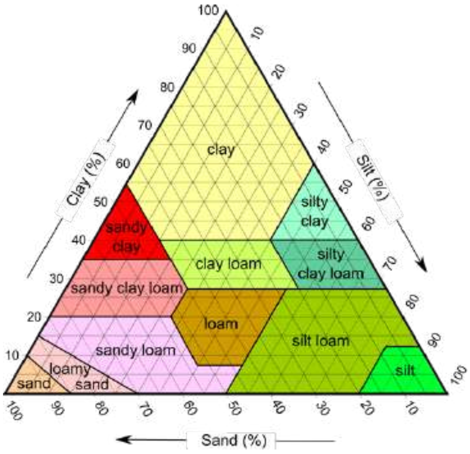

Figure 3: $A soil texture diagram

Considering the composition of silt, sand and clay within the sediment samples, it appears that a good portion of the overall sediment can be combined to produce ‘clay sand’, for which there is a readily available market (see section 2.7). For example: Sample 12 and 13 contain more than 30% clay, whilst other samples, can be categorized as loam soil, and sandy loam (sample 4).

Typically, as a reservoir fills up with sediment, coarse sediment, including gravel and sand, deposits in the upstream ends of the reservoir (so-called delta deposits, see figure 4), whilst silt and clay settles further down. One sample ‘*PK-23 Uz*’ (the first sample in table 1), was taken upstream of the reservoir and contains mostly pure sand. It confirms that the THC is likely to provide sustainable supplies of sand for the construction industry.

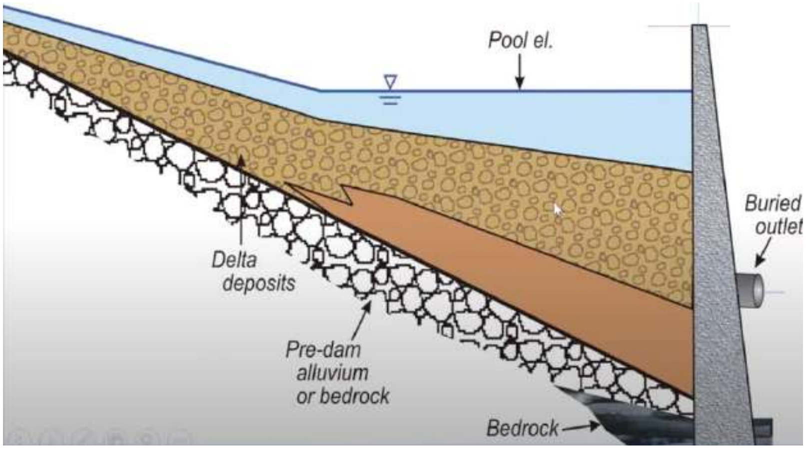

Figure 4: Typical reservoir deposition (Randle 2018)

2.2. Global demand and supply of sand

According to the UN Environment Programme (UNEP 2022b), sand and gravel account for up to 85% of everything mined globally and it is the second most used resource worldwide[8], after water (UNEP 2022b). In some parts of the world, people are going to increasingly great lengths to get their hands on the golden grains. A 'sand mafia' in India intimidates locals in order to extract and transport the material. In Morocco and the Caribbean, thieves are stripping beaches bare (The Economist 2017). Sand is vital to economic development. It is used to make concrete and asphalt, silicon chips, glass and a wide variety of other products. It is critical for infrastructure, from roads and hospital and modern cities are built with it. No surprise, then, that Asia is the biggest consumer of sand.

Globally however, there is a rapidly unfolding sand supply crisis, as demand has begun to outstrip the amount that can be produced and regenerated (Yirka 2022). Recent research projects a ~45% increase in global building sand use from 2020 to 2060, with a 300% increase across lrow-and-lower-middle-income regions and a slight decrease in higher-income regions (Zhong et al., 2022) Specifically, global demand for sand is likely to jump from 3.2 billion metric tons a year in 2020 to 4.6 billion metric tons in 2060.

Despite ample sand in the environment, such as the massive dunes in the Sahara Desert, most of it is unsuitable for industrial use. Thus, whilst it is not known how much sand there is in natural reserves, there is likely to be a major shortfall based on current supply and demand projections (Yirka 2022).

2.3 Demand for construction material in Uzbekistan and Turkmenistan

The production of building materials is one of Uzbekistan's leading industries and influences the further development of other important sectors of the country's economy (Habil et al., 2021). The key sectors in the Uzbekistan construction market are commercial construction, industrial construction, infrastructure construction, energy and utilities construction, institutional construction, and residential construction (GlobalData 2022). According to ADB (2021), the contribution of the construction sector to the country's GDP was estimated at 6.5% of GDP in 2019.

Infrastructure construction was the largest sector in Uzbekistan's construction industry in 2021. It is supported by the government's investments in transport infrastructure projects to boost regional connectivity, together with the financial support from the ADB to implement transport projects. The growth in commercial construction sector is also supported by the government's focus on developing and restoring tourism, coupled with a gradual rebound in the country's tourism activity (GlobalData 2022).

As large urban centers, such as Tashkent, Bukhara, and Samarkand continue to be attractive to workers, migrating from rural areas, a substantial increase in the production of affordable urban housing units is needed (according to ADB 2021). The residential construction sector's output is supported by a rise in housing demand, the relative stabilization of the exchange rate, and affordable housing programs. Finally, industrial construction, energy and utilities market in Uzbekistan, is forecasted, to be supported by an improvement in global economic conditions, coupled with a rebound in manufacturing and export activities and investments in renewable energy, water, and gas projects. The growth rate of the construction industry as a whole is projected to be above 4% per annum (table 3). This trajectory is supported by business-friendly reforms, counteracting inflationary tendencies and reduced remittances from

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[8] 50 billion tons is used every year: enough to build a wall 27 metres wide and 27 metres high around planet Earth each year

Russia. FocusEconomics panelists project GDP to grow 3.9% in 2022 and 5.2% in 2023[9] (GlobalData 2022).

Table 3: Market report scope of the construction market in Uzbekistan
Source: GlobalData (2022)

Market size (Year – 2021)	$11.2 billion
Growth rate (2023 – 2026)	Average annual growth rate AAGR of >4%
Forecast period	2022-2026
Key sectors	Commercial Construction, Industrial Construction, Infrastructure Construction, Energy and Utilities Construction, Institutional Construction, and Residential Construction
Key stages	Pre-Planning, Planning, Pre-Execution, and Execution

2.4 Inferring demand for sand from concrete and cement use

Concrete is the most commonly used construction material in the construction industry. It is a very strong structural building material that consist of a mix of cement, water, gravel, sand and stones (Esub 2020). Concrete is used in basic foundations, exterior surfaces, superstructures, floor construction, wastewater treatment facilities, and parking lots/structures and other permanent structures (Beaulieu 2022).

A typical concrete mixture ratio is 1:1.5:3:0.57 (cement:sand:coarse aggregates:water[10]). As such, for every unit of cement, 1.5 units of sand is needed and 3 units of aggregates. One may thus look to output from the cement industry to infer the likely demand for sand in Uzbekistan and Tajikistan.

According to the avestagroup (2022), in Uzbekistan, average annual growth of cement production for period 2015-2020 was 10%. More than 12 million m^2 of housing is commissioned on average per year. With the construction of 11 new cement production units in 2021 (in Andijan, Namangan, Samarkand, Tashkent, Kashkadarya and Fergana provinces), Uzbekistan had a total installed capacity of 25.3 million tons in 2021. Cement production in 2021 was in the order of 16.4 million tons according to the Association of Construction Materials (Tashkent Times 2021). Neighboring Uzbekstan, which serves as another potential market for sand from the Tuyamuyun, is reaching a production capacity of 2 million tons of cement per year, by December 2022 (Central Asia News 2020). The location of the cement plants in Turkmenistan and Uzbekistan are shown in figure 4 and 5 and indicates where construction materials from the Tuyamuyun are in high demand.

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[9] BUKHARA STATE UNIVERSITY/JSC UZBUILDMATERIALS/TASHKENT STATE UNIVERSITY. Binder production in the Republic of Uzbekistan: Present and future. https://www.zkg.de/en/artikel/zkg_Binder_production_in_the_Republic_of_Uzbekistan_Present_and_future_2507310.html

[10] Effects of Sand Quality on Compressive Strength of Concrete: A Case of Nairobi County and Its Environs, Kenya. https://www.scirp.org/html/7-1880259_49799.htm#:~:text=Silt%20and%20clay%20content%20testing.,size%20and%20ordinary%20Portland%20cement.

Figure 5: Cement construction facilities in Uzbekistan (Cemnet 2022)

Figure 6: Cement construction facilities in Turkmenistan (Cemnet 2022)

2.5 Demand for sand in Uzbekistan and Turkmenistan

Counting Uzbekistan and Turkmenistan, the total demand for cement was roughly in the order of 19 million tons in 2021 (including the 0.5 million tons cement were also imported in 2021 (taskkenttimes 2022). As recalled from earlier, cement is never used alone, but is used in a 1-1.5 ratio when producing concrete. Accounting for other uses of sand, such as for glass production, asphalt for roads, it may be assumed that the annual demand for sand for Turkmenistan and Uzbekistan is at least 28.5 million tons (~20 million m^3), using the conversion rates in annex 1.

In 2020, Uzbekistan imported $656k in sand, which suggest that there is scope for the THC to help overcome the national deficit (Indexbox 2022).

Table 4: Inferred demand for sand

Demand for cement and sand	Annual (2021)
Uzbekistan - cement (tons)	17'000'000
Turkmenistan - cement (tons)	2'000'000
Uzbekistan & turmenistan - dry sand demand (to produce concrete when mixed with cement) (tons)	28'500'000
Lower bound level of dry sand demand (in m3)	20'357'143

It can furthermore be assumed that demand will grow at the rate as the construction industry (4%) in Uzbekistan[11]. Unlike demand for sand, it has not been possible to obtain estimates of the total volume of clay or clay sand that may be demanded in Uzbekistan and Turkmenistan. However, demand is likely to increase at the same pace as the construction industry as a whole.

2.6 Marketable sediment

There is readily available market for sand and clay sand in Uzbekistan. According to the online retailer Pesok.uz, clay sand is widely used in the Tashkent construction industry, for construction materials and a wide range of excavation works and landscaping (Pesok.uz 2022). A characteristic feature of the material is the high content of clay particles (more than 30%), loam soil (10-30%), sandy soil (3 to 10%).

In terms of assessing the actual quantities of sand and clay sand that may be available from the THC for the construction industry, we can only work with assumptions. Firstly, because the overall sediment composition of the reservoir cannot be deduced from the sixteen sediment samples[12] (section 2.1). Secondly, it is unknown how the maintenance dredging campaign will unfold and whether more or less effort will be undertaken downstream versus upstream (where more of the sandy deposits exists).

For this reason, conservative estimates are used in what may be viewed as a first “feasibility analysis of sediment reuse from the THC. In particular, it is assumed that 20% of sediment in the reservoir is extracted and processed into respectively sand and clay sand. As such, under pilot maintenance dredging campaign of some 1-2 million m^3 sediment, an annual supply of 150,000 m^3 to 300,000 m^3 of sand and clay sand respectively may be guaranteed, and possibly more. These quantities will easily be absorbed on local markets.

Material extracted	**Fraction**
Sand	20%
Clay sand	20%

Table 5a: Assumed share of sediment to be re-used for sand and clay sand (assumptions used in the economic feasibility assessment).

Table 5b: Quantities of sediment dredged in the first five years of a maintenance dredging programme (assumptions used in the economic feasibility assessment)

Maintenance dredging	**Sediment loads dredged (m3, 1st year)**	**Sediment loads dredged (m3), 2-3rd year**	**Sediment loads dredged (m3), 4th & 5th year**
Maintenance dredging (m3 / year), year 1-5	1'000'000	1'500'000	2'000'000
Sand for re-use(m3 / year)	200'000	300'000	400'000
Clay sand or re-use (m3 / year)	200'000	300'000	400'000

If a large-scale capital dredging campaign is mobilized later, Giri (2022) advises that a minimum of 500 million m^3 of deposited sediment in channel reservoir is dredged within a

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[11] Moreover, sand is a globally traded commodity, especially where there are well established transportation routes. If there are economies of scale in the dredging and processing of sand from the Tuyamuyun, it is not excluded that sand from the THC can be exported to other countries, provided reasonable transportation costs.

[12] The samples, were taken from the upper layer of the reservoir bed. Given that the deposited layer is significant (up to 15 m near the dam) and there appear to be underlayers with older deposition, only the compositions and quality of the upper or surficial layer may not be representative for all deposited sediment. In future endeavors, it is necessary to assess the soil samples from deeper layers.

period of five years. Under capital dredging, a supply of some 40 million m^3 of sand and clay sand may be made available per year. Export markets for clay sand may need to be explored for materials that is not absorbed in Uzbekistan and Turkmenistan.

2.7 Market prices for sand and clay sand

Buyer of sand include, commercial material suppliers (e.g., concrete and concrete products); civil engineering firms engaged in sourcing crushed rock, sand, gravels and using these materials in construction activities; R&D and materials scientists, construction project managers, operations managers, sales support, supply chain managers (at firm level) (UNEP 2022b).

Commercial material suppliers in Uzbekistan distinguish between clay sand and washed sand, and provide readily available estimates of the retail value of each (figure 7 below).

Washed sand
Price: 100 000 sum / м^3 + VAT

Clay sand
Price: 60 000 sum / м^3 + VAT

Figure 7: Screenshot from Uzbekistan based online retailer of raw materials for construction.

Complementary market research by WASH construction engineers, Davlatbek Davlatov and Dislhod Juraev, working with Mission East in Uzbekistan and Tajikistan, have provided additional quotes on the retail value of sand and clay-sand (table 5). The feasibility assessment uses the average domestic price (green). On international markets, silica sand export price amounted to $34 per m^3 (or 48 per ton in 2021) increasing by 3.8% against the previous year (Indexbox 2022).

Table 6: Prevailing prices in 2022 for sand and clay sand

Washed sand	**Price per m^3**	**$ per m^3**	**Source**
In Uzbekistan	100,000 sum	9.1	Pesok.uz
In Uzbekistan	125882 sum	11.5	Davlatov (2022)
Average price		**10.3**	
International markets		34	Indexbox.io[13]
International markets		29	Nuntioz.com
Clay sand	**Price per m^3**	**$ per m^3**	**Source**
In Uzbekistan	60,000 sum	5.46	Pesok.uz
In Uzbekistan	78,571 sum	7.15	Davlatov (2022)
Average price		**6.3**	

2.8 Extraction and dredging

Clay sand and sand is extracted form a variety of locations, such as beaches, dunes, quarry mines, or dredged from the ocean floor and river beds. It is less common to dredge sand from

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[13]

reservoirs. As reservoirs around are lost to sedimentation, whilst a supply crisis unfolds, reservoirs may serve as an increasingly important source of sand.

The extraction process can range from having a front loader just scoop up and transport the sand from a riverbank to using floating dredges (figure 8) to loosen sand deposits and then using a suction pipe to suck up the sediment. If the sand is extracted via front loader, it is typically dumped onto a conveyor belt to be taken to be processed, or deposited (World Atlas).

If the processing facility is farther away than the sediment is placed in a truck to be taken there. If the sand is extracted via floating dredge, then it is pumped through a pipeline to the disposal facility and/or processing plant. Considering the large quantities to be dredged and the presence of suitable disposal areas (section 3.3.2 in Giri 2022) within the vicinity of Tuyamuyun Hydropower facility, confined disposal and processing, can be located in proximity to the reservoir.

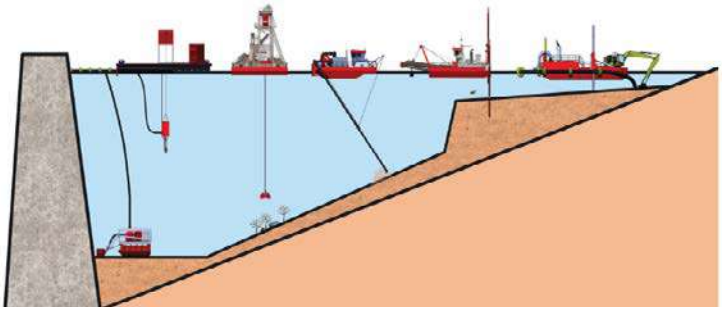

Figure 8: Floating dredges that can be used at the THC (from Giri 2022)

Dredging at the Tuyamuyun will inevitably be a large-scale undertaking. Any material that is not re-used, will have to be stored in confined disposal facilities (CDFs). In some cases, sediments may also be stored in CDFs until the day they are processed and sold to sand users/buyers. As for actual **dredging costs**, these are estimated by Royal IHC, for a maintenance dredging campaign close to the dam, to be in the order of 1.66 EUR/m3 to 1.98 EUR/m3, for dredging volumes of 2 to 5 million m^3 per year. The profit loss account presented in section 3, uses a value of $2 per m^3. To this cost, it is important to add: disposal facilities (next section), sediment processing and transportation costs.

2.9 Disposal facilities

Confined disposal is the placement of a dredged material into a secure area where the sediment is physically contained. The purpose of a confined disposal facility (CDF) is to retain as high a percentage of the sediment particles as practical (Miller et al. 1997).

Upland confined disposal facilities may be formed by the construction of earthen dikes or use existing pits or depressions. The size and shape of a CDF are determined by the required storage capacity and local site conditions. The CDF's may also have compartments for sediment segregation. In the case of the Great Lakes in the US, local sponsors have implemented productive and beneficial uses for CDFs, including the development of recreational areas, new or expanded marinas and wildlife refuges (Miller J., A., 1998).

The size, shape, design and level of complexity of these facilities varies widely depending on dredging quantities, methods of disposal, sediment contamination levels, state and local requirements and site characteristics (Miller, J. A., 1998). Costs are therefore also specific to the project under consideration. In this study, the “Slufter” CDF at the port of Rotterdam in the Netherlands, is used to provide a benchmark of possible construction and operation costs. The facility has been operational since 1987 and has a storage capacity is 150 million m$^{3.}$ (R.M. van Swam, not dated).

Between 1996 and 1999, 65% of all dredged sediment were re-used for construction materials[14]. The CDF include clay ripening fields and sand separation is undertaken through the use of sedimentation basins and mechanical sieving. This is done at reasonable economic cost (R.M. van Swam, not dated). However, finding a commercial destination for the clay and sand materials that are produced, is difficult, because they originate from contaminated sediments and the location is distant from most construction sites. Contamination is not a problem with sediments from the THC, but transportation costs may be a challenge.

The total cost of constructing the facility is about $177 million when inflated to $2022. As such, the construction cost per m^3 of storage capacity generated is in the order of $1.2 per m^3. Operating costs run at approximately $9 million per year for the Slufter facility, which is about $0.06 per m^3 of sediment disposed.

Table 7: Disposal facilities

Sediment disposal facility costs	**Cost**	**Expense per year (depreciated), 50 years**
Construction cost per m3 capacity	1.2 $/m3	0.02
CDF capacity requirement during maintenance dredging	4'800'000 m3	
CFD construction cost for 5.6 million m3 capacity	5'675'146 $	113'502
Yearly O & M costs per m^3 capacity	0.06 $/m3	
Yearly O & M costs for 5.6 million m3 capacity	288'000 $	

In this analysis, it is assumed that 40% of the sediment from the THC is re-used annually for construction materials, either after disposal in the CDF or directly following the dredging option. In this case, the CDF would need to cater to 4.8 million m^3 of sediment during the five-year maintenance dredging phase[15] (table 7). Basing estimates on the Slufter facilities and assuming constant economies of scale in construction, a CDF next to the THC, would cost in the order of $5.6 million m3, or $113'502 per annum when depreciated over 50 years.

With a storage capacity of 150 million m^3 the Slufter experience also serves as an example of what could be achieved Tuyamuyun, during a potential capital dredging campaign, that requires some 100 million m3 of sediment to be dredged per year (section 3.4.2.1, Giri 2022). For a more fine-tuned cost estimates, a financial feasibility assessment would need to be undertake by competent firms at the THC.

2.10 Sediment processing costs

After sediment is extracted from the THC or the CDF, it is sent to a processing plant that is usually in the general vicinity of where the deposit of sand being extracted. The first step in processing sand is called sorting, in which the sand is mixed with water into a slurry and then discharged through a large screen to separate out foreign material, such as rocks or sticks. The slurry and the foreign materials then all go onto separate conveyor belts. In the second step, the slurry is washed in a log washer before it is once again further screened. The blades of the log washer churn through the slurry to remove any remaining foreign materials. The slurry mix is then pumped into a horizontal sand classifying tank that sinks all of the sand in

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[14] It is however, not always possible to find a commercial destination for sand and clay materials, because they originate from contaminated sediments and the location distant from most construction sites.

[15] Corresponding to 60% of the 8 million m3 of sediment that is dredged over a 5-year maintenance dredging phase.

the slurry to the bottom. Once all the sand is at the bottom of the tank, the water is pumped out and the sand is removed to be placed into storage[16].(World Altas 2022[17]).

The price of processing sand is in the order of \$0.3 to \$0.6 per m3 of sand according to construction engineers that are familiar with the construction industry in Uzbekistan and Tajikistan (Davlatov 2022). A higher bound estimate of \$0.6 per m^3 is used for the profit and loss account produced in section 3. Processing costs for clay sand are lower than for pure sand (Davlatov 2022), but in order to not overestimate potential profits to be made from sediment re-use, the higher bound estimates of \$0.6 per m^3 is also used for clay sand.

Table 8: Sediment processing cost

Processing costs	**Minimum ($)**	**Maximum ($)**
Sand and clay loam processing cost $ per ton	0.5	1
Sand and clay loam processing cost $ per m3	0.3	0.6

In comparison, the construction cost of a new modular sand processing facility in Australia, (which accommodates two million tonne of sand per annum) is in the order of US\$14.4 million in \$2022 (Quarry Magazine 2019). Assuming an operational lifetime of 50 years the cost of processing sand (excluding O&M costs) are in the order of \$0.26 per m3. In a similar range to those provided from Davlatov (2022).

Table 9: Example of sand processing costs in Australia for a 2-million-ton facility

CDE sand processing plant in Australia	**Capacity (tons/m3)**	**Cost ($2022)**	**Construction Cost ($2022) per m3 capacity**	**Annual expense (depreciated)**
Sand processing capacity in tons	2’000’000	14388920	7.2	0.14
Sand processing capacity in m3	1’111’111	14388920	13.0	0.26

2.11 Transportation costs

The processed sediment must be transported to the buyers, with appropriate heavy vehicles. Transportation costs for sand are not negligible. These are in the order of \$17 for a truckload of 9 m^3 of sand transported 100 km from the sites (Davlatov 2022) resulting in a cost of \$0.02 per m^3 per km transported by trucks. To keep profit margins high, it is important that buyers are located within reasonable vicinity of the Tuyamuyun facility. A google search suggest that in the city of Urgench, located within 96 km of the Tuyamuyun hydropower facility there are 20 construction firms (figure 9). It may thus be assumed that the volumes of sand that can be recovered from the Tuyamuyun through maintenance dredging phase, can be sold in local markets.

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[16] The last step in processing sand, which is optional is called crushing. This is when a crusher crushes sand into a specific shape or size that does not occur naturally

[17] https://www.worldatlas.com/articles/top-20-sand-exporting-countries.html

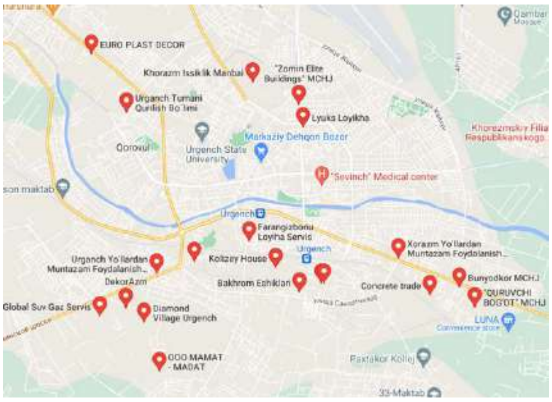

Figure 9: Google screenshot. Construction firms, including road construction firms, in Urgench.

3. The economics of dredging, disposal, processing and sale of sediment from the Tuyamuyun hydropower complex

A profit and loss (P&L) statement is the most popular financial statement in a business plan, as it shows how much profit or loss can be generated by a business[18]. The P&L statement presented here, summarises the revenues, costs, and expenses that are expected to be incurred during the first five years of the maintenance dredging phase.

Revenue from the sale of sand and clay sand, features as the top line, and subtracts the costs of doing business, including the cost of goods sold (COGS), operating expenses (OPEX) and interest expenses (when these are known). The difference, known as the bottom line, is net income or profit. The COGS is the total amount that the business pays as a cost directly related to the sale of products. These include for example, raw materials, processing costs and labour for the selling the materials. OPEX includes expenditures that are not directly tied to the production of goods or services. For example, maintenance dredging and disposal of sediments are necessary expenses to mitigate risks and guarantee the continuous functioning of the hydropower complex in the short term. They are not directly associated with the sale of sediments.

In the following, a P&L account is produced for a business or public-private partnership that is selling processed sediment for the construction industry. A step-wise approach is taken by assessing first and foremost the cost associated with dredging and disposal of sediments, which are incurred independently of sediment re-use (OPEX expenses) followed by the COGS.

3.1. Profit and loss (P&L) account of sediment re-use for the construction industry

3.1.1 Cost of dredging and disposal

With dredging costs at \$2 per m^3 and a possible CDF construction cost of \$2.3 million depreciated over 50 years, the average annual financing cost amount to \$113'503 per year,

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[18] No attempt is made here to undertake a traditional CBA and assess the global net present value of the sediment re-use project. That is because, we do not possess detailed equipment acquisition costs (for sediment processing and dredging), but rather estimates of expenses in volumetric terms, which include both equipment and operational costs per m3 of sediment. Moreover, the equipment and disposal facilities are expected to have a life-time of 50-years, but the actual volumes of sediment that will be dredged and re-used, beyond the first 5 years of maintenance dredging can take many directions. For this reason, it was more appropriate to opt for a profit and loss account, to understand the economic interest in re-using sediment from the Tuyamuyun.

whilst O&M costs are assumed to be in the order of $288'000. Consequently, the total annual cost of running a maintenance dredging program, will be in the order of $2.4 to $4.4 million per year, as dredging volumes increase from 1 to 2 million m^3. Interest payments are not included here, as it is not clear how operations will be financed (through grants or loans). All the assumptions used in the cashflow are shown in appendix 1.

Table 10: Sediment dredging and disposal costs

YEAR	**2023**	**2024**	**2025**	**2026**	**2027**
Quantities dredged					
Quantity of sediment dredged	1'000'000	1'500'000	1'500'000	2'000'000	2'000'000
Dredging cost					
Dredging cost ($/m3)	2	2	2	2	2
Total dredging cost - all sediments	-2'000'000	-3'000'000	-3'000'000	-4'000'000	-4'000'000
Confined disposal facility - all sediment					
Average cost per m3 capacity	1.18	1.18	1.18	1.18	1.18
Total construction cost for a 2 mil m3 facility (depreciated over 50 years)	-113'503	-113'503	-113'503	-113'503	-113'503
Operation and maintenance cost ($/m3)	0.06	0.06	0.06	0.06	0.06
Operation and maintenance cost ($)	-288'000	-288'000	-288'000	-288'000	-288'000
Total cost					
Total dredging & disposal cost	**-2'401'503**	**-3'401'503**	**-3'401'503**	**-4'401'503**	**-4'401'503**

On the benefit side, maintenance dredging will help maintain the hydropower generating capacity of the THC and maintain dam safety (Giri 2022). Complementary action is required to maintain, monitor and adapt dredging actions. With an average annual inflow of 50 million m3 of sediment, maintenance dredging, will not allow for restoring storage capacity of the reservoir. That pertains to longer-term large-scale measures and interventions (discussed in the introduction), which require proper project scoping and detailed impact assessment given the requirement for large financial and technical resources

These long term measures however, do not exclude the use of maintenance dredging however. Consequently, the investment opportunities analyzed here and sediment re-use associated with maintenance dredging applies beyond the first 5-year time-horizon analyzed here.

3.1.1 Revenues and COGS

The previous section has shown that maintenance dredging of some 1-2 million m3 of sediment is likely to involve a cost of $ 2.4 to $ 4.4 million over the next five years. These may be considered as OPEX expenditures, that are independent of the sale of construction material. If 20% of the sediment is processed and sold as sand and another 20% for clay sand, within Uzbekistan or Turkmenistan, revenues in the order of $ 3.3 to $ 6.6 million could be generated (see figure 10 and 11).

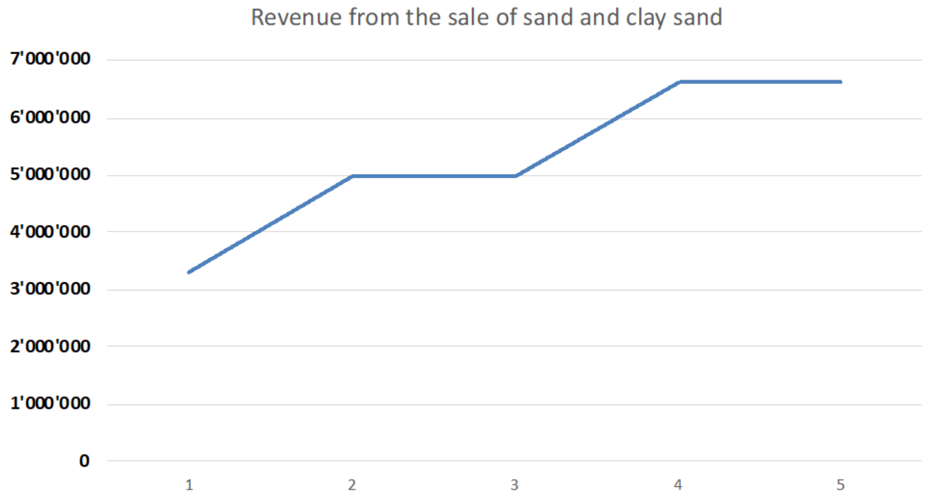

Figure 10: Projected revenue from the sale of sediment during the first five years of a maintenance dredging phase

There would however also be new costs associated with the processing and transport of sediment to nearby markets – such as Urgench located within 100 km of the Tuyamuyun. Deducing the cost of goods sold (COGS) from the revenue, a gross profit margin of $ 2.3 million to 4.6 million per year is generated. Deducting the full range of costs, OPEX and COGS from the sales value, a total annual loss of -0.6 million is incurred in the first year. This is however significantly lower than the inevitable dredging and disposal cost of minimum $ 2.2 million in that first year. Moreover, as of second year, dredging becomes profitable.

As such, gross profits from the processing, transport and sale of sediment can cover at least 97% to 106% of the first imminent maintenance dredging phase. Figure 10 illustrates the breakdown of costs and how sales revenues outweigh costs.

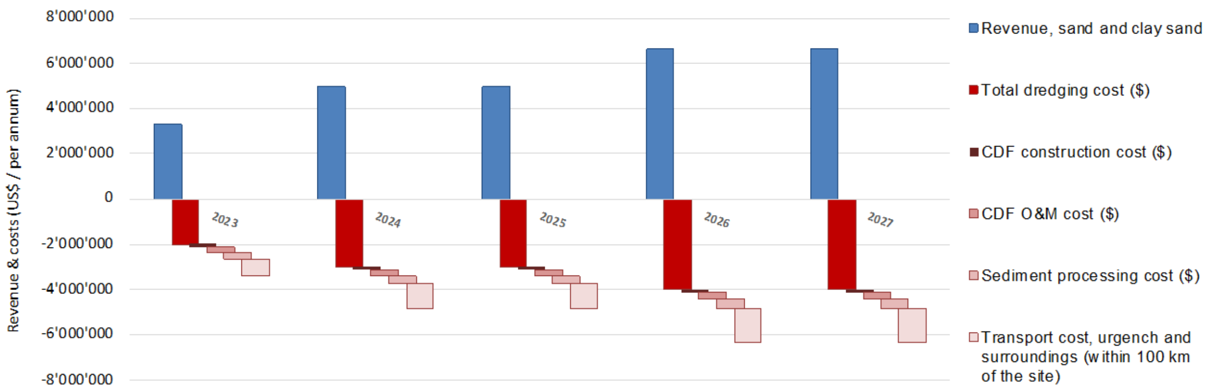

Figure 11: Projected revenues and costs of maintenance dredging with sediment re-use

Table 11: Profit and Loss statement of sediment re-use

YEAR	**2023**	**2024**	**2025**	**2026**	**2027**
Revenue from sale of sand & clay ($)					
Price of sand, Uzbekistan ($/m3)	10	10	10	10	10
Price of clay, Uzbekistan ($/m3)	6	6	6	6	6
Production of sand (m3)	200'000	300'000	300'000	400'000	400'000
Production of clay (m3)	200'000	300'000	300'000	400'000	400'000

Revenue from sale of sand & clay ($)	**3'316'529**	**4'974'794**	**4'974'794**	**6'633'059**	**6'633'059**
Sand and clay-sand processing cost					
Processing cost ($/m3)	0.6	0.6	0.6	0.6	0.6
Total processing cost ($)	-222'222	-333'333	-333'333	-444'444	-444'444
Transportation cost					
Urgench and surroundings ($/m3) for 100 km trip	1.9	1.9	1.9	1.9	1.9
Total transport, urgench and surroundings (within 100 km of the site)	-755'556	-1'133'333	-1'133'333	-1'511'111	-1'511'111
Dredging cost					
Dredging cost ($/m3)	2	2	2	2	2
Total dredging cost ($) (capitalized expenditure[19])	-2'000'000	-3'000'000	-3'000'000	-4'000'000	-4'000'000
Confined disposal facility for sand					
Construction cost ($/m3)	1.18	1.18	1.18	1.18	1.18
Construction cost ($) (capitalized expenditure)	-113'503	-113'503	-113'503	-113'503	-113'503
O&M cost ($/m3)	0.06	0.06	0.06	0.06	0.06
O&M cost ($)	-288'000	-288'000	-288'000	-288'000	-288'000
Total cost					
Maintance dredging & disposal all sediment ($)	-2'401'503	-3'401'503	-3'401'503	-4'401'503	-4'401'503
Processing and transportation ($)	-977'778	-1'466'667	-1'466'667	-1'955'556	-1'955'556
Dredging, construction, processing, transport ($)	-3'379'281	-4'868'170	-4'868'170	-6'357'058	-6'357'058
Profit and Loss					
Gross profit - Revenues less processing and transportation costs	2'338'752	3'508'127	3'508'127	4'677'503	4'677'503
Net profit - Revenues less dredging, disposal, processing, transport of sand & clay sand	-62'751	106'625	106'625	276'000	276'000
Cost-recovery (gross profit/dredging and disposal cost)	**97%**	**103%**	**103%**	**106%**	**106%**

4. PPPs and efficient use of Tuyamuyun's water resources

4.1 Using PPPs to finance a sediment re-use campaign

A public-private partnership (PPP) is an arrangement made between two or more entities from the public/government and private sectors. Typically, it involves private capital financing government projects and services up-front, and then drawing revenues, e.g. from the sale of sediment or from taxpayers over the course of the PPP contract (Caves 2004). Public–private partnerships are primarily used for infrastructure projects (Bovaird 2015) and are also used to ensure re-use of construction materials (Rakhshan 2020).

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[19] Capitalized expenditure is an expense that is made to acquire an asset that has a useful life longer than a year or improve the useful life of an existing capital asset (like a hydropower facility)

The interest with a PPP, is that it would allow for reducing the risks that the Ministry of the Water Resources of Uzbekistan holds (the owner of the THC). For example, the risk that equipment fails or that new infrastructure is not correctly built or scheduled. The key question is usually: *Will the private developer give us the dredging equipment, processing and disposal facilities that we need to ensure reliable and safe infrastructure to the public*?

PPPs, can help share project risks with the private entity that deliver the project, for example, through a “design-build and maintain” project, which shifts the life-cycle of maintenance responsibility to the developer. It also includes a finance component, where the concessionaire provides private capital, for example, to procure dredging equipment, and build the disposal and sediment processing facility. This way, the developer is incentivized to provide the best infrastructure possibly that will last as long as possible.

The many activities that are involved in sediment dredging, storing, re-use and sale of sediment, may be considered as separate projects in that typically they are done by different ‘stakeholders’, for example sand extraction, dredging and production companies; civil engineering firms; and firms involved in initial processing and transport of sand recycles, recycling industry.

A campaign of this enormous scale it will require a consortium of financially stable major earth works companies that will also need to put in investment (Stern 2022). Efficiency may be gained by combining several of the separate projects into one project to reduce, for example, the number of procurements the Ministry of the Water Resources of Uzbekistan, may need to undertake.

Moreover, experiences have shown that a collaborative environment that fosters communication between all parties at the time when the procurement document is drafted, is highly advantageous for the final outcome. It enables contractors or developers to come-in and suggest ideas, as the project is designed. How can you do things differently or better? The developer can challenge the owner and suggestions by the developer can be incorporated. By the time the dredging, construction and sediment processing works start, the owner(s), designer and contactors are working together. The key component to being successful and fostering innovation as an owner, is to create a collaborative environment as soon as possible. The “design-build and maintain” project concept has also been used to conceive very large multifaceted large infrastructure projects in the US (The Civil Engineering Podcast 2022).

Considering that sand extraction from the Tumanyan is sustainable relative to sand extraction from dynamic environments (lakes, estuaries, rivers, deltas, and coasts), special incentives, such as tax credits, or low interest loan, could also be granted to companies, which would make it attractive for them to invest in sand extraction from the THC, relative to other areas. As highlighted in UNEP (2022b) such incentives, can help drive much needed sustainable change in the sand supply chains.

4.2 Using THC capacity efficiently to secure Water Energy and Food security

Maintaining and generating water storage capacity of the THC is expensive, whichever option is taken. Any such expense can only be legitimized if water is used efficiently and wisely and the benefits of water use exceed the costs of providing that water. Aside from declining reservoir, studies on climate change projections for the region predict that water availability may decline up to 30 percent in the Aral Sea Basin (Siegfried et al., 2012)

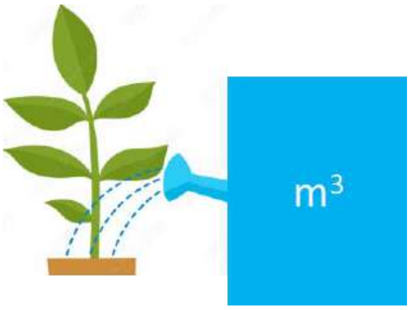
Considering that Uzbekistan is the biggest agricultural water consumer in Central Asia, with an estimated irrigated area of about 4.3 million hectares (ADB, 2012) it is relevant to assess the benefits provided by the large-scale irrigation systems. Generally practiced methods of irrigation include furrow irrigation, basin and border irrigation. Excessive use of water however, has led to waterlogging and salinization, which affect 50% of irrigated area in Uzbekistan (Hamidov 2022).

The Karshi Steppe of Kashkadarya region, is home to the largest irrigation scheme in Uzbekistan and a prime cotton producing area, using around 4.5 – 5.0 billion m^3 of irrigation water within a hydrological year. Most of the irrigation water is abstracted from Amu Darya River and raised up to 157 meters, using seven pumping stations to Karshi main canal (Ministry of Water Resources 2022). The total annual consumption of water resources for all sources from the Amu Darya River basin is 60 billion.

A recent study assessed the effects of different irrigation methods on yield and water efficiency of cotton production in the Karshi Steppe (Djumaboev et al., 2019). In the following we draw on these results to provide a first-hand indication of the monetary benefit of water when used for cotton farming in Uzbekistan, focusing on drip and furrow irrigation.

Value of water from the THC - Benefit from irrigation

Under traditional furrow irrigation[20], farmers use an average of 6837 m^3/ha of irrigation and have an average raw cotton yield of 3508 kg/ha. For every one cubic meter (1 m3) of water that is used, raw cotton yield increase by 0.51 kg/ha. This corresponds of a water use efficiency of 0.21 kg/m3 for cotton lint (Baffes 2022). Cotton lint currently sells for $2.1 per kg on international markets (Business Inside 2022).



The additional revenue from water consumption can thus be estimated as follows:

Marginal revenue $_{\textbf{Furrow Irrigation}}$ = 2.1 \$/kg x 0.21 kg/m^3 = 0.4 \$/m^3 of water (eq.1)

There are however also costs associated with bringing that water to the farmer. Using estimates from WB (2022) on electricity pumping costs, that cost is in the order of 0.5 $/m3 of water

Marginal profit $_{\textbf{Furrow Irrigation}}$ = 0.4 \$/m3 – 0.05 \$/m^3 = 0.35 \$/m^3 of water (eq. 2)

The maximum benefit from a m^3 of water used in a furrow irrigation can therefore be considered as 0.35 \$/m^3. This is however, likely to be an over-estimate, as we have not accounted for the cost of the losses of water in the irrigation system and the cost of reduced land productivity due to frequent over-irrigation, salination of soils.

Under drip irrigation however, an average 3247 m^3/ha of water is used, average yield is in the order of 4598 kg/ha and water use efficiency is significantly higher: 1.41 kg/m^3 for raw cotton and 0.59 kg/m^3 for cotton lint. After accounting for pumping costs, the marginal profit is 1.15 \$ per m^3 of water used in a drip irrigation scheme (equation 3)

Marginal profit$_{\text{Drip irrigation}}$ = \$2.1 kg x 0.59 kg/m^3 – 0.05 \$//m^3 = 1.15 \$/m^3 of water (eq. 3)

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[20] Using furrow irrigation, farmers flow water down small trenches running through their crops. It is one of the oldest methods of irrigating fields is surface irrigation (USGA.org)

Cotton	Applied water (m3/ha)	Mean yield	Water use efficiency (cotton lint)	Incremental revenue (\$/m3)	Incremental profit (\$/m3)
Traditional furrow Irrigation	6837 m^3	3508 kg/ha	0.21 kg/m^3	0.4 \$/m^3	**0.35 \$/m^3**
Drip irrigation	3247 m^3	4598 kg/ha	0.6 kg/m^3	1.2 \$/m^3	**1.15 \$/m^3**

Considering that there is an average annual inflow of approximately 50 m3 million m3 of sediment into the THC, continuous dredging efforts are required to maintain storage capacity.

As dredging costs are easily in the order of \$2 per m^3 or higher, traditional irrigation systems provide only **\$0.35 of benefits for every \$2 spent.** It is therefore not justified to pay for recovering water storage capacity of the THC, for the purpose of using that water in traditional furrow irrigation schemes. Inevitably, water resources can be better spent in more climate smart farming systems and through the use of drip irrigation systems (see below)

Moreover, because of problems triggered by large-scale monoculture cotton production, and poor irrigation techniques that causes the loss of nutrients (mostly nitrogen and phosphorus) from the soil, in Karakalpakstan the average use of mineral fertilizers (233 kg/ha) is higher than the world average (141 kg/ha) (UNECE 2020), which makes fertilizers a significant operational expense for farmers in the Aral Sea region (Couetil and et al. 2020).

4.3 The case for climate proofing farming systems in Central Asia

Drip-irrigation however provides significantly higher economic returns to water use. Despite the support from the Government in the past decade however, water-saving irrigation technologies are not expanding at an adequate pace (UNECE 2020). There is also growing empirical evidence that efficiency improvements in irrigation water use may create rebound effects, i.e., they may trigger changes in farmers' behavior that offset the technical water savings expected under *ceteris paribus* conditions. Hamidov et al., (2022) find evidence of such rebound effects in Uzbekistan, through an increase in irrigated area and a switch to more water-intensive crops in Uzbekistan amongst farmers employing efficient irrigation schemes.

With increasing water scarcity and variability in Central Asia, and dwindling water resources due to the siltation of the THC, attention should be brought to enhancing climate resilience of Centra Asia's farming systems altogether. In this regard, new research has confirmed that regenerative farming practices, including no-tillage, and use of cover crops, can increase both yields and water use efficiency of cotton production schemes, compared to standard tillage and no cover-cropping in semi-arid environments like the Karshi Steppe. The application of irrigation water at a critical growth stage, is also more efficient than early season irrigation (DeLaune et al., 2020).

A new report by the Global Green Growth Institute *"Green Rehabilitation Investment Project for Karakalpakstan Republic in Uzbekistan to address impacts of the Aral Sea Crisis »,* also calls for reforestation, through orchard farming and planting of windbreaks to enhance climate resilience and farmer incomes (Robalino et al., 2022). These measures are coherent with resolution of the President No. 4912 (drip-irrigation targets for 2022-2023), No. 4850 (protective forest plantations for 2022-2030) as well as the targeted increase for fruit and vegetable growing areas for 2022-2025 (Robalino 2022). Allocating Tuyamuyun's water resources, to uses where they provide their highest returns to society, will help safeguard water, energy and food security in Central Asia.

5. Conclusion

Sedimentation has significant impacts on the useful capacity of reservoirs. As such, they may be seen as resources out of place. It is estimated that global reservoir volume is declining at 0.8% per year, as a result of sedimentation of reservoirs. As sustainable sediment management has not built in effectively into the design of reservoirs, from the outset, dredging interventions are therefore often unavoidable (Bagarani et al., 2020). Dredging generates an undesired accumulation of materials that represent an environmental cost, but that can be used as intermediate products in other products and processes coherent with principles of the circular economy and enhancing the nexus around water, energy, food and waste.

In this chapter we have assessed the scope for re-using sediment from the THC, for the construction industry in Turkmenistan and Uzbekistan. Soil samples from the THC show that the sediment is uncontaminated and contain clay, loam and sand in proportions that would allow for using a significant proportion of the dredged sediment for the construction industry. A market scoping analysis furthermore suggest that the construction industry is growing and there is enough demand to absorb the volumes of materials that would be dredged within the first five years of a maintenance dredging phase.

Assuming conservatively that 20% of the sediment from the Tuyamuyun classify as pure sands, and another 20% can be processed into clay sand, for which there are readily available buyers –significant revenue flow can be generated, on the basis of prevailing market prices for sand and clay sand.

When accounting for additional processing and transportation costs of the materials to buyers in nearby urban markets, a net profit of -$62,000 in the first year to $276 thousand in the last year (when dredging volumes are in the order of 2 million m^3). The gross profit that can be earned from the sale of sediment can cover the inevitable dredging costs and placement of sediment in confined disposal facilities – in the order of 100% - associated with the maintenance dredging phase.

Sand deposits are typically found in the upper reaches of dams. If sand deposits are larger than what we have assumed here, sales revenues will be higher and net profits higher. Gravel, may likewise be a source of revenue, as it is also heavily used in the construction industry.

Table 12: Simplified profit and loss account of annual revenues, costs and profits during a 5-year maintenance dredging phase

+	**Sales revenue** $ 3.3 to $ 6.6 million
-	**Processing and transportation costs** - $ 1 to - $ 2 million
=	**Gross profit** (sales revenues minus processing and transport costs) $ 2.3 to $ 4.7 million
-	**Dredging and disposal costs** - $ 2.2 to - $ 4.2 million
=	**Net profit** - $ 62,000 to $ 276,000 thousand
→	**Recovery of dredging and disposal costs*** 97 – 106%

* = Gross profit/total dredging and disposal costs

Whilst it makes good economic sense to re-use sediment, it also makes environmental sense. There are significant negative impacts from sand extraction within active sand bodies - such as rivers, estuaries, beaches - which can tip the natural balance, resulting in potentially critical social, economic, and environmental impacts (see section 1.2). Sustainable extraction of sand therefore requires careful mitigation and management, as increasingly recognized, for example, in a new UN resolution[21] that calls for actions on sustainable sand management. It was adopted by all member states at the fifth United Nations Environment Assembly (UNEA 2022).

Proposed solutions, to move towards a circular economy for sand, include banning the landfilling of mineral waste (UNEP 2022b). There is a strong parallel between trapped sediment in a reservoir, or dredged sediment that are disposed of in confined disposal facilities. Dredging sand from the THC, would offer a promising pathway to truly sustainable extraction, since it would help alleviate pressure from sand extraction in sensitive environments whilst mitigating the imminent supply crisis.

A significant portion of the sediment in the THC is silt, which is usually considered an undesirable by-product from sediment and gravel quarrying. In alignment with new research, showing that raw fine sediment particles can be used as an amendment in concrete mixture and substitute 10% of cement, it is also advised that the opportunity to use silt for concrete production is explored. This could lead to a significant decrease in greenhouse gas emissions associated with the production of cement. Silt may also be explored as a potential soil amendment on degraded soils, preferably downstream of the THC reservoir[22].

Consequently, sediment dredging and re-use should not be considered an option, but an imperative, to safeguard proper functioning of the THC, and make efficient use of resources that are currently trapped in the THC reservoir. Moreover, water that is discharged from the THC should be allocated to its optimal uses. As shown in section 4.2, dominant furrow irrigation schemes, may be costing society more than the benefits it is providing. There is a strong case for climate proofing farming systems in Uzbekistan and Turkmenistan, using regenerative farming practices, such as no-tillage, cover-cropping and crop rotations, and reforestation, using orchards and windbreaks.

Conclusively, as part of the first efforts to safeguard the THC, maintenance will serve as an excellent pilot for a potentially much larger sediment re-use programme. There is an imminent global supply crisis of sand, whilst reservoirs around the world are reaching their economic life-time due to sediment build-up. The THC project could be amongst the first of its kind to properly demonstrate the value of reservoirs as a source of sand, that have been sustainable excavated, whilst safeguarding food, water and energy security and promoting a circular economy in central Asia.

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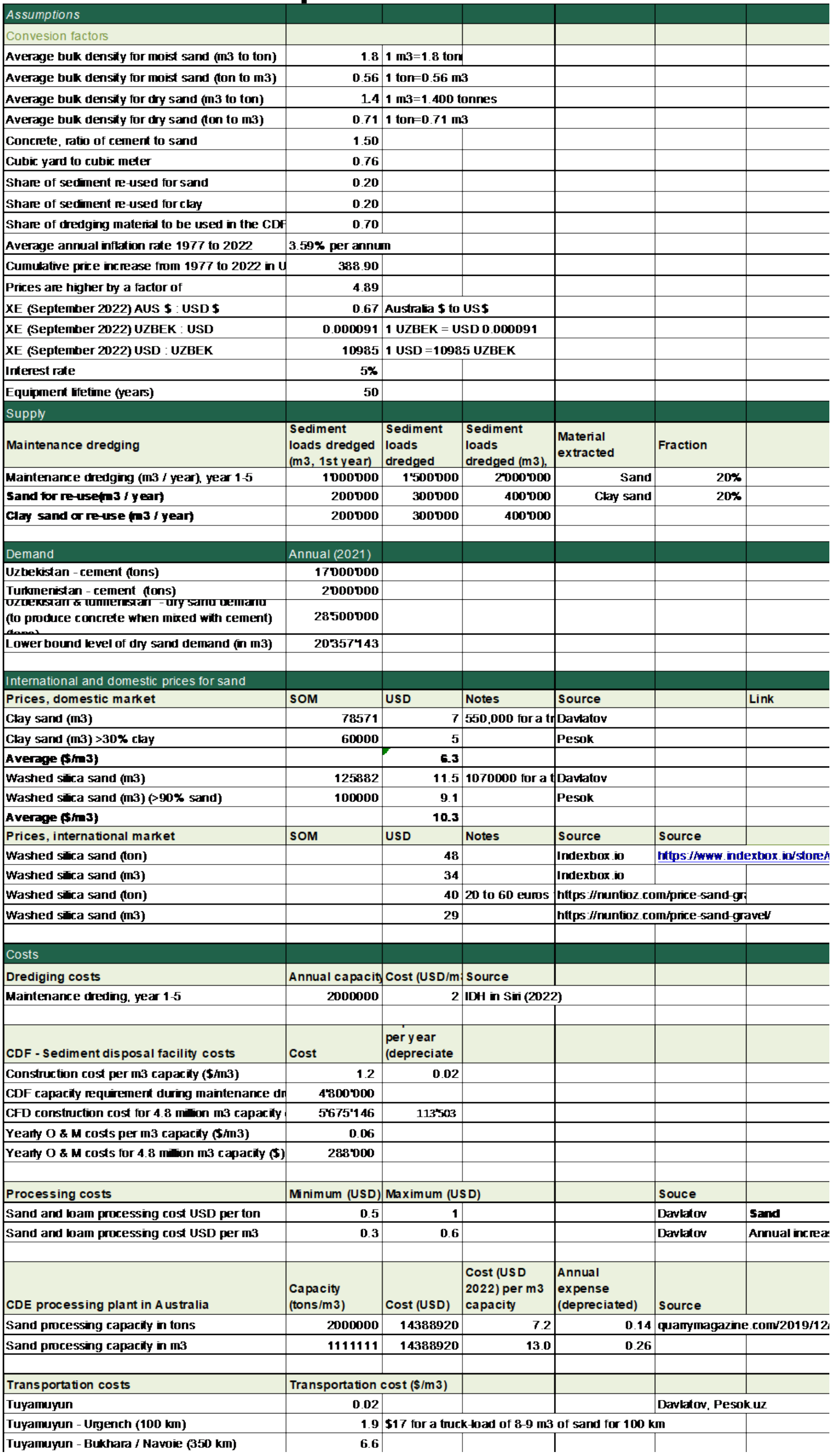
[21] Resolution titled: '[Environmental aspects of minerals and metals management.]

[22] Because of sediment being trapped in the reservoir, the stream morphology downstream from the dam can be dramatically affected by erosion which can induce impact on the infrastructures and ecology of the regulated river (Brandt 2000; Graf 2006). From an ecological perspective therefore, downstream uses, should be considered in the first hand, to offset part of the loss that the reservoir is inducing downstream.

Annex 1: Assumptions used in the P&L account



Assumptions						
Convesion factors						
Average bulk density for moist sand (m3 to ton)	1.8	1 m3=1.8 ton				
Average bulk density for moist sand (ton to m3)	0.56	1 ton=0.56 m3				
Average bulk density for dry sand (m3 to ton)	1.4	1 m3=1.400 tonnes				
Average bulk density for dry sand (ton to m3)	0.71	1 ton=0.71 m3				
Concrete, ratio of cement to sand	1.50					
Cubic yard to cubic meter	0.76					
Share of sediment re-used for sand	0.20					
Share of sediment re-used for clay	0.20					
Share of dredging material to be used in the CDF	0.70					
Average annual inflation rate 1977 to 2022	3.59% per annum					
Cumulative price increase from 1977 to 2022 in U	388.90					
Prices are higher by a factor of	4.89					
XE (September 2022) AUS $: USD $	0.67	Australia $ to US$				
XE (September 2022) UZBEK : USD	0.000091	1 UZBEK = USD 0.000091				
XE (September 2022) USD : UZBEK	10985	1 USD =10985 UZBEK				
Interest rate	5%					
Equipment lifetime (years)	50					
Supply						
Maintenance dredging	**Sediment loads dredged (m3, 1st year)**	**Sediment loads dredged**	**Sediment loads dredged (m3),**	**Material extracted**	**Fraction**	
Maintenance dredging (m3 / year), year 1-5	1'000'000	1'500'000	2'000'000	Sand	20%	
Sand for re-use(m3 / year)	200'000	300'000	400'000	Clay sand	20%	
Clay sand or re-use (m3 / year)	200'000	300'000	400'000			
Demand	Annual (2021)					
Uzbekistan - cement (tons)	17'000'000					
Turkmenistan - cement (tons)	2'000'000					
Uzbekistan & turkmenistan - dry sand demand (to produce concrete when mixed with cement) (tons)	28'500'000					
Lower bound level of dry sand demand (in m3)	20'357'143					
International and domestic prices for sand						
Prices, domestic market	**SOM**	**USD**	**Notes**	**Source**		**Link**
Clay sand (m3)	78571	7	550,000 for a tr	Davlatov		
Clay sand (m3) >30% clay	60000	5		Pesok		
Average ($/m3)		**6.3**				
Washed silica sand (m3)	125882	11.5	1070000 for a t	Davlatov		
Washed silica sand (m3) (>90% sand)	100000	9.1		Pesok		
Average ($/m3)		**10.3**				
Prices, international market	**SOM**	**USD**	**Notes**	**Source**	**Source**	
Washed silica sand (ton)		48		Indexbox.io	https://www.indexbox.io/store/	
Washed silica sand (m3)		34		Indexbox.io		
Washed silica sand (ton)		40	20 to 60 euros	https://nuntioz.com/price-sand-gr		
Washed silica sand (m3)		29		https://nuntioz.com/price-sand-gravel/		
Costs						
Drediging costs	**Annual capacity**	**Cost (USD/m**	**Source**			
Maintenance dreding, year 1-5	2000000	2	IDH in Siri (2022)			
CDF - Sediment disposal facility costs	**Cost**	**per year (depreciate**				
Construction cost per m3 capacity ($/m3)	1.2	0.02				
CDF capacity requirement during maintenance dr	4'800'000					
CFD construction cost for 4.8 million m3 capacity	5'675'146	113'503				
Yearly O & M costs per m3 capacity ($/m3)	0.06					
Yearly O & M costs for 4.8 million m3 capacity ($)	288'000					
Processing costs	**Minimum (USD)**	**Maximum (USD)**			**Souce**	
Sand and loam processing cost USD per ton	0.5	1			Davlatov	**Sand**
Sand and loam processing cost USD per m3	0.3	0.6			Davlatov	Annual increa
CDE processing plant in Australia	**Capacity (tons/m3)**	**Cost (USD)**	**Cost (USD 2022) per m3 capacity**	**Annual expense (depreciated)**	**Source**	
Sand processing capacity in tons	2000000	14388920	7.2	0.14	quarrymagazine.com/2019/12/	
Sand processing capacity in m3	1111111	14388920	13.0	0.26		
Transportation costs	**Transportation cost ($/m3)**					
Tuyamuyun	0.02				Davlatov, Pesok.uz	
Tuyamuyun - Urgench (100 km)	1.9	$17 for a truck-load of 8-9 m3 of sand for 100 km				
Tuyamuyun - Bukhara / Navoie (350 km)	6.6					

References

ADB (2021). Harnessing Uzbekistan's Potential of Urbanization: National Urban Assessment. The Asian Development Bank. Institutional Document. Available through URL : https://www.adb.org/documents/uzbekistan-national-urban-assessment

Agostini, F.; Skoczylas, F.; Lafhaj, Z. About a possible valorisation in cementitious materials of polluted sediments after treatment. Cem. Concr. Compos. 2007, 29, 270–278

Annandale, G. W. (2013), *Quenching the Thirst: Sustainable Water Supply and Climate Change*, CreateSpace, North Charleston, S. C.

Annandale, George W., Gregory L. Morris, and Pravin Karki. 2016. Extending the Life of Reservoirs: Sustainable Sediment Management for Dams and Run-of-River Hydropower.

Apitz, S.E. (2012). Conceptualizing the role of sediment in sustaining ecosystem services: Sediment-ecosystem regional assessment (SEcoRA). Science of The Total Environment, 415, 9–30.

Asian Development Bank. 2012. ADB Concept paper. Proposed Loan Uzbekistan: Water Resources Management. https://www.adb.org/sites/default/files/project-document/75147/45437-002-uzb- cp.pdf

Avastagroup (2022). Review of Cement Industry of the Republic of Uzbekistan. https://avestagroup.com/wp-content/uploads/2021/03/Cement_9M2020.pdf.

Baffes (2022). Distortions to Cotton Sector Incentives in West and Central Africa.

Baffes, John. (2022). Distortions to Cotton Sector Incentives in West and Central Africa.

Bagarani, M.; De Vincenzo, A.; Ievoli, C.; Molino, B. The Reuse of Sediments Dredged from Artificial Reservoirs for Beach Nourishment: Technical and Economic Feasibility. Sustainability 2020, 12, 6820. https://doi.org/10.3390/su12176820

Basson, G. R. (2009), Management of siltation in existing and new reservoirs. General Report, paper presented at the 23rd Congress of the International Commission on Large Dams, Int. Com. on Large Dams, Brasilia.

Beaulieu, D., (2022). The difference between sand, cement and mortar. When to Use These Building Materials for Your Next Project. The Spruce magazine. Available from URL: https://www.thespruce.com/difference-between-cement-concrete-and-mortar-2130884

Beddaa, H.; Ben Fraj, A.; Lavergne, F.; Torrenti, J.-M. Reuse of Untreated Fine Sediments as Filler: Is It More Beneficial than Incorporating Them as Sand? Buildings 2022, 12, 211. https://doi.org/10.3390/ buildings12020211

Bovaird, Tony (25 September 2015). Bovaird, Tony; Loeffler, Elke (eds.). Public Management and Governance. doi:10.4324/9781315693279. ISBN 9781315693279.

Brandt, S.A. Classification of geomorphological effects downstream of dams. Catena 2000, 40, 375–401.

Business Insider (2022). Cotton-price. Consulted 10.10.2022 from URL https://markets.businessinsider.com/commodities/cotton-price
CAREC (2021). Tuyamuyun Hydro Complex: Risks, Vulnerabilities and Solutions. Seminar on the Assessment of Climate Risks and Vulnerabilities in the territory of Tuyamuyun Hydro Complex (Turkmenistan – Uzbekistan)". Blogpost. https://ca-climate.org/eng/news/tuyamuyunskiy-gidrouzel-riski-uyazvimosti-i-puti-resheniya-/
Caves, R. W. (2004). Encyclopedia of the City. Routledge. pp. 551. ISBN 9780415252256)

Cemnet (2022) Cement construction facilities in Turkmenistan and Uzbekistan, available from: https://www.cemnet.com/global-cement-report/country/uzbekistan and https://www.cemnet.com/global-cement-report/country/turkmenistan

Central Asia News (2022). https://centralasia.news/6901-turkmenistan-to-increase-cement-production-by-2-million-tons-per-year.html

Dasgupta, A.K.; Pearce, D.W. Cost-Benefit Analysis; Springer: Cham, Switzerland, 1972

Davlatov (2022). Davlatbeg Davlatov. Personal communication, via emails and phone-call. WASH construction engineer and Natural Resource Management Specialist in Tajikistan.

De Vincenzo, A.; Covelli, C.; Molino, A.J.; Pannone, M.; Ciccaglione, M.; Molino, B (2019). Long-Term Management Policies of Reservoirs: Possible Re-Use of Dredged Sediments for Coastal Nourishment. Water 2019, 11, 15.

De Vincenzo, A.; Molino, B.; Viparelli, R.; Albergo, G (2007). Silting-up in reservoir: A risk and a resource. In Proceedings of the 32nd IAHR World Congress, Venice, Italy, 1–6 July 2007; pp. 2–10.

DeLaune, P.B, Mubvumba, P. Kimura, S. Ale, E. Impact of no-till, cover crop, and irrigation on Cotton yield. Agricultural Water Management, Volume 232, 2020,

Djumaboev, Kakhramon & Manthrithilake, Herath & Ayars, James & Yuldashev, Tulkun & Akramov, Bekzod & Karshiev, Rustam & Eshmuratov, Davron. (2019). Growing Cotton in Karshi Steppe, Uzbekistan: Water Productivity Differences with Three Different Methods of Irrigation.

Dubois, V., N.E. Abriak, R. Zentar,G. Ballivy (2009). The use of marine sediments as a pavement base material, Waste Manage. 29 (2009) 774-782. doi:10.1016/j.wasman.2008.05.004.

Esub (2020). How is Concrete used in Construction Projects. Esub construction software. Blogpost available from URL: https://esub.com/blog/how-is-concrete-used-in-construction-projects/

Evered, Kyle T. (2008). *Environmental problems of Central Asia and their economic, social and security impacts*. Chapter 5, Olsson, O., Bauer, M., Ikramova, M., Froebrich, J. The Role of the Amu Darya Dams and Reservoirs in Future Water Supply in the Amu Darya Basin. Dordrecht, the Netherlands: Springer. pp. 284–287. ISBN 978-1402089602.

Faure A. C. Coudray 2, B. Anger 2, I. Moulin 1, H. Colina 3, F. Théry 2, A. Smith 4. Beneficial reuse of dam fine sediments as clinker raw material

Fourvel, G., L. Vidal-Beaudet, A. Le Bocq, V. Brochier, F. Théry, D. Landry, T. Kumarasamy, P. Cannavo, Early structural stability of fine dam sediment in soil construction, J. Soils Sediments. 18 (2018) 1-17. doi:10.1007/s11368-018-1926-2.

George, M. W., S.M.ASCE; Rollin H. Hotchkiss, Ph.D., P.E., D.WRE, F.ASCE; and Ray Huffaker, Ph.D. Journal of Water Resources Planning and Management/Volume 143 Issue 3 - March 2017.

Giri, S., Stern, E., (2022) Management of sediment-induced problems at Tuyamuyun Hydro-Complex (THC). A desk study. Deltares and Tipping point.

Global Data (2022). Uzbekistan Construction Market Size, Trends and Forecasts by Sector – Commercial, Industrial, Infrastructure, Energy and Utilities, Institutional and Residential Market Analysis, 2022-2026. https://www.globaldata.com/store/report/uzbekistan-construction-market-analysis/

GlobalData (2022). Uzbekistan Construction Market Size, Trends and Forecasts by Sector – Commercial, Industrial, Infrastructure, Energy and Utilities, Institutional and Residential
Gopal, B. (2020). Managing Sediments (Sand and Gravel) in Rivers for Ecology and Economy. Centre for Inland Waters in South Asia. https ://www.researchgate.net/publication/346754842_Managing_Sediments_Sand_and_Gravel_in_Rivers_for_Ecology_and_ Economy.

Graf, W.L. Downstream hydrologic and geomorphic effects of large dams on American rivers. Geomorphology 2006, 79, 336–360.

Grim, Ralph (2016). "Clay mineral". Encyclopædia Britannica.

Habil., A.A. Tulaganov, E.M. Akramov, Mukhitdinov, A.A, Nizamov, T.A., Mag. B.A. https://www.zkg.de/en/artikel/zkg_Binder_production_in_the_Republic_of_Uzbekistan_Present_and_future_2507310.html

Hamidov, A.; Kasymov, U.; Djumaboev, K.; Paul, C. Rebound Effects in Irrigated Agriculture in Uzbekistan: A Stakeholder-Based Assessment. *Sustainability* **2022**, *14*, 8375. Available from URL : https://www.mdpi.com/2071-1050/14/14/8375

DeLaune, P. Mubvumba, S. Ale, E. Kimura, Impact of no-till, cover crop, and irrigation on Cotton yield, Agricultural Water Management, Volume 232 (2020), 106038, ISSN 0378-3774, https://www.sciencedirect.com/science/article/abs/pii/S037837741931858X

Indexbox (2022). World - Silica Sands (Quartz Sands or Industrial Sands) - Market Analysis, Forecast, Size, Trends and Insights Update: COVID-19 Impact Please mention the Source: https://www.indexbox.io/store/world-silica-sands-quartz-sands-or-industrial-sands-market-analysis-forecast-size-trends-and-insights/ https://www.indexbox.io/store/world-silica-sands-quartz-sands-or-industrial-sands-market-analysis-forecast-size-trends-and-insights

Junakova, N., J. Junak, M. Balintova, Reservoir sediment as a secondary raw material in concrete production, Clean Technol. Envir. 17 (2014) 1161-1169. doi:10.1007/s10098-015- 0943-8.

Limeira, J. M. Etxeberria, M. Agulló, D. Molina, Mechanical and durability properties of concrete made with dredged marine sand, Constr. Build. Mater. 25 (2011) 4165-4174. doi:10.1016/j.conbuildmat.2011.04.053.

Liu, S., Luo, G., Wang, H., (2020). Temporal and Spatial Changes in Crop Water Use Eciency in Central Asia from 1960 to 2016. Sustainability 2020, 12, 572; doi:10.3390/su12020572

Mahmood, K. (1987), Reservoir Sedimentation: Impact, Extent, Mitigation, World Bank, Washington, D. C. White, R. (2001), Evacuation of Sediments From Reservoirs, Thomas Telford, London.

Market Analysis, 2022-2026. Available from URL: https://www.globaldata.com/store/report/uzbekistan-construction-market-analysis/

Messina, F.; Ferone, C.; Molino, A.; Roviello, G.; Colangelo, F.; Molino, B.; Cioffi, R. Synergistic recycling of calcined clayey sediments and water potabilization sludge as geopolymer precursors: Upscaling from binders to precast paving cement-free bricks. Constr. Build. Mater. 2017, 133, 14–26

Miller, J. A., (1998). CONFINED DISPOSAL FACILITIES ON THE GREAT LAKES. Great Lakes & Ohio River Division U.S. Army Corps Of Engineers 111 North Canal Street Chicago, Illinois 60606-7205

Miller, J.A., Lee, C.R. and T.J. Olin. 1997. “Reclaiming soil from dredged material disposal areas,” presented at U.S.-Japan Experts Meeting of Management of Bottom Sediments Containing Toxic Substances, Kobe, Japan.

Ministry of Water Resources (2022). Personal Communication, Ikhom at Ministry of Water Resources, Uzbekistan.

Molino, B.; De Vincenzo, A.; Ferone, C.; Messina, F.; Colangelo, F.; Cioffi, R. Recycling of Clay Sediments for Geopolymer Binder Production. A New Perspective for Reservoir Management in the Framework of Italian Legislation: The Occhito Reservoir Case Study. Materials 2014, 7, 5603–5616.

Molino, B.; De Vincenzo, A.; Ferone, C.; Messina, F.; Colangelo, F.; Cioffi, R. Recycling of Clay Sediments for Geopolymer Binder Production. A New Perspective for Reservoir Management in the Framework of Italian Legislation: The Occhito Reservoir Case Study. Materials 2014, 7, 5603–5616

Morris, G. L., 2020. Classification of Management Alternatives to Combat Reservoir Sedimentation. Water. March 2020. Water 12(3):861

Myers, T. E. and J.M. Brannon. 1991. "Technical Considerations for Application of Leach Tests to Sediments and Dredged Material," Environmental Effects of Dredging Program Technical Note EEDP-02-15, US Army Engineer Waterways Experiment Station: Vicksburg, MS.

OECD (2012), Recommendation of the Council on Principles for Public Governance of Public-Private Partnerships, https://www.oecd.org/governance/budgeting/PPP-Recommendation.pdf

OECD (2012), Recommendation of the Council on Principles for Public Governance of Public-Private Partnerships, https://www.oecd.org/governance/budgeting/PPP-Recommendation.pdf

OECD (2017). OECD POLICY PERSPECTIVES Multi-Purpose Water Infrastructure. Recommendations to maximise economic benefits

Olin, T.J. and D.W. Bowman. 1996. “Soil Washing Potential at Confined Disposal Facilities,” Environmental Effects of Dredging, D-96-3, USACE Waterways Experiment Station, Vicksburg, MS.

Olive, W.W., (1989). Chleborad, A.F.; Frahme, C.W.; Shlocker, Julius; Schneider, R.R.; Schuster, R.L. (1989). "Swelling Clays Map of the Conterminous United States". U.S. Geological Survey Miscellaneous Investigations Series Map. I-1940. Retrieved 8 December 2020

Olsson, Oliver & Bauer, Melanie & Ikramova, Malika & Froebrich, Jochen. (2008). The Role Of The Amu Darya Dams And Reservoirs In Future Water Supply In The Amu Darya Basin. 10.1007/978-1-4020-8960-2_20.

Ozer-Erdogan, P, H. Merve Basar, I. Erden, L. Tolun, Beneficial use of marine dredged materials as a fine aggregate in ready-mixed concrete: Turkey example, Constr. Build. Mater. 124 (2016) 690-704. doi:10.1016/j.conbuildmat.2016.07.144.

Palmieri, A., Shah, F., Annandale, G. W. and Dinar, A. “Reservoir Conservation: The RESCON approach.” Vol. I, 2003, The World Bank.

Palmieri, A., Shah and Dinar, A. (2001). Economics of reservoir sedimentation and sustainable management of sediments. Journal of Environmental Management. Volume 61, Issue 2, February 2001, Pages 149-163.

Pesok.uz (2022). Clay Sand. Accessed 31.10.2022 from URL https://pesok.uz/en/clay-sand/

Quarry Magazine (2019). Cost estimates revealed for sand processing plant.https://www.quarrymagazine.com/2019/12/04/cost-estimates-revealed-for-sand-processing-plant

R.M. van Swam (not dated) Guidelines for Marine, Nearshore and Inland Confined Disposal Facilities Case Study Slufter CDF. Ministerie van Verkeer en Waterstaat Directoraat-Generaal Rijkswaterstaat Bouwdienst Rijkswaterstaat. 3526 LA Utrecht Griffioenlaan 2.The Netherlands

Rakhshan K, Morel J-C, Alaka H, Charef R. Components reuse in the building sector – A systematic review. *Waste Management & Research*. 2020;38(4):347-370. doi:10.1177/0734242X20910463

Randle, T. Kimbrel S. Collins K. Boyd P. Jonas M. Vermeeren, R., Eidson, D. Cooper, D. Shelley J, Kyle Juracek, K., Altinakar, M. Hotchkiss, R. Kondolf, M. Nelson,P. Weirich, F. Morris, G. Annandale, G. Jensen, K. Whelan M. (2017). Frequently Asked Questions about Reservoir Sedimentation and Sustainability Contribution and review by the Subcommittee on Sedimentation. National Reservoir Sedimentation and Sustainability Team. April 2017. Accessed from URL: https://acwi.gov/acwi-minutes/acwi2017/Presentations/04c_reservoir_sedimentation_and_sustainability_faqs.pdf

Randle, T., Boyd, R., (2018). Sedimentation management for multi-purpose Reservoirs: A federal perspective. Presentation by Dr. Tim Randle, Bureau of Reclamation, and Dr. Paul Boyd, U.S. Army Corps of Engineers. Webinar available from URL: https://cires.colorado.edu/events/sedimentation-management-multi-purpose-reservoirs-federal-perspective

Reservoir Conservation Volume I: the RESCON Approach Economic and Engineering Evaluation of Alternative Strategies for Managing Sedimentation in Storage Reservoirs

Robalino, JJ., Russell, A.J.M, Oblomuradov, N & J. Kazbekov (2022) Green Recovery Investment Analysis – Climate-Resilient Agriculture in the Republic of Karakalpakstan, Global Green Growth Institute (GGGI), Seoul, South Korea.

Schroeder, P.R. and M.R. Palermo. 1990. "The Automated Dredging and Disposal Alternatives Management System (ADDAMS)," Environmental Effects of Dredging Program Technical Note EEDP-06-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Sheehan, J. Harrington, J.D. Murphy, A technical assessment of topsoil production from dredged material, Resour. Conserv. Recy. 54 (2010) 1377-1385. doi:10.1016/j.resconrec.2010.05.012.

Shirokova Y. I. (2022): ОТЧЕТ по проекту «Проведение комплексного биохимического анализа состава ила руслового водохранилища Туямуюнского гидроузла» Контракт № EMP-2022-C-026. Министерство водного хозяйства Республики Узбекистан (МВХ РУз). Научно-исследовательский институт Ирригации и водных проблем (НИИИВП)

Stern, E (2022). Eric Stern, Personal Communications. Partner, Strategic Operations/Sediment Management Tipping Point Resources Group.

Tashkent Times (2021). 11 cement plants to be launched this year. Available from URL: http://tashkenttimes.uz/business/6770-11-cement-plants-to-be-launched-this-year-uzqurilishmateriallari#:~:text=It%20was%20noted%20that%20the,Jizzakh%2C%20Fergana%20and%20Tashkent%20provinces

The Economist (2017). Why there is a shortage of sand. The economist explains. https://www.economist.com/the-economist-explains/2017/04/24/why-there-is-a-shortage-of-sand?

The Third Pole (2022). Sand mining is destroying Asia’s rivers. Available from URL : https://www.thethirdpole.net/en/nature/sandmining-asia/

Tulaganov (2021). Binder production in the Republic of Uzbekistan: Present and future

UNEP (2022a). Our use of sand brings us “up against the wall”, says UNEP report. Press release. April 2022.

UNEP (2022b). Sand and sustainability: 10 strategic recommendations to avert a crisis. GRID-Geneva, United Nations Environment Programme, Geneva, Switzerland

UNESCO (2012) WWAP (World Water Assessment Programme) 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk; UNESCO: Paris, France, 2012.

USACE. 1987a. "Confined disposal of dredged material", Engineer Manual EM 1110-2-5027, Washington, D.C.

UNECE. 2020. *Environmental Perfromance Reviews - Uzbekistan - Third Review.* Geneva: United Nations.

$A. http://nrcs.$a.gov/Internet/FSE_MEDIA/nrcs142p2_050242.jpg by CMG Lee

USGS (2018). Irrigation Methods: Furrow or Flood Irrigation. US Department of the Interior. https://www.usgs.gov/special-topics/water-science-school/science/irrigation-methods-furrow-or-flood-irrigation

Valenti, G.; Bernardo, G.; Marroccoli, M.; Molino, B. (2003) Beneficial reuse of reservoir sediment in the cement industry. In Proceedings of the International Conference on Remediation of Contaminated Sediments, Venice, Italy, 30 September–3 October 2003.

Van Bunderen, C.; Snellings, R.; Vandewalle, L.; Cizer, O. Early-age hydration and autogenous deformation of cement paste containing flash calcined dredging sediments. Constr. Build. Mater. 2019, *200*, 104–115

Van Bunderen, C.; Snellings, R.; Vandewalle, L.; Cizer, O. Early-age hydration and autogenous deformation of cement paste containing flash calcined dredging sediments. Constr. Build. Mater. 2019, 200, 104–115

Van Bunderen, C.; Snellings, R.; Vandewalle, L.; Cizer, O. Early-age hydration and autogenous deformation of cement paste containing flash calcined dredging sediments. Constr. Build. Mater. 2019, 200, 104–115

Wisser, D., Steve Frolking, S., Hagen, S., F. P., Bierkens, M., (2013). Beyond peak reservoir storage? A global estimate of declining water storage capacity in large reservoirs. Water Resources Research.

World Bank (2022) In press. Valuing ecosystems services and prioritizing landscape restoration investments in Vakhsh catchment to support sustainable hydropower

Yirka, B., (2022). Calculating global sand demand for the coming years and ways to avoid a demand crisis. March 2022. Psys.org

Zhong, X., Deetman, S., Tukker, A. et al (2022). Increasing material efficiencies of buildings to address the global sand crisis. Nature Sustain 5, 389–392 (2022). https://doi.org/10.1038/s41893-022-00857-0