Improving Agricultural Irrigation on the Balkhab River, Afghanistan

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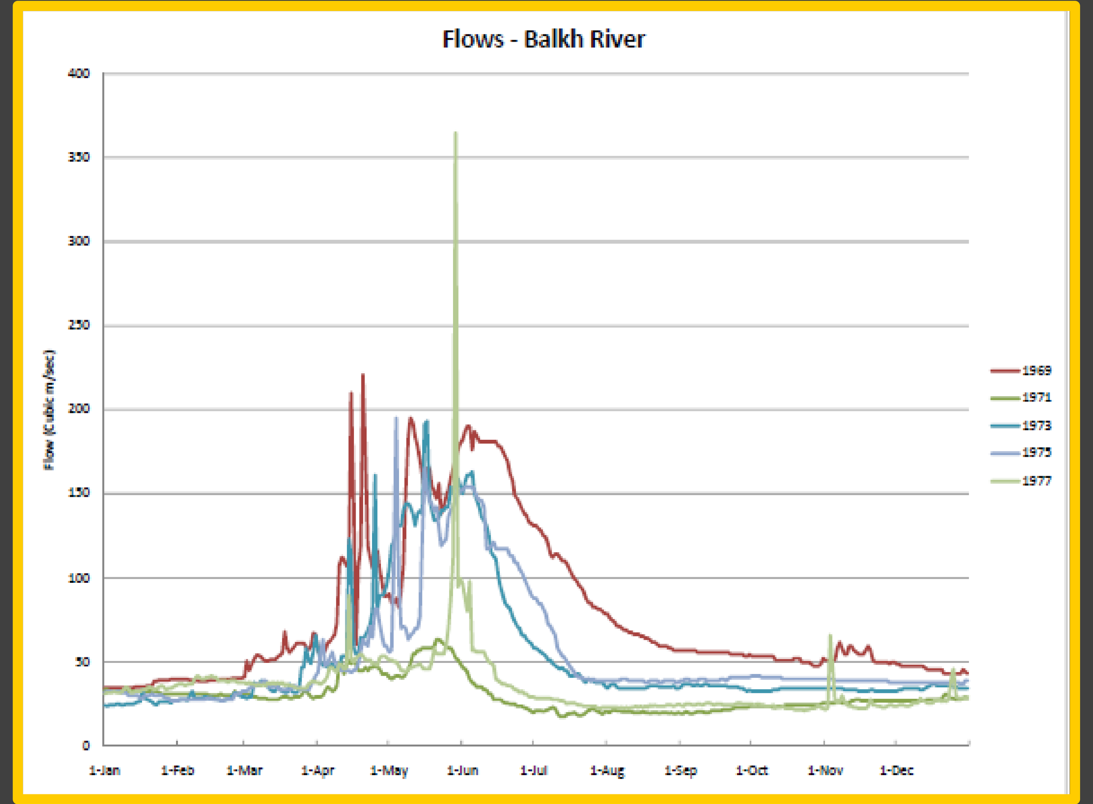
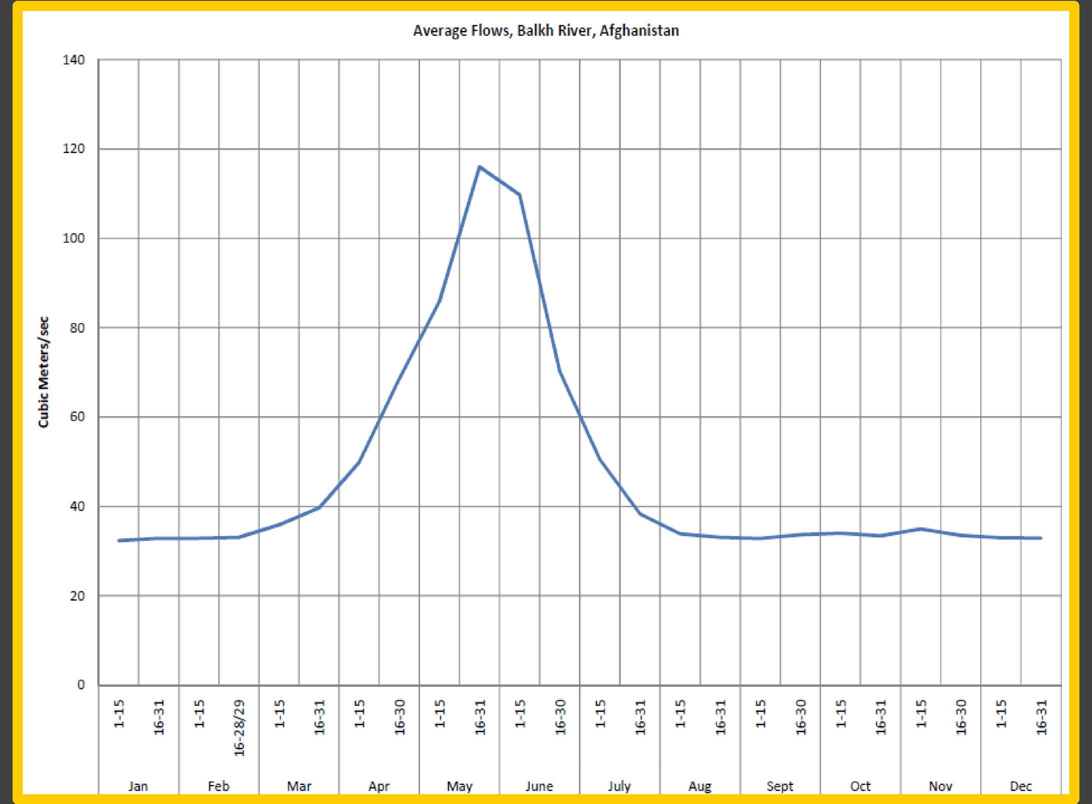
Problem: insufficient and highly seasonal water supply

Abstract/Introduction

In Afghanistan, where 80% of the population is rural, irrigated agriculture is important for satisfying subsistence needs. While most of the irrigated agriculture is fed by diversion canal systems which tap surface flows, legal and physical water infrastructure in the region is generally poor. A math programming model is used to optimize irrigation strategies under different water-availability and policy scenarios. It is found that the construction of a reservoir could increase net revenues to a representative farming community by up to 30%. However, even greater benefits may result from increasing distribution efficiencies, depending on the initial level of conveyance losses. Further, property rights schemes may be implemented to distribute wealth more evenly through various zones at minimal cost to the agricultural community as a whole. These results may prove useful to policymakers or water authorities in reestablishing water rights.





Water flows in the Balkhab River are highly seasonal, as can be seen from the above hydrographs. The majority of the water supply is available from May until July and is supplemented by scant rainfall – about 5” – throughout the year. There is also considerable variation from year to year; 1971 was a particularly dry year – as can be seen above – and was used to model optimal water allocation during drought conditions. (USGS)

Afghan villagers construct a sod diversion dam (above). These dams are washed out several times a year, especially during the periods of high flows (see hydrographs, top). The goal of this project is to determine the most economically-optimal method of managing these flows. (Fipps, 2009)

Methodology: maximize profits via infrastructure improvements

$$\max Z = \sum_{i=1}^{7}\sum_{p=1}^{24}\sum_{q=1}^{3} NR_{iq}\, x_{iq} - t(T_p + w_{ipq}x_{iq}) \quad \text{s.t.} \qquad \text{I}$$

$$\sum_{i=1}^{7}\sum_{q=1}^{3} x_{iq} \le L_q \qquad \text{II}$$

$$\sum_{i=1}^{7}\sum_{p=1}^{24}\sum_{q=1}^{3} x_{iq} l_p \le \bar{l}_{pq} \qquad \text{III}$$

$$\sum_{i=1}^{7}\sum_{p=1}^{24}\sum_{q=1}^{3} x_{iq} w_{ipq} \le 0.05(W_p + T_p) \qquad \text{IV}$$

$$\sum_{p=1}^{24} T_p \le R \qquad \text{V}$$

$$\sum_{i=1}^{7}\sum_{q=1}^{3} Y_{iq} x_{iq} \ge S_{iq} \quad \forall\, i = \{\text{wheat, potatoes, and maize}\} \qquad \text{VI}$$

$$\sum_{q=1}^{3} x_{alfalfa,q} \ge 0.10 x_{iq} \qquad \text{VII}$$

where:

NR_{iq} = net revenue for the i-th crop in area q
x_{iq} = the amount of land, in hectares, devoted to the i-th crop in area q
T_p = the amount of water sent from the reservoir to the farmland in period p
R = the quantity of water in the reservoir
L_q = the total amount of land available for farming in area q
l_p = the labor requirements in the p-th period per hectare of crop i
$\bar{l}_{pq}$ = the total amount of labor available per period in area q
w_{ipq} = the water requirement in period p for crop i in area q
W_p = total water availability in period p
Y_i = yield from crop i
S_i = subsistence needs for crop i
t = the per-unit tax on water

A math programming model is used to optimize the allocation of water among three agricultural zones in the Balkh River Basin by maximizing net returns to farmers under different water management scenarios, including dams of various sizes, improving distribution efficiency, and different water rights schemes. Subsistence needs are accounted for by requiring the model to produce a given amount of maize, wheat, and potatoes, and 10% of the total land planted must be alfalfa for draft animals.

Dam sizes modeled are 4.8, 1.3, and 0.5 million cubic meters in capacity. Conveyance efficiency improvements will be modeled as 20%, 40%, and 60% from a given baseline. The various water rights schemes modeled are equal shares between zones, percent based on land size, and 20%, 30%, and 50% distributions to the to each of the three areas, from the smallest to the largest zone by land size.

Data

Zone	Wheat	Barley	Potatoes	Melon	Maize	Cotton	Alfalfa
Upper	256.23	-338.27	733.55	405.24	-203.61	-217.81	-94.07
Middle	277.33	-317.68	793.96	438.61	-191.21	-204.55	-88.34
Lower	301.45	-294.15	863.00	476.75	-177.05	-189.40	-81.80

Table 1: Net revenues ($US) of each crop modeled. The highest revenues are found in the lower-altitude, more productive lower region. (Eberle, et al 2009)

	Wheat	Barley	Potatoes	Melons	Maize	Cotton	Alfalfa
Planting	29	66	147	84	65	55	38
Harvesting	29	29	17	147	29	70	108
Total	58	95	164	231	94	125	146

Table 2: Labor requirements per acre of crop planted, measured in person-days. (Eberle, et al 2009)

Zone	Wheat	Barley	Maize	Alfalfa	Cotton	Potatoes	Melons
Upper	460 m^3 8-day int.	460 m^3 8-day int.	460 m^3 8-day int.	460 m^3 9-day int.	460 m^3 8-day int.	345 m^3 6-day int.	460 m^3 9-day int.
Middle	492 m^3 8-day int.	492 m^3 8-day int.	492 m^3 8-day int.	492 m^3 9-day int.	492 m^3 8-day int.	369 m^3 6-day int.	492 m^3 9-day int.
Lower	532 m^3 8-day int.	532m^3 8-day int.	532 m^3 8-day int.	532 m^3 9-day int.	532m^3 8-day int.	399 m^3 6-day int.	532 m^3 9-day int.

Table 3: Water requirements per acre of crop planted in cubic meters. The bottom number of each cell indicates the interval over which irrigation is practiced. Irrigation practices consist primarily of flood irrigation in which land is flooded to a certain depth. The depth was converted to rough volumes for inclusion into the model. (USAID 2003)

Zone	Median losses	High losses	Low losses
Upper	15%	25%	7.5%
Middle	23%	43%	11.5%
Lower	33%	53%	16.5%

Table 4: The various assumptions of conveyance inefficiencies included in the model. Losses increase with distance from the gauging station .

Zone	Wheat	Maize	Potatoes	Alfalfa
Upper	204,215 kg 84 hectares	15,070 kg 5.9 hectares	48,854 kg 2.3 hectares	10% of land 110 hectares
Middle	334,170 kg 127 hectares	24,660 kg 9 hectares	79,943 kg 3.5 hectares	10% of land 180 hectares
Lower	482,690 kg 169 hectares	35,620 kg 12 hectares	115,473 kg 4.6 hectares	10% of land 260 hectares

Table 5: Subsistence requirements for important crops in each of the three zones. The top number is the absolute quantity of the crop needed per year, while the bottom number is the amount of land in each zone that must be planted with the given crop. (UN FAOSTAT Food Balance Sheets)

Water policy is generally set by *mirabs* in a given community. Mirabs are the water authorities and are critical, highly respected figures in Afghan society. (Fipps, 2006)

Results: options for welfare improvements

Dam

		Average Flow Year				Drought Year			
Cap. (m^3)		None	4,760,000	1,271,000	496,700	None	4,760,000	1,271,000	496,700
Total Profits		$1,373,549	+2.47%	+0.90%	+0.35%	$627,752	+27.29%	+7.30%	+2.85%
Land Use	*Upper*	519 ha	0%	0%	0%	366 ha	0%	0%	0%
	Middle	838 ha	0%	0%	0%	589 ha	+11.44%	0%	0%
	Lower	2,432 ha	+5.41%	+1.97%	+0.77%	1,061 ha	+12.86%	+5.00%	+1.96%
	Total	3,789 ha	+3.47%	+1.27%	+0.50%	2,017 ha	+10.11%	+2.63%	+1.03%

Table 6: When assuming average conveyance losses, significant benefits can accrue to the community, especially during drought years. The lower zone in particular reaps the benefit of greater water supplies, as it has greater supplies of land to bring into production.

Canal Efficiency Improvement

	Average Flow Year			Drought Year		
Median loss	+20%	+40%	+60%	+20%	+40%	+60%
Net Revenue	1.45%	3.05%	4.77%	7.54%	15.90%	24.95%
Total Land Use	2.03%	4.28%	6.89%	2.72%	5.74%	9.19%
High loss	+20%	+40%	+60%	+20%	+40%	+60%
Net Revenue	1.58%	3.66%	6.21%	11.81%	25.68%	42.20%
Total Land Use	2.19%	2.73%	6.27%	4.16%	7.21%	12.29%
Low loss	+20%	+40%	+60%	+20%	+40%	+60%
Net Revenue	0.84%	1.72%	2.63%	3.80%	7.75%	11.89%
Total Land Use	1.26%	2.58%	3.95%	1.67%	3.41%	5.22%

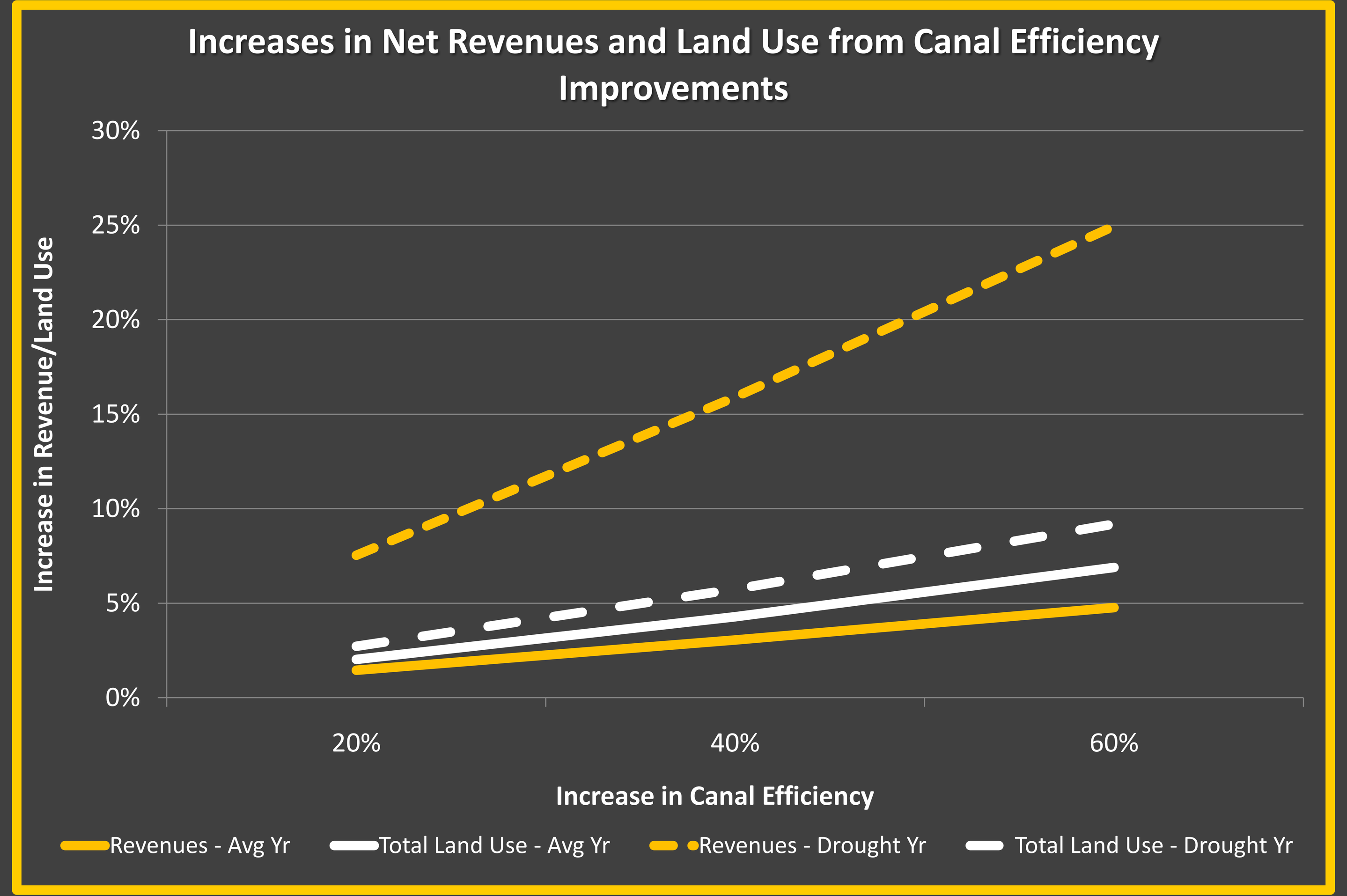


Table 7: By improving distribution efficiency, farmers can enjoy greater access to already-existing water supplies. As seen above, benefits can approach those of building a dam during a drought year and can exceed benefits from a dam during a year with average river flows.

Water Rights Schemes

		Land Size		Equal		20,30,50%		10,20,70%	
		Avg. yr	1971 yr	Avg. yr	1971 yr	Avg. yr	1971 yr	Avg. yr	1971 yr
Net Revenue		-17.8%	N/A*	-1.9%	-8.99%	-18.6%	N/A*	N/A*	N/A*
Land Use	*Upper*	+112.1%	N/A*	+99.1%	102.2%	+112.1%	N/A*	N/A*	N/A*
	Middle	+52.2%	N/A*	+52.7%	15.3%	+46.8%	N/A*	N/A*	N/A*
	Lower	-54.8%	N/A*	-38.8%	-34.7%	-54.8%	N/A*	N/A*	N/A*
	Total	-8.3%	N/A*	+0.32%	+4.8%	-9.5%	N/A*	N/A*	N/A*

Table 8: Most allocation schemes were infeasible due to the subsistence constraints placed on each agricultural zone. However, equal water rights among zones, regardless of land area, increased the net returns to the generally poorer upper and middle zones at the cost of the lower zone. This served to more effectively equate wealth across zones while only decreasing revenues to the entire region by 2%.

Photo from Fipps, "Kabul Journal"

Conclusion and Discussion

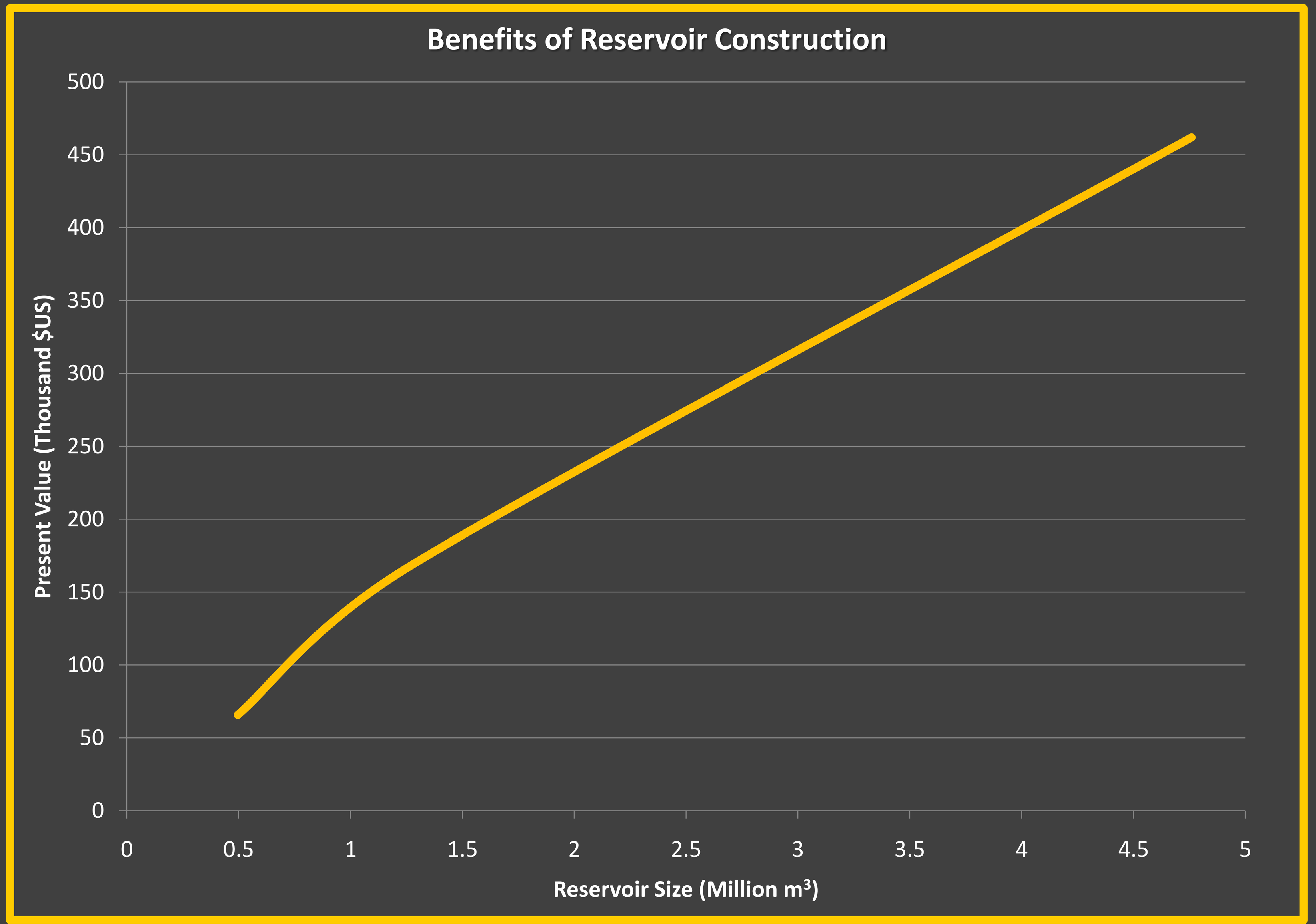
Table 9: The uncertainty regarding the parameters used in this model play a major role in making optimal policy decisions. The table below shows that the form of infrastructure improvements that should be chosen among available alternatives depends largely on the level of distribution inefficiency present in the canal network. The graph to the left indicates that benefits from building a reservoir increase at a decreasing rate as reservoir size increases.

However, the graph at right shows that significant benefits can accrue to the farmers following the construction of the dam, especially if significant levels of foreign aid can be used to finance construction.

	Median distribution inefficiency		High distribution inefficiency	
	Reservoir (4.8 million m^3)	60% conveyance loss improvement	Reservoir (4.8 million m^3)	60% conveyance loss improvement
Net revenues	27%	25%	30%	42%
Land use	10%	9%	10%	12%

Areas for further research: *More data is needed* to fully assess the conditions of agricultural areas in Afghanistan, especially as it results to current stream flows from the Balkhab River and the current state of irrigation infrastructure. Information on construction costs for the various alternative projects must also be known in order to fully assess the values of proposed improvements.

Above: Afghan villagers construct a sod diversion dam. Quality improvements can serve to limit the amount of labor necessary to operate and maintain irrigation infrastructure. (Fipps, 2006)



Present value of benefits from reservoir construction, using a 20-year dam structure life and a 4% discount rate.

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