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JUSTIFICATION OF THE DAILY CONSUMPTION REGIME, BALANCING STORAGE AND BLENDING RATIO IN AN INTER-REGIONAL WATER TRANSFER SYSTEM

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Abstract

The daily water consumption regime of the districts and towns of the Andijan and Fergana regions located along the Kampirravat – Fergana inter-regional water transfer system is analysed. Using rural- and urban-type demand patterns and a two-step supply schedule (2.5/4.5 %), the balancing storage volumes are determined: 7.82 % of the daily demand for rural-type consumers, 4.58 % for Fergana city and 5.73 % for Margilan city. Hourly flows for consumer groups and balancing volumes for different supply schedules are calculated, and the total reservoir volume for Fergana city is justified. For blending Kampirravat water (hardness 2.1–6.1 meq/l) with groundwater (8.5–14 meq/l), the minimum share of Kampirravat water ensuring the standard hardness is obtained from a mass balance (46 % for the Pakana–Logan well field and 71 % for the hardest sources).

Keywords: daily water demand, peaking factor, balancing storage, water hardness, blending, Fergana.



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Introduction

Inter-regional water transfer systems supply consumers of different types in several administrative areas from a single source. Along the route of the Kampirravat – Fergana system lie the Jalakuduk, Khojaabad, Bulakbashi and Markhamat districts of the Andijan region, the Kuva and Tashlak districts of the Fergana region, and the cities of Kuvasay, Fergana and Margilan [1]. The consumption regimes of these consumers differ: rural settlements show sharp morning and evening peaks, whereas in large cities the demand curve is relatively flatter.

A trunk conduit is most efficient and reliable when it operates at a constant or slowly varying flow during the day: the risk of water hammer is reduced, the pumping stations operate at optimal duty, and no excess pressure arises at night. The difference between the demand and supply schedules is covered by balancing storage (reservoirs) on the consumer side [2–4].

The second important issue is water quality. The hardness of groundwater in the Fergana region is 8–14 meq/l, above the O‘z DSt 950:2011 standard (7 meq/l) [5]. According to the design, Kampirravat water is blended with water from existing sources before being supplied to the city networks, but the blending ratio has not been justified.

The aim of the paper is to analyse the daily consumption regime of consumers along the route, to determine the balancing storage volumes and to justify the blending ratio that ensures the standard hardness.

Study object and input data

The Andijan reservoir has a total capacity of 1750 million m³ and a useful capacity of 1600 million m³; it is fed by the Karadarya, Yassi and Kurshab rivers.

Since the reservoir catchment consists of granite, slate and limestone, the water has low mineralisation. The main quality parameters are given in Table 1.

Table 1 Main quality parameters of the Andijan reservoir water

Parameter	Reservoir water	Standard (O‘z DSt 950:2011)
Total mineralisation, mg/l	≤ 520	1000
Total hardness, meq/l	2.1–6.1	7.0
pH	7.05–8.2	6.0–9.0
Ammonium nitrogen, mg/l	0.35	2.0
Nitrate nitrogen, mg/l	0.006–0.09	10.0
Petroleum products, mg/l	0–0.25	0.1
Phenols, mg/l	0–0.006	0.001
Turbidity, mg/l	2–83	1.5
Dissolved oxygen, mg/l	≥ 4.6	–

Only turbidity, phenols and, during floods, petroleum products may exceed the standard in the reservoir water; these are reduced to standard levels at the Kampirravat treatment plant by settling, coagulation and filtration. In terms of hardness and mineralisation, the reservoir water is considerably better than the groundwater of the region.

The daily demands of the consumers were taken from the design data: Markhamat district – 5785, Bulakbashi – 4768, Khojaabad – 5957, Jalakuduk – 6756, Kuva – 2253, Tashlak – 2850, Kuvasay city – 6487, Fergana city – 48,200 and Margilan city – 2588 m³/day [6]. Rural-type hourly demand patterns were used for the districts and small towns, and urban-type patterns for Fergana and Margilan. The conduit was assumed to operate in a two-step regime, supplying 2.5 % of the daily demand per hour from 0 to 4 h and 4.5 % during the remaining hours.

The balancing storage volume was determined from the cumulative difference between the supply and demand schedules [2, 7]:

$$S_\tau = \sum_{j=1}^{\tau}(a_j - b_j), \qquad W_{bal} = \frac{Q_{day}(\max S_\tau - \min S_\tau)}{100} \tag{1}$$

where a_jj and $b_j$are the supply and demand in hour j, % of the daily demand; Q_{day} is the daily demand, m³/day. The hourly peaking factors were determined as $K_{max} = b_{max}/b_{avg}$ and $K_{min} = b_{min}/b_{avg}$ (b_{avg} = 100/24 = 4.167 %).

Results

The hourly demand and supply schedules and the cumulative differences are given in Table 2 and Figs. 1–2.

Table 2 Hourly water demand and supply schedules, % of daily demand

Hour	Districts	Fergana c.	Margilan c.	Supply	Σ (districts)	Σ (Fergana)	Σ (Margilan)
0–1	2.70	3.13	2.98	2.5	−0.20	−0.63	−0.48
1–2	1.58	2.12	1.92	2.5	0.72	−0.25	0.10
2–3	1.57	2.10	1.91	2.5	1.65	0.15	0.69
3–4	1.58	2.10	1.91	2.5	2.57	0.55	1.28
4–5	2.01	2.55	2.36	4.5	5.06	2.50	3.42
5–6	2.99	3.36	3.23	4.5	6.57	3.64	4.69
6–7	5.02	4.83	4.90	4.5	6.05	3.31	4.29
7–8	5.18	4.93	5.02	4.5	5.37	2.88	3.77
8–9	6.05	5.50	5.68	4.5	3.82	1.88	2.59
9–10	5.92	5.41	5.58	4.5	2.40	0.97	1.51
10–11	5.34	5.03	5.14	4.5	1.56	0.44	0.87
11–12	4.86	4.71	4.76	4.5	1.20	0.23	0.61
12–13	3.93	4.07	4.03	4.5	1.77	0.66	1.08
13–14	3.72	3.91	3.85	4.5	2.55	1.25	1.73
14–15	3.49	3.74	3.66	4.5	3.56	2.01	2.57
15–16	4.14	4.21	4.19	4.5	3.92	2.30	2.88
16–17	4.51	4.48	4.50	4.5	3.91	2.32	2.88
17–18	4.32	4.34	4.35	4.5	4.09	2.48	3.03
18–19	4.69	4.60	4.63	4.5	3.90	2.38	2.90
19–20	5.49	5.14	5.26	4.5	2.91	1.74	2.14
20–21	5.78	5.32	5.48	4.5	1.63	0.92	1.16
21–22	6.25	5.63	5.83	4.5	−0.12	−0.21	−0.17
22–23	5.63	5.23	5.37	4.5	−1.25	−0.94	−1.04
23–24	3.25	3.56	3.46	4.5	−0.00	−0.00	0.00

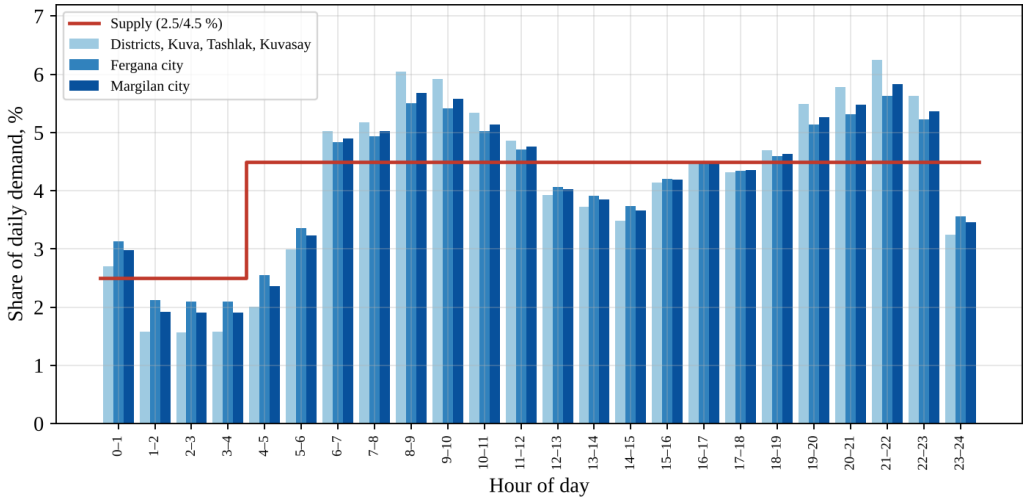


Fig. 1. Hourly water demand of consumers and supply schedule of the conduit

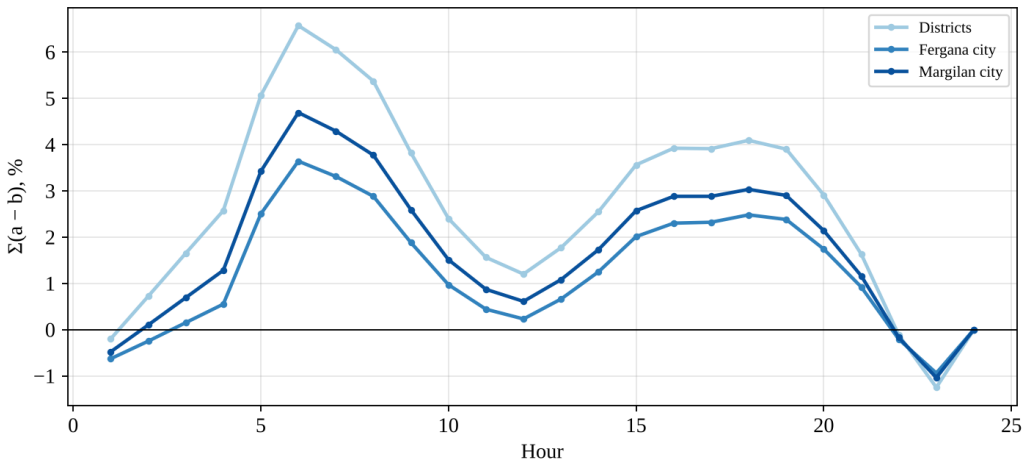


Fig. 2. Cumulative difference between supply and demand schedules

Table 2 and Fig. 1 show that for rural-type consumers the maximum demand occurs at 21–22 h (6.25 %) and the minimum at 2–3 h (1.57 %); the hourly peaking factors are K_max = 1.50 and K_min = 0.38. The schedule for Fergana

city is flatter: K_max = 1.35, K_min = 0.50. The cumulative difference curves in Fig. 2 show that the reservoirs are filled during the night and afternoon hours (0–6 and 12–18 h) and drawn down during the morning (6–12 h) and evening (19–23 h) peaks.

The balancing storage volumes determined by (1) are given in Table 3.

Table 3 Balancing storage volumes for consumers

Consumer	Q_{day}, m³/day	K_{max} / K_min	W_{bal}, %	W_{bal}, m³
Markhamat d.	5,785	1.50 / 0.38	7.82	452
Bulakbashi d.	4,768	1.50 / 0.38	7.82	373
Khojaabad d.	5,957	1.50 / 0.38	7.82	466
Jalakuduk d.	6,756	1.50 / 0.38	7.82	528
Kuva d.	2,253	1.50 / 0.38	7.82	176
Tashlak d.	2,850	1.50 / 0.38	7.82	223
Kuvasay city	6,487	1.50 / 0.38	7.82	507
Fergana city	48,200	1.35 / 0.50	4.58	2,208
Margilan city	2,588	1.40 / 0.46	5.73	148

Table 3 shows that the balancing storage is 7.82 % of the daily demand for rural-type consumers, 4.58 % for Fergana city and 5.73 % for Margilan city. The volume required for Fergana city (2,208 m³) equals 11 % of the reservoir capacity designed at the Pakana water distribution station (2×10,000 m³); the remaining volume is sufficient for the fire-fighting and emergency reserves. The balancing volumes for the Andijan region districts (373–528 m³) can be accommodated in the existing reservoirs of the district distribution stations.

To determine the blending ratio, a mass balance equation was used:

$$H_{mix} = (1 - x)H_1 + xH_2, \qquad x_{min} = \frac{H_1 - H_s}{H_1 - H_2} \tag{2}$$

where H_1 is the hardness of the groundwater source; $H_2 = 4.1$ meq/l is the average hardness of Kampirravat water; $H_s = 7$ meq/l is the standard hardness; x is the share of Kampirravat water in the blend. The results are given in Table 4 and Fig. 3.

Table 4 Total hardness of the blend versus the share of Kampirravat water, meq/l

Groundwater source (H_1)	x = 0.2	x = 0.3	x = 0.4	x = 0.5	x = 0.6	x_{min}
Pakana – Logan (9.5)	8.42	7.88	7.34	6.80	6.26	0.46
Fergana (average) (10.5)	9.22	8.58	7.94	7.30	6.66	0.55
Margilan (9.0)	8.02	7.53	7.04	6.55	6.06	0.41
Kuva (9.5)	8.42	7.88	7.34	6.80	6.26	0.46
Highest (14.0)	12.02	11.03	10.04	9.05	8.06	0.71

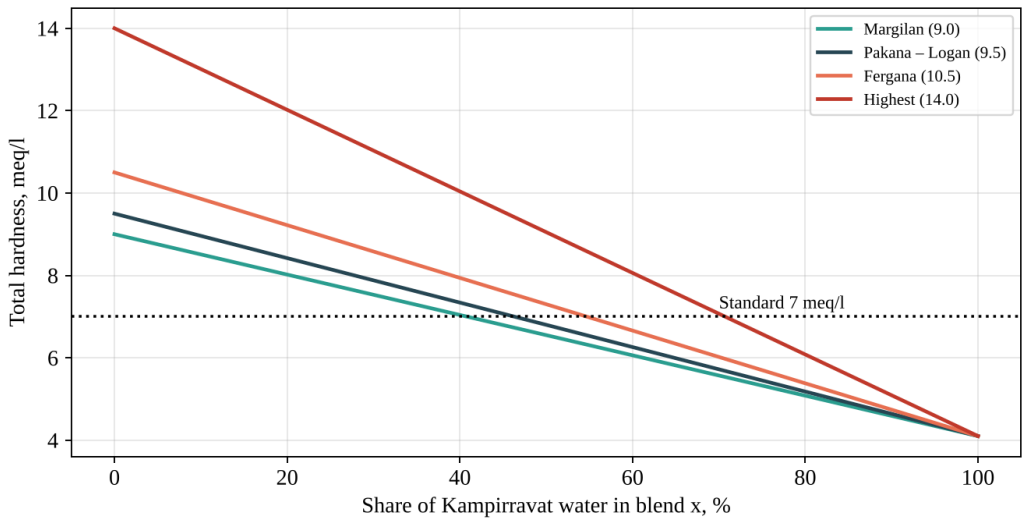


Fig. 3. Hardness of the blend versus the share of Kampirravat water

Table 4 and Fig. 3 show that to achieve the standard hardness, the share of Kampirravat water in the blend must be at least 46 % for the Pakana – Logan well field, 41 % for the Margilan sources and 71 % for the hardest sources. This agrees with the estimate in the design documents (hardness after blending 6.7–7.0 meq/l). The standard hardness is reached when the first-stage volume of Kampirravat water (48.2 thousand m³/day for Fergana city) provides 45–50 % of the total city consumption.

Hourly flows and total reservoir volume

To select the equipment of the distribution stations (pumps, flow meters, control valves), hourly flows were determined for consumer groups (Table 5). The Andijan region districts (Markhamat, Bulakbashi, Khojaabad, Jalakuduk) and the rural-type consumers of the Fergana region (Kuva and Tashlak districts and Kuvasay city) were combined into separate groups.

Table 5 Hourly water demand of consumer groups and hourly supply of the conduit, m³/h

Hour	Andijan region districts	Fergana region districts and Kuvasay	Fergana city	Margilan city	Total demand	Supply
0–1	628	313	1,509	77	2,527	2,141
1–2	368	183	1,022	50	1,622	2,141
2–3	365	182	1,012	49	1,609	2,141
3–4	368	183	1,012	49	1,612	2,141
4–5	468	233	1,229	61	1,991	3,854
5–6	696	347	1,620	84	2,745	3,854
6–7	1,168	582	2,328	127	4,205	3,854
7–8	1,205	600	2,376	130	4,312	3,854
8–9	1,408	701	2,651	147	4,907	3,854
9–10	1,377	686	2,608	144	4,816	3,854
10–11	1,242	619	2,424	133	4,419	3,854

11–12	1,131	563	2,270	123	4,087	3,854
12–13	914	455	1,962	104	3,436	3,854
13–14	866	431	1,885	100	3,281	3,854
14–15	812	404	1,803	95	3,114	3,854
15–16	963	480	2,029	108	3,581	3,854
16–17	1,049	523	2,159	116	3,848	3,854
17–18	1,005	501	2,092	113	3,710	3,854
18–19	1,091	544	2,217	120	3,972	3,854
19–20	1,277	636	2,477	136	4,527	3,854
20–21	1,345	670	2,564	142	4,721	3,854
21–22	1,454	724	2,714	151	5,043	3,854
22–23	1,310	653	2,521	139	4,622	3,854
23–24	756	377	1,716	90	2,938	3,854
Total	23,266	11,590	48,200	2,588	85,644	85,644

Table 5 shows that the total demand is 5,043 m³/h in the peak hour (21–22 h) and 1,609 m³/h in the minimum hour (2–3 h), a ratio of 3.4. The conduit operates in only two steps (2,141 and 3,854 m³/h). The difference between peak demand and conduit supply (1,189 m³/h at 21–22 h) is covered from the consumers' reservoirs. The balancing storage volume depends on the operating schedule of the conduit. Three schedule options were considered (Table 6): uniform supply, two-step supply and three-step supply adapted to the demand peaks.

Table 6 Balancing storage versus supply schedule, % of daily demand

Supply schedule	Districts	Fergana c.	Margilan c.	K_{max} of conduit
Uniform (4.167 %)	13.49	10.25	11.40	1.00
Two-step (2.5/4.5 %)	7.82	4.58	5.73	1.08
Three-step (2.5/4.0/5.0 %)	7.32	4.32	5.33	1.20

Table 6 shows that bringing the supply schedule closer to the demand schedule reduces the balancing storage: with the three-step schedule it falls to 4.32 % for Fergana city. However, the maximum flow in the conduit then exceeds the average by a factor of 1.20, which in a 92.7 km gravity conduit increases head losses by 44 % and leads to a shortage of residual head at the Fergana WDS. The two-step schedule is therefore optimal for the system: it reduces the reservoir volume compared with uniform supply while increasing the maximum flow in the conduit by only 8 % above the average.

The corresponding balancing volumes in cubic metres for the consumer groups are given in Table 7.

Table 7 Balancing storage volumes of consumer groups for the three supply schedules, m³

Consumer group	Q_{day}, m³/day	Uniform (4.167 %)	Two-step (2.5/4.5 %)	Three-step (2.5/4.0/5.0 %)
Andijan region districts	23,266	3,138	1,819	1,703
Fergana region districts and Kuvasay	11,590	1,563	906	848
Fergana city	48,200	4,939	2,208	2,082
Margilan city	2,588	295	148	138
Total	85,644	9,935	5,082	4,772

Table 7 shows that changing from uniform to two-step supply reduces the total balancing volume of the system from 9,935 to 5,082 m³, i.e. by 49 %, whereas the three-step schedule gives a further reduction of only 310 m³. This small additional saving does not justify the higher peak flow and head losses in the gravity conduit. The two-step schedule is also convenient in operation: the flow

is changed only twice a day, at 0 h and 4 h, by adjusting the control valve at the Kurgantepa node, which keeps the number of transients – and hence the risk of water hammer – to a minimum.

The variation of the balancing volume in the Fergana city reservoirs during the day is shown in Fig. 4. The reservoirs are filled from 23 to 6 h and from 12 to 19 h and drawn down during the morning and evening demand peaks.

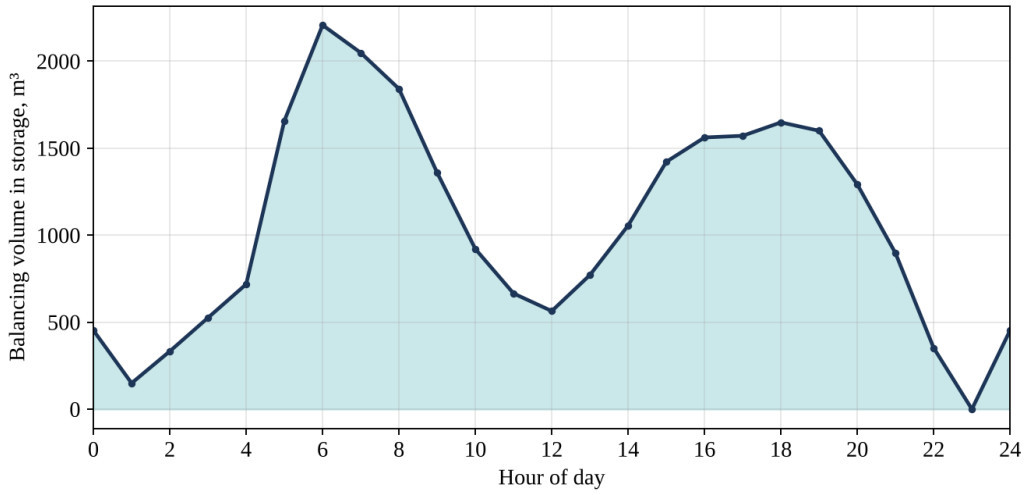


Fig. 4. Variation of the balancing volume in the Fergana city reservoirs during the day

The total reservoir volume is the sum of the balancing, fire-fighting and emergency volumes [7]:

$$W_{res} = W_{bal} + W_{fire} + W_{em} \quad (3)$$

For Fergana city: W_{bal} = 2,208 m³; the fire-fighting volume, for two simultaneous fires (q_fire = 40 l/s) extinguished over 3 hours, is $W_{fire} = 2 \cdot 40 \cdot 3 \cdot 3.6 = 864$ m³; the emergency volume, providing 70 % of the average hourly demand during the repair of a single d = 1000 mm line (12 hours), is $W_{em} = 0.7 \cdot 2{,}008 \cdot 12 = 16{,}870$ m³. Hence W_{res}= 19,942 m³, which matches the reservoir capacity designed at

the Pakana water distribution station (2×10,000 m³). Thus the main part of the reservoir volume (≈ 84 %) is the emergency reserve, which is the key factor of reliability for a long single-line conduit.

Discussion

The results lead to two practical conclusions. First, placing the balancing storage on the consumer side allows the trunk conduit to operate at an almost constant flow throughout the day. This mitigates the problem identified on the Khanabad – Andijan system – a sharp rise of pressure in the lower part of the route at night when the flow decreases – and reduces the energy consumption of the pumping stations. Second, the blending ratio must be continuously monitored: when the share of Kampirravat water drops below 45 % (for example, during an accident or repair works on the main), the hardness of the blend exceeds the standard.

It is therefore recommended to install analysers for continuous measurement of hardness, turbidity and residual chlorine at the blending points, as well as flow meters for each source, connected to the dispatch system. The current lack of metering devices in Fergana, Margilan and Tashlak makes it difficult to manage the actual quantity and quality of water supplied to the network.

It should also be noted that the rural-type demand patterns used here are typical design curves. Once flow meters are installed at the district distribution stations, the actual hourly demand should be recorded over at least one summer and one winter month, and the balancing volumes and the supply schedule should be refined accordingly. Since the reservoir volume at the Pakana station is governed mainly by the emergency reserve, such refinement will mostly affect the operating schedule rather than the required reservoir capacity.



Conclusions

1. The hourly peaking factor is K_{max} = 1.50 for rural-type consumers along the route, 1.35 for Fergana city and 1.40 for Margilan city.
2. With the two-step supply schedule (2.5/4.5 %), the balancing storage is 4.58–7.82 % of the daily demand: 2,208 m³ for Fergana city and 373–528 m³ for the Andijan region districts.
3. The two-step supply schedule is optimal: it reduces the reservoir volume compared with uniform supply and increases the maximum flow in the conduit by only 8 % above the average; the required total reservoir volume for Fergana city is 19,942 m³, which matches the designed 2×10,000 m³.
4. To ensure the standard hardness (7 meq/l), the share of Kampirravat water in the blend must be at least 46 % for the Pakana – Logan source and 71 % for the hardest sources.
5. Continuous water quality monitoring at the blending points and metering of flows from each source are recommended.

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