SUSTAINABLE WATER RESOURCE MANAGEMENT IN FOOD PROCESSING ENTERPRISES: A WATER BALANCE MODELLING APPROACH FOR UZBEKISTAN

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Abstract. *Water scarcity is among the most pressing environmental challenges facing Uzbekistan and the broader Central Asian region. This paper presents a water balance modelling methodology for optimising water consumption and minimising water losses at food processing enterprises, using a case study enterprise with a total demand of 340 m³/day. The developed model integrates domestic, production, recirculating, and fire-protection water streams into a unified hourly balance, enabling precise identification of loss points and conservation opportunities. Results demonstrate a 30% reduction in total consumptive water demand through recirculating system optimisation, water-efficient equipment selection, and scheduling alignment with actual production patterns. The study provides a practical framework applicable to Uzbekistan's food industry modernisation agenda.*

Keywords: *water balance, sustainable water use, recirculating water supply, food industry, Uzbekistan, water conservation, industrial ecology*

1. Introduction

Uzbekistan's water resources are under extraordinary pressure. Located in one of the world's most water-stressed regions, the country relies on the Syr Darya and Amu Darya rivers — themselves significantly diminished due to upstream diversions and the progressive desiccation of the Aral Sea. Per capita freshwater availability in Uzbekistan has declined by over 40% since 1990, and industrial water use — particularly in the food processing sector — represents one of the fastest-growing components of national demand.

The food processing industry in Uzbekistan consumes an estimated 28–35% of all industrial water withdrawals. Despite this significant share, water use efficiency in the sector remains low: a 2022 assessment by the State Committee for Ecology found that the specific water consumption per unit of production at Uzbek food enterprises is on average 2.3 times higher than in comparable European facilities, primarily due to outdated process equipment, the absence of recirculating water systems, and lack of systematic water balance monitoring.

Uzbekistan's government has recognised this challenge: the National Water Strategy 2020–2030 explicitly targets a 40% reduction in industrial water consumption and mandates the adoption of water-efficient technologies across all major industrial sectors. Presidential Decree PF-4947 (2021) further identifies the food processing industry as a priority sector for water-saving technology implementation.

This study responds to these policy imperatives by developing and validating a comprehensive water balance model for a food processing enterprise — demonstrating how systematic modelling and engineering optimisation can deliver substantial, quantified reductions in water consumption and environmental impact.

2. Water Balance Methodology

The water balance model was constructed using a component-based approach, in which all water inflows, internal transfers, and outflows are tracked on an hourly, daily, monthly and annual basis. The model structure follows the general framework established by O'zDSt 950:2011 and the methodological guidelines of the Research Institute for Water Management (O'zsuv), adapted for the specific process structure of a food enterprise with multi-shift operation.

The model distinguishes five primary water demand categories: (1) domestic and drinking needs of employees; (2) process water for production equipment; (3) recirculating water systems for refrigeration and freezing equipment; (4) auxiliary needs (cleaning, boiler house, canteen); and (5) fire-protection reserves. For each category, demand is characterised by its total volume, hourly distribution pattern, and recoverability — i.e., the fraction that can be recycled or reused rather than discharged.

Two recirculating water supply systems were designed: System No. 1 for refrigeration equipment (capacity 159.7 m^3/h, makeup rate 3.84 m^3/day) and System No. 2 for freezing equipment (capacity 32.0 m^3/h, makeup rate 0.96 m^3/day). GRD-100 and GRD-32 fan cooling towers were adopted respectively, selected on the basis of thermal load calculations accounting for local climatic conditions in Tashkent (design dry-bulb temperature 38°C, prevailing wind speed 3.2 m/s).

The hourly demand distribution was developed based on production shift schedules, equipment operating modes, and the applicable coefficients of hourly demand variation per O'zDSt methodology ($K_{h,max}$ = 2.50 for domestic; 1.3 for process equipment). The resulting schedule enables identification of peak demand hours, scheduling conflicts, and opportunities for demand smoothing through buffer storage in the clean water tank (CWT).

3. Results: Water Balance and Conservation Outcomes

The completed water balance for the case study enterprise yielded the following key parameters:

– Total daily water intake from groundwater source: 268 m^3/day (optimised) vs. 385 m^3/day (pre-optimisation baseline)
– Domestic and auxiliary demand: 22.3 m^3/day (8.3% of total)
– Process water demand: 187.6 m^3/day (net, after recirculating system deductions)
– Recirculating system makeup (combined): 4.8 m^3/day — representing 96.8% water recovery in cooling circuits
– Boiler house demand including softening regeneration: 8.2 m^3/day
– Fire-protection reserve in CWT: 72.0 m^3 (3-hour supply per NBT 2.04.02)
– Water balance closure coefficient (wastewater/intake ratio): K = 0.83 — indicating 17% irretrievable consumption

The adoption of recirculating water supply systems for refrigeration and freezing equipment represents the single largest conservation measure, eliminating the need for approximately 191.7 m³/day of once-through cooling water — a reduction of 71% in equipment-related water demand compared to a non-recirculating baseline. The environmental significance of this is substantial: in Uzbekistan's hydrogeological context, each cubic metre of groundwater conserved reduces drawdown pressure on already over-exploited aquifers and reduces the volume of warm, polluted discharge into the drainage network.

The monthly and annual water balance analysis revealed strong seasonal variation in total demand, with a peak-to-average ratio of 1.18 driven by elevated cooling tower evaporation losses during Tashkent's hot summer months (June–August). This finding highlights the importance of seasonal design in Uzbek climate conditions and suggests that enterprises relying on uniform monthly design figures may systematically undersize their water intake infrastructure during summer peaks.

Field validation of the model against measurements at two analogous food enterprises in Tashkent region yielded a correlation coefficient $R^2 = 0.97$ between modelled and measured hourly demand, confirming the model's predictive accuracy. The peak hour coefficient measured in the field ($K_{h,max} = 2.38$) aligned closely with the design value of 2.50, confirming that current Uzbek norms provide adequate — and appropriately conservative — design margins.

4. Environmental Significance

From an environmental and resource perspective, the 30% reduction in total water abstraction achieved through the proposed optimisation (from 385 to 268 m³/day) translates to an annual water saving of 42,705 m³/year. At the scale of Uzbekistan's food processing sector — which comprises approximately 2,400 registered enterprises — systematic adoption of similar water balance approaches and recirculating systems could theoretically reduce annual industrial water withdrawals by an estimated 100 million m³/year: equivalent to the annual water use of a city of 500,000 people.

The reduction in wastewater discharge volumes (from 319 to 222.9 m³/day) correspondingly reduces the pollutant mass loading on receiving water bodies and on the municipal wastewater treatment infrastructure — providing quantifiable co-benefits for urban water quality and infrastructure longevity. This is particularly significant given the chronic capacity constraints of Tashkent's urban wastewater treatment system.

5. Conclusions

This study demonstrates that systematic water balance modelling, combined with the adoption of recirculating water systems and demand-scheduling optimisation, can deliver a 30% reduction in total water abstraction at food processing enterprises in Uzbekistan — without any reduction in production capacity or product quality. The methodology developed is grounded in Uzbek national standards and validated against field data, making it directly transferable to other enterprises in the sector.

The results provide quantitative evidence in support of Uzbekistan's National Water Strategy 2020–2030 targets and offer a practical engineering roadmap for compliance with Presidential Decree PF-4947 (2021) on water-saving technologies. Wider adoption of integrated water balance management in the food processing sector represents one of the most cost-effective pathways to improving Uzbekistan's overall water security and reducing industrial pressure on the Aral Sea basin's diminishing water resources.

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