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The Search for Water-Secure Agricultural Growth in Kazakhstan

On a Tuesday morning in Astana, the car of Kazakhstan's Vice Minister of Agriculture crossed the Yesil River from the old city toward the wide boulevards of the left bank. Snow was falling on the frozen water below, a detail that struck the vice minister as grimly ironic. At Government House, the inter-ministerial task force on water resources was convening for its fifth and final deliberative session before submitting a unified recommendation to the Prime Minister on the 2030 Water Resources Management Concept.

The vice minister, who had spent twelve years designing and defending agricultural development programmes for the southern oblasts, knew what hung in the balance. The government had anchored much of its rural development agenda to an ambitious target: expanding the nation's irrigated land from roughly one and a half million hectares to between two and a half to three million hectares by 2030.[1,2] The vice minister believed this goal was achievable, as pilot data from his ministry had recently showed that modernised drip and sprinkler systems could reduce per-hectare water consumption by 30 to 40% while doubling yields.

Meanwhile, the Ministry of Water Resources and Irrigation's Director of Water Policy sat across the table from the vice minister with a different set of numbers in her head. Glaciers and rivers flowing from the Kyrgyz Republic, Uzbekistan, China, and Russia supplied nearly half of Kazakhstan's surface water, crossing borders before they ever reached a Kazakh canal. Decades of deferred maintenance had left much of Kazakhstan's canal network unlined and cracked: by conservative estimates, seepage and evaporation consumed up to three quarters of diverted water before it reached any crop. Climate models projected that total runoff would remain broadly stable in the near term before declining sharply through the second half of the century.[3] And the Aral Sea basin, which Soviet irrigation planners had drained in pursuit of cotton yields, had never recovered – a warning still legible from space via a salt-crusted shoreline.

"We are not arguing against agricultural development," the Director of Water Policy had said at the previous task force session. "We are arguing against the assumption that water will simply appear to support that development."

The Prime Minister's office had given the task force thirty days to produce a unified proposal. The road ahead was a tough one. Underpinning the disagreements was a question no technical model could answer: how much risk was Kazakhstan entitled to impose on its rivers, its neighbours and the generations that would inherit whatever the task force decided in thirty days?

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[1] Official Information Source of the Prime Minister of the Republic of Kazakhstan, "Irrigated areas in Kazakhstan to expand to 2.5 mln ha by 2030," January 30, 2024, https://primeminister.kz/en/news/irrigated-areas-in-kazakhstan-to-expand-to-25-mln-ha-by-2030-27152.

[2] Official Information Source of the Prime Minister of the Republic of Kazakhstan, "Kazakhstan plans to bring irrigated land to 3 million hectares by 2030," July 14, 2020, https://primeminister.kz/en/news/v-kazahstane-planiruyut-dovesti-ploshchadi-oroshaemyh-zemel-do-3-mln-ga-do-2030-goda-1463938.

[3] Annina Sorg et al., "Climate change impacts on glaciers and runoff in Tien Shan (Central Asia)," *Nature Climate Change* 2, no. 10 (2012): 725-731, https://doi.org/10.1038/nclimate1592.

This case was written by Tara Thean Mei Feng under the guidance of Assistant Professor Aliya Assubayeva, Graduate School of Public Policy, Nazarbayev University. The scenarios and packages are illustrative and created for pedagogical purposes. While the policy issue this case study explores is real, the characters, quotes, events and organisations depicted are fictional. The case does not reflect the views of the sponsoring organisation nor is it intended to suggest correct or incorrect handling of the situation depicted. The case is not intended to serve as a primary source of data and is meant solely for class discussion.

A Downstream Water Nation

Figure 1: Kazakhstan's main rivers and lakes, with basin boundaries shown and neighbouring countries labelled. The white area represents Kazakhstan.
Source: World Bank, "General Water Security Assessment: Kazakhstan," 2024.

Kazakhstan is the world's largest landlocked country. Most of the country's land is steppe and desert,[4] and while Kazakhstan is not water-scarce by national per capita measures, its southern agricultural regions face acute stress due to uneven water distribution and decades of intensive irrigation withdrawal. Kazakhstan's surface water system comprises eight major river basins, of which the Syr Darya in the south and the Irtysh in the north are the most significant for agriculture and industry.

Kazakhstan's water supply carries an unavoidable geopolitical vulnerability. Approximately 44% of its total surface water inflows originate from upstream neighbours outside the country's territory such as China, Uzbekistan, Russia and the Kyrgyz Republic.[5] The Syr Darya, for example, originates in Kyrgyzstan and flows through Uzbekistan and Tajikistan before reaching Kazakhstan, and accounts for a substantial share of the water used in the country's most productive agricultural zones (Figure 1). This dependence translated to geopolitical exposure that the Ministry of Water Resources and Irrigation had been documenting for years. Upstream infrastructure such as Kyrgyzstan's Toktogul reservoir or Chinese irrigation expansion in the Ili River basin could alter seasonal water flows in ways that Kazakhstan's planners couldn't control. The 1992 Almaty Agreement between the five newly independent Central Asian states – Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan – and subsequent bilateral compacts provided frameworks for

[4] "The Republic of Kazakhstan," Official website of the President of the Republic of Kazakhstan, accessed May 2026, https://www.akorda.kz/en/republic_of_kazakhstan/kazakhstan.
[5] "Kazakhstan's Water Usage: Challenges, Path to Reform," *The Astana Times*, January 31, 2025, https://astanatimes.com/2025/01/kazakhstans-water-usage-challenges-path-to-reform/.

water sharing and obliged signatories not to harm downstream neighbours, but regulation and enforcement mechanisms were not strong enough to incentivise compliance. Allocation disputes flared periodically, particularly in drought years.

Climate change compounded Kazakhstan's water vulnerability. Mountain glaciers in the Tian Shan range – natural reservoirs that moderated summer flows – were retreating at accelerating rates. Researchers had predicted relatively stable meltwater runoff levels in the near term, followed by a long-run decline by the end of the century.[6] Policymakers might mistake the runoff stability for a permanent baseline. Meanwhile, five of the six major glacierised basins in the northern Tian Shan had already passed their glacier runoff tipping points, meaning meltwater in those basins was already declining, and annual streamflow was projected to fall by roughly a quarter by the end of the century.[7]

Agriculture, Irrigation and the Food Security Agenda

Kazakhstan's irrigated agriculture sector accounted for approximately 60% of the country's total freshwater withdrawals[8] – a figure that had remained stubbornly high despite decades of efficiency rhetoric. The sector was concentrated in the southern and southeastern areas of the country, where farmers grew cotton, wheat, rice, vegetables and fruit in the Turkestan, Kyzylorda, Zhambyl and Almaty oblasts. These regions were also among the country's most agriculturally dependent.

The Ministry of Agriculture's 2021-2030 agricultural development policy document outlined the Kazakh government's food security strategy. By 2030, the strategy targeted full self-sufficiency in poultry, apples and dairy products such as cheese and cottage cheese, 83% self-sufficiency in sugar, and an overall domestic provision level of at least 90% across food products. Increasing the share of processed agricultural goods, including milk, meat, oilseeds and rice, to 70% of agro-industrial output was a further ambition.[9] Irrigation expansion featured prominently in the government's strategy for achieving these goals, particularly in the arid south, where the document set a target of over 1.3 million hectares under water-saving technologies by 2030. The logic was straightforward: rain-fed agriculture was unreliable in a country where annual precipitation in southern agricultural regions was less than 200 mm, and even the more temperate northern zones averaged only 400 to 500 mm of precipitation per year.[10] Without irrigation, yields were volatile and investments in mechanisation or improved seed varieties delivered inconsistent returns.

Infrastructure lagged the government's high ambitions. Soviet-era engineers had built most of Kazakhstan's irrigation canals, and these canals had seen little substantial rehabilitation or maintenance.[11] Many farmers practised flood irrigation, which involved releasing water across fields and letting it spread via gravity – a method requiring little capital investment, but one that introduced substantial inefficiencies. Across the full irrigation system, from canal intake to field, seepage and evaporation losses were so severe that only around a quarter of all diverted water actually went to crop irrigation.[12] The case for modernisation was therefore partly about expansion, and partly about recovering efficiency from existing infrastructure.

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[6] Sorg et al., "Climate Change Impacts on Glaciers and Runoff in Tien Shan (Central Asia)."
[7] Qiudong Zhao et al., "Quantifying glacier and snow shrinkage: future water stress in Northern Tien Shan, Central Asia," *Catena* 263 (2026), https://doi.org/10.1016/j.catena.2025.109734.
[8] "Kazakhstan's Water Usage: Challenges, Path to Reform".
[9] Government of the Republic of Kazakhstan, *On Approval of the Concept for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan for 2021-2030*, Resolution No. 960 (December 30, 2021), accessed June 11, 2026, https://adilet.zan.kz/rus/docs/P2100000960.
[10] World Bank, *Kazakhstan General Water Security Assessment* (Washington, DC: World Bank, 2023).
[11] World Bank, *Kazakhstan General Water Security Assessment*.
[12] Yessenkul Kalybekova et al., "Minimizing seepage in irrigation canals in land reclamation systems via an innovative technology," *Frontiers in Sustainable Food Systems* 7 (2023), https://doi.org/10.3389/fsufs.2023.1223645.

The Voices Around the Table

Vice Minister, Ministry of Agriculture

The son of a collective farm agronomist, the Ministry of Agriculture's Vice Minister grew up in the Turkestan oblast. He had watched, in his childhood, the slow death of the Soviet irrigation works: crumbling headworks, silt-choked channels, farms reverting to salt flats. When he joined the Ministry of Agriculture in 2012, his first project was in reconstruction – of canals, but also of the case for irrigation as a national development driver.

The Vice Minister's position was straightforward: modern irrigation technology could deliver more food from the same water. The Ministry was already subsidising drip-irrigation installations at up to 80% of capital cost;[13,14] in pilot projects in Kyzylorda, water consumption per hectare had dropped by 35% while tomato yields had nearly doubled. Scale those savings up, and Kazakhstan could irrigate 2.8 million hectares while using no more river water than it currently used to irrigate 1.5 million hectares. The net withdrawal from rivers could stay flat, or even fall, the vice minister argued.

"If we tell farmers they cannot expand, we are telling them that they cannot feed their children," the vice minister said. "Every hectare we leave unirrigated is a family that stays poor, a young man who leaves for the city. The village will empty out."

The ministry was also facing pressure from below. The akimats – regional administrations whose appointed governors ultimately answered to the President – were a powerful constituency, and the governors of the Turkestan and Kyzylorda oblasts had both submitted letters to the Prime Minister arguing that irrigation expansion was essential to reducing rural unemployment and stemming urban migration. For the vice minister, blocking expansion meant confronting farmers as well as the political architecture of the south.

The vice minister's preferred package was an expansion-first strategy: accelerate land opening, expand credit access for farmers investing in water-saving equipment, maintain subsidy programmes for water-saving technology and trust that efficiency gains would prevent a net increase in the total amount of water pulled out of rivers and aquifers across Kazakhstan. To tackle transboundary issues, he felt that Kazakhstan should build the infrastructure it needed and engage diplomatically with upstream neighbours, rather than pre-emptively constrain its own development.

Director of Water Policy, Ministry of Water Resources and Irrigation

The Director of Water Policy at the Ministry of Water Resources and Irrigation had an academic background in hydrology and had spent three years on the International Fund for Saving the Aral Sea executive board in Almaty before joining the ministry. The assumption that water would always be available to support farming expansion concerned her, though she had no quarrel with farmers or food production. The director had observed at close range what happened when political imperatives, rather than hydrological ones, drove water allocation decisions: she had seen aquifers drawn down, rivers not reaching their deltas, ecosystems collapsing and eventually the agricultural systems themselves failing.

Her core concern with the expansion-first approach was what economists called a rebound effect: a phenomenon whereby efficiency-boosting technology led users to consume *more*, not less, of a resource by

[13] "Drip Irrigation Equipment Plant to Open in South Kazakhstan," *The Times of Central Asia*, February 2, 2024, https://timesca.com/drip-irrigation-equipment-plant-to-open-in-south-kazakhstan/.

[14] Saniya Sakenova, "Kazakhstan Adopts New Draft Concept to Ensure National Water Security," *The Astana Times*, January 30, 2024, https://astanatimes.com/2024/01/kazakhstan-adopts-new-draft-concept-to-ensure-national-water-security/.

making each unit of consumption cheaper. A classic modern example of this effect in practice was fuel-efficient cars. When cars got better mileage per unit of gas, driving became cheaper per kilometre, leading people to drive more – sometimes enough to cancel out the fuel savings entirely. Evidence from water-saving technology programmes elsewhere in Central Asia, and from the Ministry of Water Resources and Irrigation's own data, suggested that efficiency gains often enabled farmers to expand cultivated area rather than reduce withdrawals. If a farmer who had previously irrigated ten hectares with 100,000 cubic metres of water now needed only 65,000 cubic metres to do the same, the rational response was to irrigate fifteen hectares, now consuming 97,500 cubic metres. The efficiency gain was real, but the water saving was not.

The Ministry of Water Resources and Irrigation had been developing a digital monitoring system for major canals that included real-time flow measurement, satellite-based soil moisture tracking and a water-accounting framework that would make actual consumption at the farm level visible. But deployment was slow and politically sensitive; farmers and akimats resisted metering as a prelude to pricing or quotas. The director wanted to use the 2030 Water Resources Management Concept as a mandate to accelerate stricter water allocation limits or metering and introduce basin-level allocation caps before the government locked in expansion commitments.

Farmer, South Kazakhstan

A 41-year-old farmer in South Kazakhstan farmed 80 hectares in the Shardara district of Turkestan oblast, growing cotton on 50 hectares and vegetables on the remaining 30. He was open to drip irrigation, having attended two government workshops on it, and had no ideological commitment to flood irrigation, but he was also running a business on thin margins and needed to think carefully about capital allocation.

The drip installation for the farmer's cotton fields would cost approximately 1.2 to 1.5 million tenge per hectare, or roughly 60 to 75 million tenge ($130,000 to $160,000) for his cotton area. Even with an 80% subsidy, the remaining cost was well beyond what he could finance through the regional agricultural development bank, which had tightened lending standards. Many of his neighbours were in a similar position.

Beyond the financing problem, the farmer's more fundamental anxiety was water reliability. His main canal draw came from the Syr Darya, via a secondary canal that the regional water management unit maintained. In three of the past five years, upstream releases had been lower than expected, forcing him to reduce vegetable plantings. He did need irrigation expansion, but needed reliable water even more than that – and drip technology could not guarantee reliable water if upstream flows were inadequate.

"What use is a drip system if the canal runs dry in August?" he said.

Environmental Scientist, Central Asian Regional Glaciological Centre

An environmental scientist at the Central Asian Regional Glaciological Centre had spent fifteen years studying what happened to rivers when their glaciers disappeared. She had tracked glacial retreat across the Tian Shan, contributed to three Intergovernmental Panel on Climate Change working group reports on Central Asian water systems and sat on the scientific panel for the International Fund for Saving the Aral Sea. The inter-ministerial task force on water resources had invited her to present as an external expert.

The environmental scientist's presentation had contained one exhibit she hoped the task force would not easily forget: a map showing the 1990, 2000 and 2014 extent of the Aral Sea's eastern basin. By 2014, satellite imagery confirmed that the eastern basin had vanished entirely – an event without precedent in the modern era, and the first such complete desiccation in six centuries.[15] What had been open water was now the Aralkum Desert, its shoreline having retreated by tens of kilometres in a matter of decades. Kazakhstan had partially saved its portion of the Aral Sea, the North Aral, through the Kok-Aral Dam, completed in 2005.[16] But the eastern basin, fed by the Amu Darya river further south, had received no such reprieve.

Her scientific concerns also went beyond the Aral. The Ili River, which was the primary inflow for Kazakhstan's largest freshwater body Balkhash Lake, faced mounting pressure from rapidly expanding irrigated agriculture in the Chinese upstream section of the Ili-Balkhash Basin in Xinjiang, where the area under irrigation had grown by nearly a fifth between 2000 and 2015.[17] Modelling studies warned that any further increase in upstream water consumption would deepen shortages downstream, threatening the fragile wetlands of the Ili Delta and the Balkhash lake itself.[18] Kazakhstan was simultaneously a downstream victim and an upstream actor, experiencing the consequences of others' expansion while contemplating its own.

Thirty Days, Three Packages

By lunchtime on the task force's final day of deliberations, it was clear that consensus would not come easily. The Ministry of Finance sided with the efficiency camp (Package 2; see Table 1) – not on environmental grounds, but because Package 1's fiscal footprint was alarming in light of revenue constraints. The Ministry of Foreign Affairs had circulated a memo noting that Uzbekistan had formally requested consultations under the 1992 Almaty Agreement before any further expansion of withdrawals from the Syr Darya. The akimats, represented by a delegation from Turkestan and Kyzylorda oblasts, had submitted a joint letter suggesting that any delay in expansion would cost the government the rural south in the next regional elections.

The task force had invited the farmer from South Kazakhstan to serve as a farmer representative for one session. "Half this water never makes it to my field," he told the room. "Sort that out first, then come talk to me about new equipment."

Meanwhile, the environmental scientist's final submission to the task force had been a single page. She presented a projection of Balkhash Lake's levels under three scenarios: the current trajectory, Package 1 and Package 2 (see Table 1). Under Package 1, the lake had a 60% probability of reaching a critical threshold for fishery collapse within twenty years. Under Package 3, that probability fell to under 20%.

The Director of Water Policy's final submission had been more pointed. She presented a table showing basin-level allocation deficits under each package, with a single line at the bottom: "Package 1 requires water we have not confirmed we have."

The Vice Minister read both submissions twice, and found both the environmental scientist's projections and the Director of Water Policy's line unsettling. But he also knew that the Prime Minister's economic advisers were focused on an entirely different set of problems. They cared about rural unemployment – agricultural expansion was the main lever the government had for creating jobs in the south – and food import bills,

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[15] NASA Earth Observatory, "The Aral Sea Loses Its Eastern Lobe," September 26, 2014, https://science.nasa.gov/earth/earth-observatory/the-aral-sea-loses-its-eastern-lobe-84437.
[16] World Bank, "Saving a Corner of the Aral Sea," September 1, 2005, https://www.worldbank.org/en/results/2005/09/01/saving-a-corner-of-the-aral-sea.
[17] Tesse de Boer et al., "Evaluating Vulnerability of Central Asian Water Resources under Uncertain Climate and Development Conditions: The Case of the Ili-Balkhash Basin," *Water* 13, no. 5 (2021): 615, https://doi.org/10.3390/w13050615.
[18] de Boer et al., "Evaluating Vulnerability of Central Asian Water Resources under Uncertain Climate and Development Conditions."

which Kazakhstan believed it could reduce by growing more food domestically. They also had concerns about political stability: the akimats and rural constituencies formed a support base the government could not afford to alienate, and any government appearing to block agricultural development there was at risk of losing significant political capital.

As the task force reconvened for its afternoon session, the thirty-day clock was ticking. The Prime Minister had asked for a concrete proposal, rather than a menu of options. The room had to decide on a combination of policies, institutions, incentives and trade-offs that the task force could actually implement and defend – to farmers, to neighbouring countries and to the next generation.

Over the five sessions of deliberations, three coherent strategic positions had emerged, each with its own internal logic and its own set of winners and losers (Table 1). The task force's final proposal would have to choose between them, combine elements of them or explain why none of them was adequate. Each reflected a genuine political choice rather than a technical optimum.

Table 1: Policy packages for the 2030 Water Resources Management Concept.

	Package 1: Expansion-first	**Package 2:** Efficiency-first	**Package 3:** Basin-balanced
Core logic	Modern irrigation technology can deliver more food from the same water. Efficiency gains will offset additional water demand from expanded area, keeping net river withdrawals flat or falling.	Kazakhstan cannot responsibly expand irrigated area until it knows how much water it has and how much it is losing. Metering, allocation caps and canal rehabilitation must come before expansion commitments.	Expansion and sustainability are not mutually exclusive, but must be sequenced and conditioned. Targeted expansion in lower-risk basins, tied to verified efficiency improvements, can deliver production gains while managing hydrological risk.
Irrigated area target	2.8-3.0 million hectares by 2030	1.6-1.8 million hectares by 2030	2.0-2.3 million hectares by 2030
Key elements	Accelerate expansion. Increase subsidies for water-saving technology (up to 80% of capital cost). Expand credit access for farmers. Construct new canals and reservoirs. Engage diplomatically with neighbours.	Limit new expansion. Prioritise canal rehabilitation over new construction. Accelerate digital monitoring and farm-level metering. Implement binding basin-level allocation caps. Tie subsidies to verified water savings and metering rather than to technology adoption alone.	Conduct expansion only in basins that are not already water-stressed. Tie subsidies to verified water savings and metering. Conduct phased introduction of allocation quotas, starting with most water-stressed basins. Conduct canal rehabilitation alongside targeted new construction. Introduce joint monitoring frameworks with upstream neighbours.
Advantages	Fastest route to food security and rural employment gains. Responsive to akimat and farming constituency pressure.	Most hydrologically sustainable. Strengthens transboundary negotiating position. Reduces long-run fiscal risk by avoiding infrastructure investments that may not be supportable under declining river flows.	Attempts to balance production and sustainability. Provides a credible response to both the akimats and environmental concerns.

Risks	Efficiency gains may not translate into basin-level water savings if farmers expand cultivated area (rebound effect). High fiscal costs. May strain transboundary agreements. Highest hydrological risk.	Slower production growth in the near term. Strong farmer and akimat resistance to metering. Requires enforcement capacity that may not yet fully exist. May be perceived as prioritising the environment over rural development.	High administrative complexity. Conditional and basin-by-basin rules are difficult to design and enforce. Uneven regional outcomes will create political friction. Risks becoming a compromise that satisfies no one fully.

Discussion Questions

1. You are a member of the inter-ministerial task force. Draft your recommendation to the Prime Minister. Be specific: how much irrigation expansion by 2030, and what water governance conditions, if any, would you make non-negotiable? What are the key trade-offs you would accept, and which would you refuse? Consider not only what is most defensible analytically, but what is most likely to be implemented, sustained, and enforced given the institutional realities the case describes.
2. The Vice Minister of Agriculture argues that efficiency gains from drip and sprinkler technology will prevent any net increase in total river withdrawals, even as irrigated area expands. The Director of Water Policy argues that the rebound effect undermines this logic. Who has the stronger argument? What policy design features could, in principle, prevent the rebound effect from occurring?
3. Assume that the rebound effect is a recurring concern. How would you design a subsidy programme that genuinely reduces total water consumption, rather than enabling more irrigated land?
4. The farmer's core concern is water reliability: he needs to know water will arrive before he can justify investing in equipment to use it more efficiently. How should the proposal address this? What governance mechanisms, domestic and transboundary, would give farmers a credible water right?
5. The environmental scientist argues for basin-level planning rather than national targets. What institutional changes within Kazakhstan would be necessary to operationalise a basin-level approach? What political obstacles would you anticipate, and how might they be overcome?
6. The 1992 Almaty Agreement obliged signatories not to harm downstream neighbours, but its enforcement mechanisms were never strong enough to compel compliance. What would a more effective regional water governance framework look like, and is it politically achievable?
7. Looking beyond 2030: the case describes a window of relative water abundance as glaciers continue melting, before flows decline sharply in the second half of the century. How should this long-run trajectory shape the proposal? Is there a risk that the task force is making thirty-year infrastructure commitments on the basis of conditions that will not persist?
8. Map the policy choices in this case onto short-term (0-5 years), medium-term (5-15 years), and long-term (15-30+ years) timeframes. Which decisions must policymakers make now that are difficult to reverse? Which decisions can policymakers defer without significant cost? Which decisions made today most constrain future options? Use this framing to evaluate whether the three packages differ not only in what they choose, but in how much flexibility they preserve for future policymakers.
9. The core tension in this case between expanding productive use of a shared natural resource and preserving its long-run availability recurs across many policy domains and country contexts. Identify a water, energy, land, or fisheries governance challenge in a country you know well, and apply the short-, medium-, and long-term framing from Question 8. What pressures push governments toward the short term? What institutional or political conditions make longer-term commitments credible?

Annex 1: Irrigated area and agricultural water withdrawal scenarios up to 2030 (illustrative projections).

Scenario	**Irrigated area 2025 (M ha)**	**Irrigated area 2027 (M ha)**	**Irrigated area 2030 (M ha)**	**Withdrawal 2025 (km^3/yr)**	**Withdrawal 2027 (km^3/yr)**	**Withdrawal 2030 (km^3/yr)**	**Change in total agricultural withdrawal, 2025 to 2030**
Baseline (no policy change)	1.55	1.58	1.60	~34	~34	~35	+1 km^3 (~3%)
Package 1: Expansion-first	1.70	2.20	2.85	~35	~37	~41-44	+7-10 km^3 (~20–29%)
Package 2: Efficiency-first	1.58	1.65	1.75	~33	~32	~31	-3 km^3 (~9%)
Package 3: Basin-balanced	1.62	1.85	2.15	~34	~34	~35-36	+1-2 km^3 (~3-6%)

Package 1 assumes full realisation of the rebound effect. Package 2 assumes 30% efficiency gain with binding allocation caps. Package 3 assumes a 20% efficiency gain with partial rebound dampened by conditional subsidies. All scenario projections are illustrative model outputs constructed for teaching purposes. They are not drawn from empirical data and should not be cited as official forecasts.

Annex 2: Drip irrigation adoption – costs, subsidies, and financing gap by farm size (cotton area, illustrative projections). Exchange rate: ~460 tenge per USD (April 2026, illustrative).

Farm type	**Cotton area (ha)**	**Total installation cost (M tenge)**	**Total installation cost (USD)**	**Subsidy (80%, M tenge)**	**Farmer's residual (M tenge)**	**Farmer's residual (USD)**	**Est. annual net revenue (M tenge)**	**Residual cost as % of annual revenue**
Smallholder	5	6-7.5	$13-16K	5-6	1.2-1.5	$2.6-3.2K	~3-5	~25-50%
Small-medium	20	24-30	$52-65K	19-24	4.8-6.0	$10-13K	~10-18	~27-60%
Medium	50	60-75	$130-160K	48-60	12-15	$26-32K	~25-45	~27-60%
Large	300	360-450	$780K-$1M	288-360	72-90	$156-194K	~150-270	~27-60%

The residual cost as a percentage of annual revenue column is the key figure: even after an 80% subsidy, the remaining investment represents 25-60% of a typical year's net revenue. The binding constraint is therefore credit market access, rather than subsidy generosity. All figures are illustrative constructions developed for teaching purposes. They are not drawn from empirical data and should not be cited as representative estimates.