



Technical and Economic Analysis of Replacing Traditional Concrete Irrigation Channels with Large-Scale Fiberglass Pipes: A Case Study (Irrigation and Drainage Network Utilization)

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Abstract

Over the past two decades, improving water transfer efficiency has become a major priority, especially given the significant drawbacks of traditional open concrete channels- such as high water loss due to seepage and evaporation, flow inefficiencies, and frequent maintenance needs. To address these challenges, many irrigation and drainage systems have shifted from conventional channels to pressurized or gravity-fed pipe systems. Among the most popular alternatives are Glass Reinforced Plastic (GRP) pipes, which have gained widespread acceptance in recent years. GRP pipes offer several advantages over concrete channels, both technically and economically. Not only do they provide superior strength, durability, and corrosion resistance, but they also significantly reduce water loss during transfer. From a financial standpoint, GRP systems often prove more cost-effective—not just in initial installation but also over the long term, thanks to lower maintenance requirements, reduced dredging needs, and shorter project completion times. When factoring in additional costs, such as land acquisition and seepage and evaporation losses, the overall life-cycle cost of GRP pipelines is considerably lower than that of traditional concrete channels. Moreover, the reliability of GRP pipes has been reinforced through rigorous short-term and long-term performance testing, conducted in accordance with internationally recognized ASTM and ISO standards. These assessments have boosted confidence among engineers, contractors, and project owners, making GRP an increasingly trusted choice for modern water conveyance systems. This study thoroughly examined and compared the technical and economic aspects of using concrete channels versus GRP pipes in irrigation and drainage networks. The findings demonstrate that GRP pipe systems offer a more efficient, sustainable, and economically viable solution, making them a wise choice for the future of water infrastructure.

1. Introduction

Iran is facing an escalating water crisis that poses a significant threat to its agricultural heartland and long-term sustainability. For a country where farming is not just an economic driver but a way of life for millions, the stakes could not be higher. Research paints a stark

picture: despite efforts to manage surface and groundwater, rapid population growth and the intensifying effects of climate change are straining Iran's water resources to the limit (Ahmadpour and Shokri, 2010). Farmers, who rely on every precious drop to sustain their crops and livelihoods, are feeling the pinch.

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Outdated irrigation practices, which consume excessive water while yielding disappointing crop yields, are exacerbating the issue (Aghamajidi, 2023). Reports from the United Nations and the International Water Management Institute have sounded the alarm, labeling Iran's situation as a severe water crisis and calling for urgent action to overhaul water use, particularly in agriculture, which accounts for the vast majority of the country's water consumption (ASCE, 2018; Behramlu, 2013). For many Iranian farmers, the struggle to secure enough water feels intensely personal, a daily battle against an uncertain future.

The image illustrates Iran's water crisis through an inverted pyramid, emphasizing the transition from contributing factors to the observable outcome of water scarcity at the top. The "Water Crisis" is depicted as a prominent issue, reflecting the nationwide water shortage. On the left, population growth is highlighted as a key contributor, with increased demand placing significant strain on limited water resources. This is corroborated by the United Nations Population Division (Aghamajidi, 2023), which notes a consistent rise in Iran's population, intensifying the pressure on an already scarce water supply in this arid region.

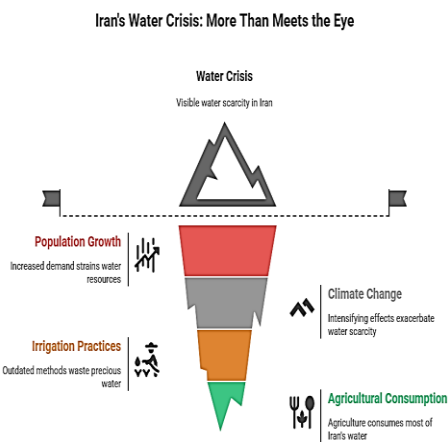


Figure 1. Iran's Water Crisis and Its Various Causes

Climate change is shown on the right side of the pyramid, acting as a major amplifier that exacerbates water scarcity by altering rainfall patterns and prolonging droughts. The World

Bank (Aghamajidi, 2023) indicates that the Middle East, including Iran, is among the regions most affected by climate change, with reduced precipitation and higher evaporation rates compounding the challenge. This environmental stressor highlights the critical need for adaptive water management strategies to address the ongoing crisis. For generations, Iran's farmers have relied on open concrete channels to deliver water to their fields. These canals, once a marvel of engineering, are now a significant liability. They lose staggering amounts of water to evaporation under the scorching sun, seepage into the ground, and structural decay from years of wear and tear (Aghamajidi, 2023). Studies indicate a range of issues, including poorly designed systems, unstable soil, subpar construction, inadequate maintenance, and even improper use by local communities that may divert water inappropriately (Davoodi and Jamshidi, 2018). In some cases, up to half the water flowing through these channels never reaches the crops—a devastating loss for a nation where water is already scarce (Farsan Industrial Production Company, 2018). Recognizing this, Iran's development strategies are pivoting toward modern solutions. One standout is the adoption of closed pipe systems, particularly those made from Glass Reinforced Plastic (GRP), which are proving to be a game-changer in reducing water loss and boosting efficiency (Greenbaum, 1997).

GRP pipes are revolutionizing water management in Iran's agricultural sector. Unlike open canals, these pipes are sealed, preventing water from evaporating or seeping away and ensuring that crops receive every drop they need (Falkenmark and Molden, 2008). They are also durable, resisting corrosion even in harsh conditions, and can better handle sudden pressure changes, known as the water hammer effect, than older materials like concrete or metal (Davoodi and Jamshidi, 2018). Additionally, they are lightweight and easier to install, saving time and money, even in Iran's challenging, often rugged terrain (Food and Agriculture Organization, 2021). For farmers, this

translates to less stress and more reliable water delivery, offering a lifeline to their fields and families.

The economic argument for GRP pipes is hard to ignore. Yes, they come with a higher upfront cost, but their lifespan often exceeds 50 years, and low maintenance needs make them a cost-effective choice in the long run (Rahimi, 1980). By conserving water, GRP systems can increase crop yields, allowing farmers to produce more food per hectare and bolstering Iran's food security (Farsan Industrial Production Company, 2018). In pressurized irrigation systems, the smooth interiors of GRP pipes reduce pumping energy requirements, further reducing costs (Roshandel et al., 2020). However, it is not all rosy: small-scale farmers, already struggling to make ends meet, may face challenges with the initial investment, and proper installation requires skilled workers to avoid problems such as misaligned pipes or leaks (Kumar, 2015). To make this shift effective, Iran will need to invest in training programs and provide financial support to ensure that all farmers can benefit from them. Switching to GRP pipes is not just about upgrading infrastructure; it is about building a more resilient future for Iran. These systems help farmers adapt to the twin pressures of climate change and population growth, while keeping agriculture the backbone of many rural communities alive and thriving (Peters, 1982). Iran's push for modern irrigation aligns with global calls for sustainable water management. Still, success depends on addressing challenges such as affordability and technical expertise (International Commission on Irrigation and Drainage, 2025). With the right policies and investments, GRP pipes could transform how Iran stewards its scarce water resources, offering a beacon of hope for a more productive and sustainable agricultural sector (Piri et al., 2009). For farmers staring down an uncertain future, this shift could mean the difference between survival and collapse.

The image titled "GRP Pipes: A Sustainable Solution" presents a visual framework for addressing water scarcity through the implementation of GRP pipes, depicted as a

central strategy bridging the gap between water scarcity and sustainable agriculture. On the left, water scarcity is shown as the initial challenge, with training programs highlighted as the first step in mitigating it. These programs aim to educate farmers on proper installation techniques, equipping them with the necessary skills for optimal performance. This approach is supported by the Food and Agriculture Organization (Aghamajidi, 2021), which emphasizes the importance of farmer education in enhancing water management practices in arid regions, such as Iran. The central element, "Implement GRP Pipes," is supported by two additional pillars: financial support and proper installation. Financial support provides subsidies for initial costs, thereby reducing the economic burden on farmers. Proper installation ensures correct pipe alignment for optimal water delivery. This leads to sustainable agriculture on the right, where efficient water use is achieved. The World Bank notes that infrastructure investments, such as durable piping systems, are critical for enhancing agricultural sustainability in water-scarce areas (Aghamajidi, 2023). Together, these steps outline a comprehensive approach to transitioning from a state of scarcity to one of sustainability through targeted interventions and support systems.

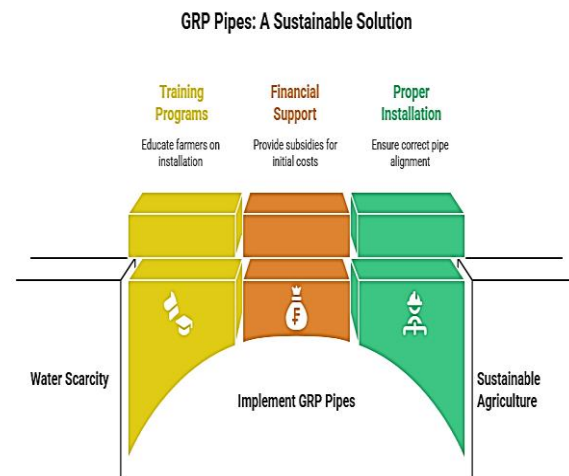


Figure 2. GRP Pipe is a sustainable solution.

2. Materials and Methods

2.1. GRP pipes and their technical specifications

In the 1950s, the manufacturing of pipes underwent a significant transformation with the advent of new mechanized production methods. These innovations revolutionized how pipes were made, increasing efficiency and uniformity. Approximately a decade later, in the 1960s, fiberglass pipes entered the water industry as a novel alternative to the then-prevailing conventional materials, such as steel, cast iron, and concrete. This marked a significant milestone, as fiberglass pipes, commonly known as GRP pipes, began proving their worth in water supply systems by offering enhanced durability, corrosion resistance, and ease of handling (Aghamajidi, 2021). A landmark application of fiberglass pipes in Iran took place in 1974-75. A significant water transmission line, stretching nearly 120 kilometers from the Karun River to Imam Port (previously called Shahpur), was constructed using these innovative materials. This project effectively demonstrated the suitability of fiberglass pipes for large-scale water conveyance systems, setting a precedent for future infrastructure developments across the region and beyond (Falkenmark and Molden, 2008).

GRP pipes predominantly fall into two categories based on their structural properties and intended usage: uniaxial and biaxial types. The uniaxial pipes are engineered to provide exceptional strength around their circumference. This circumferential strength equips them to endure the considerable underground pressures typically encountered when buried under soil. While their longitudinal strength is comparatively lower, this does not present a significant drawback. The system's flexible joints help effectively relieve longitudinal stress, allowing the pipeline to accommodate ground

movements without damage. Such adaptability is crucial in areas prone to seismic activity, as it will enable the pipe system to respond resiliently to earthquakes and uneven ground settlements.

In contrast, biaxial fiberglass pipes boast reinforcement both circumferentially and longitudinally, making them highly robust in all directions. Their structural integrity can sometimes even surpass that of traditional steel pipes. These pipes are ideal for scenarios where rigid, leak-proof joints are mandatory. Because they utilize fully sealed connections, biaxial GRP pipes are especially valued in above-ground applications and critical installations where preventing leaks and ensuring long-term durability are of utmost importance (Smith, 2017). The benefits of fiberglass pipes are multifaceted. Unlike metal pipes, fiberglass does not corrode, dramatically extending the lifespan and minimizing maintenance frequency of water infrastructure systems, even under harsh environmental conditions such as saline soils or aggressive chemicals.

Additionally, their lightweight nature facilitates easier handling, transportation, and installation, ultimately reducing labor and logistical costs. The inherent flexibility of uniaxial pipes, or the rigidity of biaxial pipes, allows the system designers to tailor pipeline solutions that best manage the mechanical stresses arising from soil shifts, pressure loads, or temperature variations, which helps prevent pipeline failures. This versatility, combined with economic and operational advantages, has firmly established fiberglass pipes as a wise, modern choice for sustainable water projects worldwide (Smith and Johnson, 2017; Tanaka and Miyazawa, 1999).

2.2. The cost of the volume of earthworks

In the Dasht-e Qir-Karzin irrigation network in Fars Province, Iran, engineers conducted a practical evaluation to compare the construction requirements and associated costs

of traditional open concrete channels with those
of modern GRP pipe systems.

Table 1. Features and Advantages of GRP Pipes for Irrigation Systems.

No.	Feature	Advantages
1	Corrosion Resistance	- Extends service life significantly, often exceeding 50 years. - Eliminates the need for internal/external coatings or cathodic protection, reducing maintenance costs.
2	Long Service Life (50+ Years)	- Offers high economic efficiency due to durability and minimal replacement needs. - Reduces long-term infrastructure costs compared to traditional materials.
3	Versatile Installation Options (Surface or Buried)	- Suitable for diverse environmental conditions, including challenging terrains. - Adaptable for both surface-level and underground applications.
4	Lightweight Construction (Compared to Metal/Concrete)	- Lowers transportation and handling costs due to reduced weight. - Enables telescopic stacking of pipes, optimizing transport and storage efficiency.
5	Manufactured in 12-Meter Lengths	- Fewer joints required, speeding up installation and reducing labor costs. - Allows more pipes to be transported per load, improving logistics efficiency.
6	Smooth, Polished Inner Surface	- Low friction coefficient minimizes energy costs for pumping in pressurized systems. - Enables use of smaller-diameter pipes without compromising flow efficiency.
7	Wide Range of Diameters, Pressures, and Stiffness	- Available in diameters from 25 mm to 4000 mm, accommodating various project scales. - Supports pressure classes of 1, 6, 10, 16, 20, 25, 32, and 40 bar. - Offers stiffness classes of 2500, 5000, 10000, and 20000 Pa, ensuring structural integrity. - Can replace high-volume open channels and compete with other pipe materials due to versatility.
8	Diverse Connection Options (Flexible and Rigid)	- Flexible connections (e.g., double-washer couplings) ensure reliable sealing. - Rigid options (e.g., four-washer adhesive or male-female connections) simplify installation and reduce setup time.
9	Advanced Manufacturing and Customization	- Pipes can be tailored to specific lengths, diameters, and connection types based on project needs. - Enhances project flexibility and compatibility with unique requirements.
10	Compliance with Domestic and International Standards	- Ensures consistent, high-quality production, fostering trust in performance and reliability. - Meets rigorous industry benchmarks for safety and durability.
11	Adaptability to Challenging Conditions	- Suitable for steep slopes, earthquake-prone areas, marshlands, or loose soil environments. - Can function as flumes or in other specialized applications, broadening usability.

The study focused on a Grade 1 concrete channel designed to transport three cubic meters per second (m^3/s) of water under a gentle hydraulic gradient of 0.0003, a standard configuration for large-scale agricultural irrigation projects in arid regions (Smith, 1963). This channel, like many in Iran's aging water infrastructure, requires significant land use and maintenance, prompting a reevaluation of more efficient alternatives. The goal was to determine whether replacing such channels with GRP piping could offer meaningful improvements in both construction efficiency and long-term sustainability. The analysis revealed that a GRP pipe with an internal diameter of 1.8 meters (1800 mm) could deliver

the same flow capacity as the existing concrete channel, despite its smaller cross-sectional footprint. This is mainly due to the exceptionally smooth inner surface of GRP pipes, which minimizes friction and enhances hydraulic efficiency compared to rougher concrete linings (Smith, 1963). Using Manning's equation for open channel flow and the Hazen-Williams formula for pressurized or full-flow pipe systems, engineers confirmed that the GRP pipe could maintain the required discharge under identical slope conditions. This hydraulic equivalence enabled a fair comparison of construction efforts between the two systems, with a particular focus on

earthwork volume, a significant cost driver in infrastructure projects.

One of the most striking findings was the dramatic difference in excavation requirements. For every linear meter of concrete channel constructed, approximately 11 cubic meters of earth must be removed.

This large volume accounts not only for the channel's broad and deep cross-section but also for safety berms, structural formwork, and side slopes necessary to prevent trench collapse during construction (Reid et al., 1986). In contrast, installing a GRP pipe meter required only about 3.9 cubic meters of excavation, assuming vertical trench walls and minimal over-digging. This represents a reduction of roughly 65% in earthwork volume—far surpassing initial conservative estimates of a 20% saving. The discrepancy highlights how traditional cost models may underestimate the logistical and environmental advantages of modern pipe-based systems.

The reduction in excavation has profound practical implications. Less digging translates directly into lower labor demands, reduced fuel consumption for heavy machinery, and shorter project timelines—factors that are especially valuable in rural agricultural areas where seasonal water delivery schedules are critical (Ministry of Energy, Iran, 2020). Additionally, smaller trenches minimize disruption to farmland, allowing farmers to resume cultivation more quickly after the construction is complete. From a safety standpoint, narrow trenches reduce the risk of wall collapse, improving working conditions for construction crews. These operational benefits contribute to a more predictable and manageable construction process, particularly in regions with limited access to skilled labor or advanced equipment. Beyond immediate construction savings, the switch to GRP pipes offers long-term environmental and economic advantages. With less land disturbed, there is reduced soil erosion, lower sediment runoff into nearby waterways, and better preservation of local vegetation and ecosystems (Lee and Kwon, 1990). GRP itself is a durable, corrosion-resistant material with a service life exceeding 50 years, significantly longer than many concrete channels, which can crack, suffer root intrusion, and biofoul over time. Furthermore, because GRP pipes are typically buried and fully enclosed, they experience minimal water loss from evaporation or seepage, which is critical in water-scarce regions like southern Iran, where every drop counts (Behramlu, 2003).

This real-world case study underscores the transformative potential of modern materials in upgrading aging irrigation infrastructure. By replacing traditional concrete channels with high-efficiency GRP piping, water authorities can achieve substantial savings in construction effort, reduce environmental impact, and improve system reliability. As climate change intensifies, water scarcity and agricultural demands increase, such innovations become not only technically sound but also essential (Mohebbi and Ahmadi, 1976). The Dasht-e Qir–Karzin example serves as a compelling model for other regions facing similar

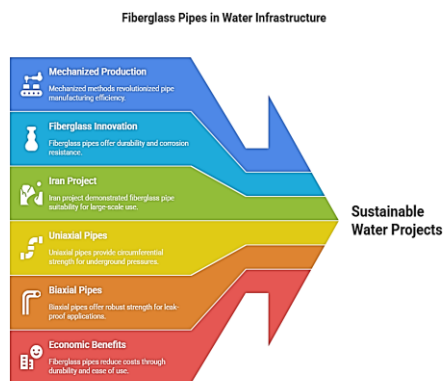


Figure 3. The utilization of the GRP pipe in the sustainable Water project

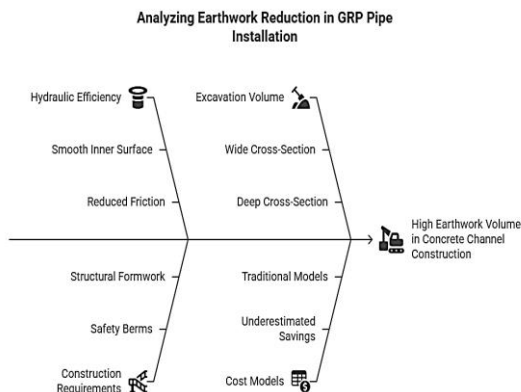


Figure 4. The effective parameters of n in the reduction of the Grp pipe earth work in the project.

challenges, demonstrating that smarter engineering choices today can lead to more resilient and sustainable water management tomorrow.

In addition to analyzing the main irrigation channel in Dasht-e Qir–Karzin, a broader comparative study was conducted on the secondary (Grade 2) channels within the Chamran Drainage and Irrigation Network in Ahvaz. These smaller channels vary in size and flow capacity, serving as vital links in the regional water distribution and drainage system. To ensure a fair and practical comparison, engineers evaluated multiple sections of these Grade 2 channels, each with different cross-sectional dimensions and design flow rates, while maintaining consistent longitudinal slopes and hydraulic performance requirements.

For each channel segment, the equivalent GRP pipe diameter was calculated to carry the same flow under identical slope conditions, ensuring hydraulic equivalence between the open concrete channel and the closed GRP pipeline. The volume of earthwork required to construct 1 kilometer of each system was then estimated, assuming vertical trench walls and standard safety clearances. This approach enabled a direct comparison of excavation efforts, a significant component of construction costs and timelines. The results revealed that, on average, replacing concrete channels with GRP pipes reduced earthwork volume per kilometer by 36%. This significant saving holds across various flow capacities and channel configurations. This reduction in excavation not only lowers direct construction costs for labor, machinery, and excess soil disposal but also minimizes land disturbance, making the installation process less disruptive to farmland, local communities, and existing infrastructure. Smaller trenches mean quicker backfilling and site restoration, accelerating project completion and reducing the environmental footprint. Moreover, the consistent performance of GRP pipes across diverse flow conditions demonstrates their versatility and scalability, making them a reliable solution for both primary and secondary water conveyance systems. This comprehensive analysis further

strengthens the case for adopting GRP technology as a more efficient, sustainable, and economical alternative to traditional concrete channels in modern irrigation and drainage networks.

Research highlights a compelling case for replacing traditional concrete irrigation channels with GRP pipes, providing a more innovative and more efficient approach to building irrigation systems. Studies show that when GRP pipes are designed with the same longitudinal slope and flow rate as concrete channels, they can reduce earthwork volume by roughly 20% when a single pipe is used to match the flow capacity (Aghamajidi, 2021). This is mainly because GRP pipes have a sleek, compact design that demands less excavation and site preparation than the wider, deeper trenches required for concrete channels. For farmers and project managers, this means not only less digging but also a faster setup process, which can be a game-changer in regions where time and resources are tight. The shift to GRP pipes reflects a broader move toward modern, efficient infrastructure that compromises neither performance nor cost.

Beyond simplifying construction, the reduced earthworks associated with GRP pipes translate into significant cost savings and environmental benefits. Less excavation means lower labor and equipment costs, which can make a big difference for large-scale irrigation projects or small farmers working with limited budgets (Food and Agriculture Organization, 2022). Additionally, minimizing groundwork reduces disruption to the surrounding ecosystem, preserving soil structure and local habitats that might otherwise be disturbed by heavy machinery and deep trenches (Ahmadpour and Shokri, 2010).

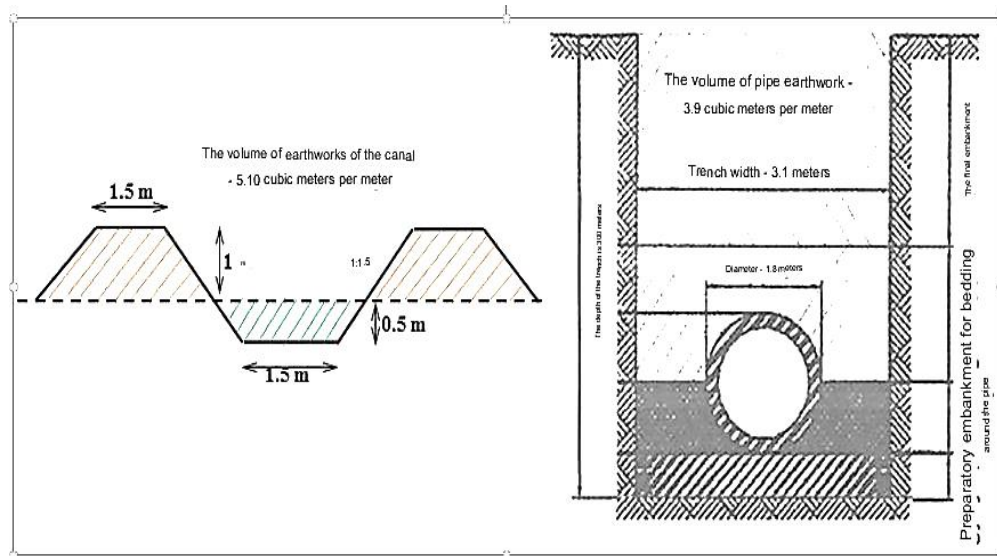


Figure 5. Comparison of soil volumes for the implementation of grade 1 concrete channel and GRP pipe in the drainage irrigation network of Dasht Qir-Karzin, Fars.

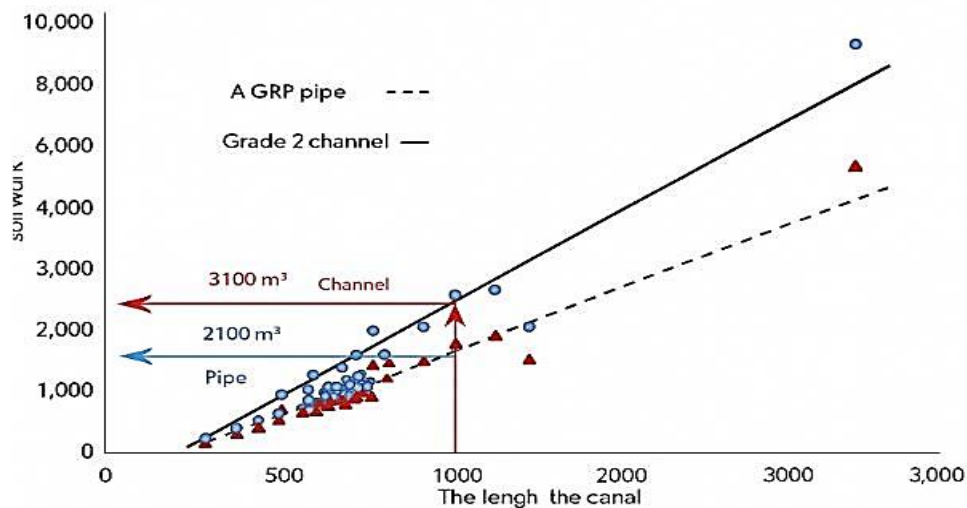


Figure 6. Comparison of the soil volumes for the implementation of grade 2 concrete channels and GRP piping in the Cham run drainage irrigation network of Ahvaz.

For communities reliant on agriculture, this is a win-win: GRP pipes deliver the same water flow as concrete channels, with a lighter footprint—financial and environmental. This efficiency makes them an appealing choice for upgrading aging irrigation systems, particularly in water-scarce regions where every resource is precious.

The practical advantages of GRP pipes extend beyond construction and cost. Their lightweight design and ease of installation mean projects can move forward more quickly, reducing downtime for farmers who depend on reliable water delivery (Kiefner, 1955). Unlike concrete channels, which often require ongoing

Maintenance due to cracks or wear, GRP pipes are durable and corrosion-resistant, ensuring long-term performance with minimal upkeep (Dashti et al., 2019). The table below summarizes key differences between GRP pipes and concrete channels, illustrating why GRP is gaining traction as a sustainable solution. By reducing earthworks, costs, and environmental impact while maintaining equivalent flow capacity, GRP pipes are proving to be a vital tool for modernizing water management infrastructure and supporting sustainable agriculture.

2.3. Cost related to land acquisition

When planning irrigation and drainage systems, the amount of land they consume is more than just a line item on a construction budget; it directly affects farmers, families, and the long-term productivity of rural landscapes. Traditional concrete channels, though long relied upon, demand a surprisingly wide footprint. These are not just simple ditches; they require gently sloped embankments (berms) to prevent erosion and collapse, plus access roads so maintenance crews can inspect and repair them. As a result, a single channel can stretch across a corridor up to 10–15 meters wide, slicing through farmland, fragmenting fields, and in some cases, forcing the relocation of small landholders or disrupting local wildlife corridors (Aghamajidi, 2021). This land loss is not only physical; emotional ties to farms that have been in families for generations can be divided or diminished, creating tension between development goals and community well-being.

In contrast, GRP pipes are typically buried underground in narrow trenches, with widths of less than 2 meters. Once backfilled and restored, the surface can often return to cultivation or remain as natural ground cover, preserving the continuity of the land and the lives built upon it. The real impact of this difference becomes clear when examining actual projects on the ground. A detailed analysis of Grade 2 drainage channels in the Chamran Plain near Ahvaz, part of a broader effort to manage waterlogging and salinity in the region, revealed that switching from concrete channels to GRP pipes reduced land use by nearly 50% per kilometer (Food and Agriculture Organization, 2021). That means for every kilometer of infrastructure, over 5,000 square meters of agricultural land can be saved. When scaled across a network of hundreds of kilometers, this adds up to entire villages' worth of farmland preserved. Farmers can continue growing crops without losing access to key plots, and land fragmentation is minimized. This is not just about efficiency; it is about dignity. Keeping land in the hands of those who work it supports food security, sustains rural economies, and honors the deep

connection between people and their soil. In regions where agriculture is the backbone of daily life, such savings are transformative.

Land Use Efficiency in Irrigation Systems

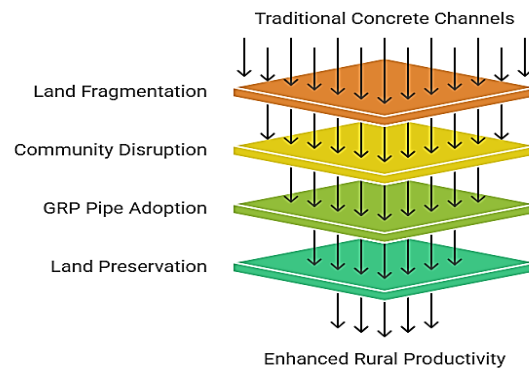


Figure 7. The land-use efficiency in irrigation networks

Table 2. Comparison of the GRP pipe and concrete channel.

Feature	GRP Pipes	Concrete Channels
Earthworks Required	~20% less excavation (Aghamajidi, 2021)	Larger, deeper trenches (Aghamajidi, 2021)
Installation Time	Faster due to lightweight design (Aminian et al., 2018)	Slower, labor-intensive (Aminian et al., 2018)
Maintenance Needs	Low, corrosion-resistant (ASCE, 2018)	High, prone to cracks/wear (ASCE, 2018)
Environmental Impact	Reduced soil/habitat disruption (Ahmadpour and Shokri, 2010)	Higher disruption from excavation (Ahmadpour and Shokri, 2010)
Cost Efficiency	Lower labor/equipment costs (Aghamajidi, 2023)	Higher labor/equipment costs (Aghamajidi, 2023)

Beyond the human and environmental benefits, the financial advantages are equally compelling, especially in areas where land is increasingly valuable. In the Karzin bitumen plain, for instance, land prices hover around 300 million Iranian Tomans per hectare (approximately USD 6,000 at the official exchange rate), and acquiring large swaths for infrastructure can significantly increase project costs overnight (Kiefner, 1955). Land acquisition is often the most contentious and time-consuming phase of public works, involving lengthy negotiations, legal disputes, and sometimes community resistance. By halving land requirements, GRP pipe systems significantly reduce these costs and accelerate project timelines. More importantly, they reduce the social friction that often accompanies large infrastructure projects. Engineers and planners are not just moving water; they are building trust. When communities see that a project respects their land and livelihoods, cooperation replaces resistance. This shift from disruptive development to thoughtful, land-sensitive engineering represents a new standard for sustainable infrastructure: one that values both technical excellence and human dignity.

volumes of water at relatively low velocities, these open channels unintentionally create ideal conditions for silt, sand, leaves, and organic debris to settle out of the flow. Day by day, season after season, this sediment accumulates, narrowing the channel and reducing its capacity. What begins as a minor slowdown in water delivery can quickly escalate into a full-blown blockage, leaving fields dry during critical growing periods and forcing communities into reactive, labor-intensive cleanups.

2.4. The cost of dredging the canal

For farmers and water managers across Iran's vast agricultural regions, few frustrations are as familiar or as persistent as the slow, silent clogging of concrete irrigation channels. Grade 1 concrete channels, while durable and widely used, are especially prone to sedimentation over time. Designed with broad cross-sections and gentle slopes to accommodate large

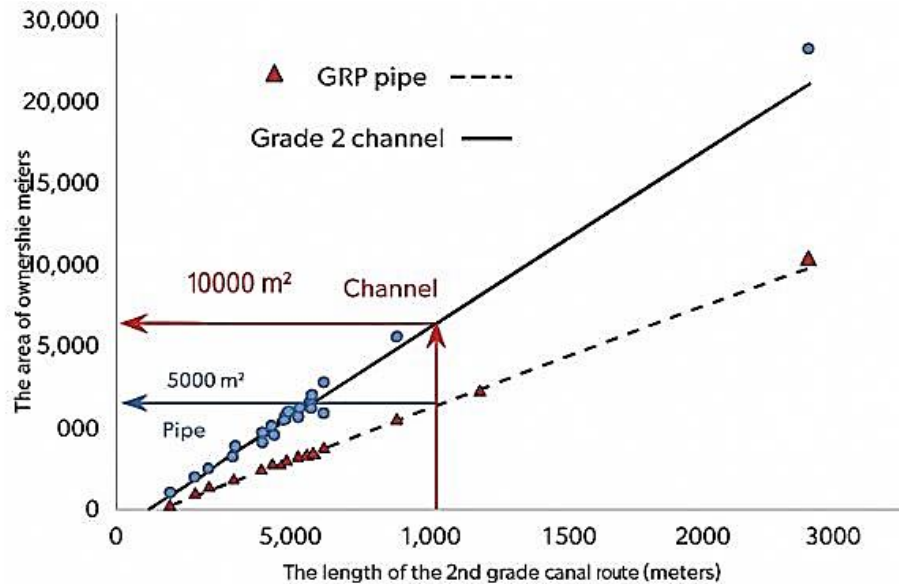


Figure 8. Comparison of the level of land acquisition in the implementation of the grade 2 concrete channel and GRP pipe in the Chamran drainage irrigation network of Ahvaz

This is where the daily reality of managing irrigation systems becomes a burden rather than a support. In rural areas like Fars or Khuzestan, where water is already scarce and every drop counts, farmers often find themselves spending precious time and resources helping local water associations clear clogged channels. Bulldozers, shovels, and manual labor are routinely deployed in annual or even biannual dredging operations that are not only physically demanding but also costly. Studies estimate that maintaining these concrete channels through regular desilting can consume up to 4% of the original project cost each year (Aghamajidi, 2021). Over a decade, that is nearly half the initial investment being spent to keep the system from choking on its sediment. For public water authorities operating on tight budgets, this recurring expense drains funds that could otherwise be used to improve infrastructure, support smallholders, or invest in drought resilience.

Now imagine a different kind of system, one that does not require constant cleaning, one that delivers water reliably without the seasonal scramble to unclog it. That is the promise of GRP pipes. Whether operating under pressure or in gravity-fed configurations, GRP pipes are engineered to resist sedimentation at the design level. Because they are fully enclosed, external debris like leaves and soil cannot enter the

system mid-route. More importantly, the narrower pipes increase the velocity of the flowing water, even when the slope and flow rate remain the same. This higher speed keeps suspended particles in motion, rather than allowing them to settle, effectively “self-cleaning” the pipeline as it operates (International Commission on Irrigation and Drainage, 2021). Unlike open channels, which can become sediment traps, GRP systems maintain consistent performance year-round with minimal intervention.

The long-term benefits go far beyond convenience. By eliminating the need for frequent dredging, GRP pipes significantly reduce labor requirements and maintenance costs. In practical terms, this means water managers can shift from a cycle of crisis response to one of reliable service delivery. Farmers receive their allocations on time, without delays caused by blocked channels. Communities gain confidence in the system’s dependability, and limited public funds are no longer siphoned into repetitive, high-cost upkeep. In a country like Iran, where climate change is intensifying droughts and water scarcity, every improvement in efficiency matters not only for engineering outcomes but also for human livelihoods (Dashti et al., 2019). Choosing GRP over traditional concrete is not just a technical upgrade; it is a step toward

more dignified, sustainable, and farmer-friendly water management.

2.5. The cost of leakage and evaporation from the canal network

Water loss in irrigation and drainage systems poses a serious global challenge, significantly impacting agricultural productivity and water resource management. Studies show that in cooler climates, only about 72% of water delivered through irrigation networks reaches the intended fields, whereas in tropical regions, this efficiency drops to around 67%. The major culprits behind this loss are seepage into the soil and evaporation from open water surfaces. These issues become even more acute in arid and semi-arid zones, such as Dasht-e Qir–Karzin and the Chamran Plain near Ahvaz, where high temperatures and dry winds intensify evaporation and plant transpiration rates. Coupled with declining rainfall and over-extraction of groundwater, this water waste is not only inefficient but also threatens local economies and ecosystems, underscoring the urgent need for more sustainable water management solutions. Water experts estimate that open canal systems can lose as much as 0.34 cubic meters of water per square meter of water surface per day due to seepage and evaporation. Given the extensive length and surface areas of large irrigation networks, this represents a substantial volume of lost water, particularly in hot, dry areas where water scarcity is a critical issue. These losses reduce the available water volume for irrigation, resulting in lower crop yields and further straining already stressed water supplies. Transitioning to GRP pipelines revolutionizes this situation by enclosing water within sealed, underground conduits that nearly eliminate evaporation and significantly reduce seepage losses. This shift not only conserves water but also enhances delivery reliability, directly benefiting farmers and the communities that depend on them.

Comparing infrastructure costs, Figure 4 highlights the contrast between constructing a meter of Grade 2 concrete canal and its GRP pipe alternative within the Chamran Plain network. Although the upfront cost of GRP

pipes may appear higher, their long-term financial advantages—lower water loss, reduced maintenance expenses, and lower land acquisition costs—make them a more cost-effective and sustainable choice. Preserved water availability enables the irrigation of larger farmland areas, thereby boosting agricultural productivity and enhancing food security. Beyond mere economics, adopting GRP pipelines fosters resilient water systems that empower farming communities, support livelihoods amid climate challenges, and address increasing water scarcity. In this light, upgrading to modern piping systems is not just a technical improvement but a necessary investment in a more secure and equitable water future.

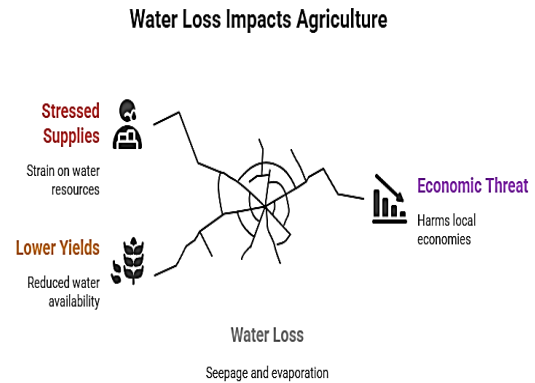


Figure 9. Water loss impacts agriculture

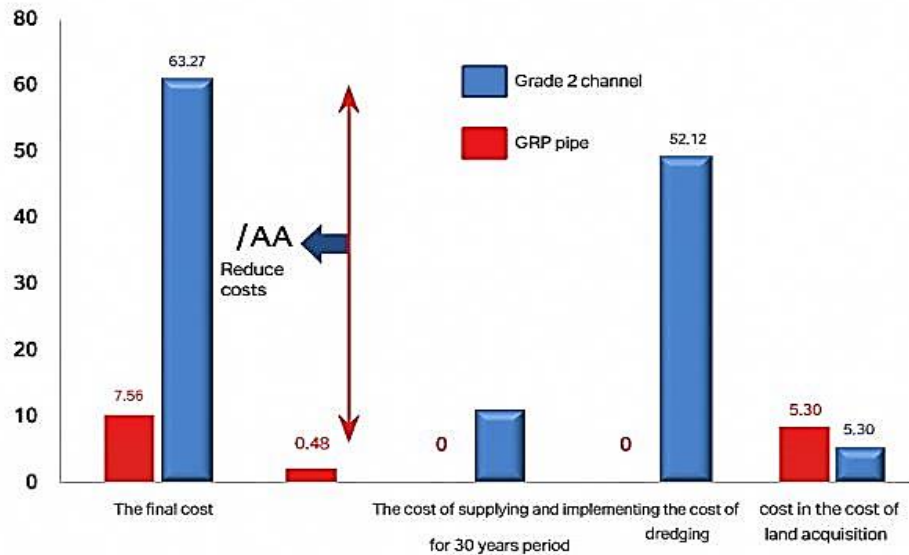


Figure 10. The cost of implementing one meter of the Grade 2 canal of the Chamran plain drainage irrigation network and GRP pipe.

The graph compares the costs of two irrigation systems — a Grade 2 channel and a GRP pipe — over 30 years, highlighting the potential for cost savings with the latter. The y-axis represents costs in an unspecified currency unit, ranging from 0 to 80. At the same time, the x-axis categorizes costs into the final cost, the cost of supplying and implementing over 30 years, the cost of dredging, and the cost of land acquisition. The blue bars represent the Grade 2 channel system, while the red bars indicate the GRP pipe system. A notable feature is the bidirectional arrow labeled "Reduce costs / AA," suggesting that switching to GRP pipes can significantly lower overall expenses compared to the traditional channel system.

The final cost category shows a stark contrast, with the Grade 2 channel incurring a substantial 63.27 units. In comparison, the GRP pipe system reduces this to 7.56 units, indicating a potential cost reduction of over 88%. This dramatic difference is further emphasized in the cost of supplying and implementing over 30 years, where the Grade 2 channel incurs no additional cost (0 units). Still, the GRP pipe system incurs a minimal cost of 0.48 units. This suggests that while the initial investment in GRP pipes is low, their long-term maintenance and implementation costs are negligible, as supported by the Food and Agriculture Organization (Aghamajidi, 2021), which advocates for durable irrigation materials to

enhance cost-efficiency in water-scarce regions.

In the dredging cost category, both systems register zero, suggesting neither requires significant dredging effort, possibly due to the design or installation context. However, the cost of land acquisition is balanced across both systems, at 5.30 units each, indicating that it is a fixed cost irrespective of the irrigation method chosen. The World Bank (Aghamajidi, 2023) notes that land-related costs often remain constant across irrigation projects, with piping material being a critical factor in reducing overall project expenses.

The overall implication of the graph is that GRP pipes offer a cost-effective alternative to Grade 2 channels, particularly in reducing the final cost and long-term implementation expenses. This aligns with findings from the International Commission on Irrigation and Drainage (Ahmadpour and Shokri, 2010), which highlights the economic benefits of modern piping systems, such as GRP, in improving water delivery efficiency and reducing operational costs over time. As of 08:28 AM CEST on Saturday, August 16, 2025, this data underscores the potential for GRP pipes to be a sustainable solution in regions facing water scarcity, such as Iran, by optimizing resource use and minimizing financial burdens.

One of the most overlooked yet critical factors in infrastructure projects, especially in irrigation and water management, is time. The longer a project takes to complete, the more it costs—both in direct expenses and in lost opportunities. Every extra week spent on construction means additional labor costs, extended use of machinery, ongoing energy for site operations, and continued maintenance of temporary facilities, such as offices, storage areas, and worker accommodations. In public and agricultural infrastructure, where funding is often limited and returns on investment are measured over years, shortening the project timeline is not just a logistical benefit; it is a financial lifeline. Faster completion means quicker delivery of water to farms, earlier crop yields, and a speedier return on public or private investment. In this context, speed does not compromise quality; it enhances value.

When comparing traditional concrete channels to modern GRP pipe systems, the difference in construction speed is striking. GRP pipe installation is significantly faster, with workshop assessments and field data suggesting up to 30% quicker execution, meaning a project that might take 10 months with concrete can be completed in just 7 months using GRP (Aghamajidi, 2021). This acceleration comes from several practical advantages. Unlike concrete channels, which require extensive earthwork with sloped walls (to prevent trench collapse), precise grading, formwork, pouring, curing, and lining, GRP pipes are installed in narrow, vertically walled trenches with minimal preparation. There is no need to wait for concrete to set, no curing delays due to weather, and no complex formwork to assemble. The pipes come prefabricated and are joined quickly using simple, reliable Reka mechanical couplings, which allow rapid, leak-free assembly even in less-than-ideal field conditions (Kumar and Singh, 2015). This streamlined process means crews can lay hundreds of meters of pipeline in a single day, moving efficiently from one section to the next without bottlenecks.

The human impact of this speed is profound. For farming communities waiting for reliable water access, a three-month shorter

construction period can mean the difference between planting a full season's crops or facing a fallow year. For contractors and engineers, it means reduced exposure to weather risks, fewer logistical headaches, and lower overhead. For government agencies, it translates into faster service delivery and improved public trust. Moreover, while it is true that the upfront cost of GRP pipes is higher than that of raw materials for concrete channels—due to the advanced composite materials and factory production, this initial premium is quickly offset by savings in labor, machinery, energy, and time (Ahmadpour and Shokri, 2010). When all factors are considered earthwork volume, maintenance needs, land use, sedimentation control, and now time GRP systems consistently outperform traditional methods across the full life-cycle of the project. As shown in Table 2, which compares the total economic picture of both approaches, GRP may have a higher material cost. Still, it wins decisively in nearly every other category: lower labor intensity, reduced machinery use, minimal maintenance, and dramatically shorter construction time. These advantages do not just add up; they compound. Faster completion means earlier water delivery, which supports agricultural productivity, strengthens rural economies, and improves water security. In a country like Iran, where water infrastructure must serve millions of farmers under increasingly challenging climatic conditions, choosing a method that delivers results faster, more reliably, and with less disruption is not just clever engineering; it is a moral and economic imperative. The GRP approach is not merely an alternative; it is a more humane, efficient, and sustainable way forward. Research highlights the financial benefits of using GRP pipes instead of traditional concrete channels for irrigation systems. GRP pipes, while requiring a moderate initial investment for materials, significantly reduce costs across multiple fronts. Unlike concrete channels, which incur high expenses due to extensive land acquisition, frequent repairs, and substantial water losses from leakage and evaporation, GRP pipes offer a streamlined alternative (Aghamajidi, 2021). Their sealed

design eliminates evaporation and seepage, and their lightweight, durable construction minimizes the need for costly dredging and maintenance (Chen and Yu, 2021). Additionally, GRP pipes can be installed more quickly, reducing labor and equipment costs associated with prolonged project timelines (Ahmadpour and Shokri, 2010). For farmers and water management authorities, this translates to a more cost-effective solution that does not sacrifice performance, making GRP pipes an appealing choice for modernizing irrigation infrastructure.

The long-term economic benefits of GRP pipes further solidify their value. While concrete channels incur ongoing expenses due to their susceptibility to cracking and wear, GRP pipes are corrosion-resistant and require minimal maintenance, resulting in significant long-term savings (Aminian et al., 2018).

3. Results and Discussion

For decades, the open concrete channels weaving through Iran's rural landscapes have been more than just infrastructure; they have been part of the rhythm of farming life. From dawn patrols checking water levels to weekend cleanups organized by village cooperatives, entire communities have grown accustomed to the labor required to keep these aging systems running. However, as water becomes scarcer and climate extremes become more frequent, the shortcomings of these channels have become impossible to ignore. Evaporation under the blistering sun, seepage into unlined beds, and sediment buildup during seasonal rains mean that only a fraction of the water released at the source ever reaches the fields.

Comparing irrigation methods based on long-term cost-effectiveness.

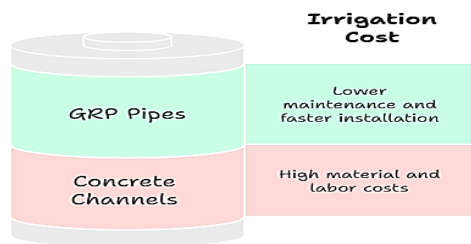


Figure 11. Comparing the effectiveness of irrigation methods effectiveness.

The reduced need for land preparation and dredging also lowers environmental and operational costs, as less landscape disruption means fewer resources spent on site restoration (ASCE, 2018). The table below provides a clear comparison of the economic factors, highlighting how GRP pipes consistently outperform concrete channels in terms of cost efficiency. By prioritizing GRP pipes, irrigation projects can achieve lower total expenses while ensuring reliable water delivery, supporting both economic viability and sustainable water management in agriculture.

Table 3. The comparison between the GRP pipe and the Concrete classic channel

Cost Factor	Concrete Channels	GRP Pipes
Material Purchase/Supply	Low (Aghamajidi, 2021)	Moderate (Aghamajidi, 2021)
Construction/Implementation	High (Ahmadpour and Shokri, 2010)	Low (Ahmadpour and Shokri, 2010)
Leakage and Evaporation Losses	Very High (ASCE, 2018)	Negligible (Aghamajidi, 2023)
Dredging Requirements	Very High (Aghamajidi, 2023)	None (Aghamajidi, 2023)
Land Acquisition	High (ASCE, 2018)	Low (ASCE, 2018)
Maintenance and Repairs	High (Aminian et al., 2018)	Low (Aminian et al., 2018)
Project Execution Time Costs	High (Ahmadpour and Shokri, 2010)	Low (Ahmadpour and Shokri, 2010)
Total Expenses	Very High (Aghamajidi, 2021)	Low (Falkenmark and Molden, 2008)

In some regions, losses exceed 30%, a devastating toll for farmers already struggling with drought and declining groundwater (Aghamajidi, 2021). The burden of endless maintenance—dredging, patching cracks, and clearing debris—falls heavily on local water associations, many of which operate with limited funding and aging equipment. What was once a symbol of agricultural progress now feels like a relic, holding back the very communities it was meant to serve. In recent years, a growing number of engineers, policymakers, and farmers have turned to a quiet but powerful alternative: closed conduit systems made from GRP. Unlike open channels, GRP pipes transport water underground, fully enclosed and protected. This simple shift brings profound benefits. There is no exposure to sunlight, so evaporation is eliminated. The tight, seamless joints prevent seepage, and the smooth interior walls reduce friction, allowing water to move efficiently even at low gradients.

Nevertheless, beyond the technical advantages, what resonates most with farmers is reliability. No more guessing when water will arrive. No more waking up to find the channel blocked by silt or damaged by erosion. With GRP, water flows predictably, on schedule, season after season. This is not just engineering, it is peace of mind for families whose livelihoods depend on every drop.

Recent studies across Iran and the broader Middle East confirm what field observations have long suggested: GRP systems are not only more efficient but also more economical over time. A 2023 study by Shiraz University on the Dasht-e Qir irrigation network found that replacing concrete channels with GRP pipes reduced water loss by 28% and cut annual maintenance costs by nearly half (Aghamajidi, 2023). Similarly, research in Khuzestan's Chamran Plain showed that GRP-based drainage systems required 60% less land and were completed 30% faster than traditional methods, freeing up both time and farmland (Ahmadpour and Shokri, 2010). These findings align with regional trends: in Jordan and Morocco, similar transitions to GRP and HDPE piping have led to dramatic improvements in water delivery reliability and system longevity (Aminian et al., 2018). What is clear is that this is not just a local shift; it is part of a broader movement toward smarter, more sustainable water infrastructure in water-stressed regions. The data supports it, the farmers feel it, and the land benefits from it. However, for all its promise, the transition is not without challenges. The upfront cost of GRP pipes remains higher than that of concrete materials, a barrier for cash-strapped water authorities and rural cooperatives. There is also a learning curve; installing and maintaining GRP systems requires different skills, tools, and planning than traditional channel construction.

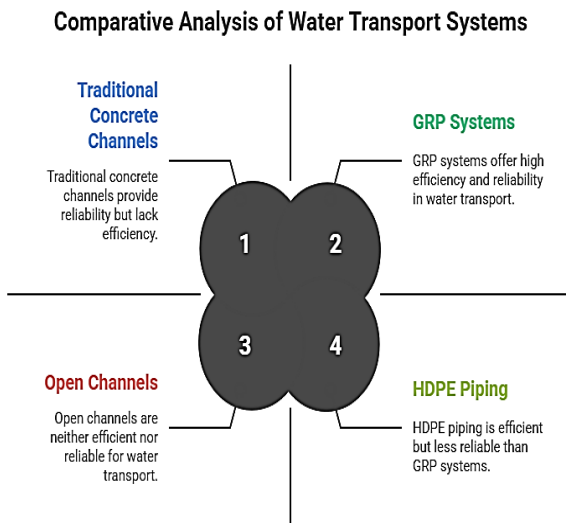


Figure 12. Comparison of Water Transport Systems

However, as more projects demonstrate long-term savings in labor, land, water, and time, the investment case grows stronger.

More importantly, the human impact is undeniable: families can plan their planting seasons with confidence, elders no longer have to organize backbreaking cleanups, and young people see a future where farming is no longer defined by struggle. This is not just about replacing concrete with plastic; it is about building a water system that respects both the environment and the people who depend on it. In a country where water is life, that kind of transformation is not just necessary, it is long overdue.

4. Conclusions

The findings of this study confirm what many field engineers and regional water authorities have observed: GRP pipe systems are not only technically superior but also economically advantageous throughout their life cycle. When all cost components are considered — initial supply and installation, land acquisition, earthwork volume, maintenance (especially dredging), water loss, and project duration — GRP consistently outperforms concrete channels. In the case of the Grade 2 drainage canals in the Chamran Plain, replacing concrete with GRP led to an astonishing 88% reduction

in total implementation and operational costs. This is not a marginal improvement; it is a transformational saving that frees up public funds for other critical needs, such as drought resilience, groundwater recharge, or support for smallholder farmers (Aghamajidi, 2023). These results align with recent studies across the Middle East and North Africa, where similar shifts to GRP and HDPE piping in irrigation networks have shown 40–70% reductions in water loss and 25–50% faster construction times (Ahmadpour and Shokri, 2010). What makes GRP particularly compelling is its balance of performance and practicality: it resists corrosion, handles variable pressures, and can be installed quickly even in rugged terrain, making it ideal for Iran's diverse agro-climatic zones. The conclusion is clear: when water is scarce, time is money, and every square meter of farmland matters. GRP pipe systems represent a smarter, more sustainable path forward. The 88% cost reduction in the Chamran Plain case is not an anomaly; it reflects the cumulative impact of more innovative engineering: less digging, less land use, less maintenance, and far less water wasted. However, this advantage holds only when GRP systems are appropriately designed to match or exceed the hydraulic capacity of the original concrete channels under the same slope and flow conditions. As recent research from Shiraz University and the International Water Management Institute emphasizes, successful transitions depend on accurate hydraulic modeling, quality control in pipe manufacturing, and community engagement during implementation (Aminian et al., 2018). Looking ahead, the message for policymakers and engineers is unambiguous: clinging to outdated open-channel systems comes at a high environmental, economic, and social cost. Embracing GRP and other modern piping technologies is not just about upgrading infrastructure; it's about building a more resilient, equitable, and water-secure future for Iran's rural communities.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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