# WATER WATER EVERYWHERE FOR LOTS OF DROPS TO DRINK:

## THE RIME OF THE FUTURE ENGINEER

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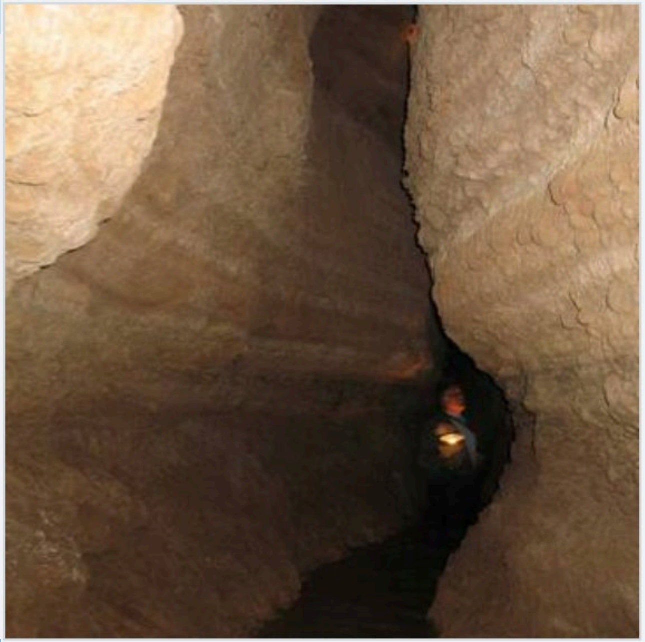
**WATER FORUM 2026**
**UH ENERGY**

# FROM THE BEGINNING OF TIME

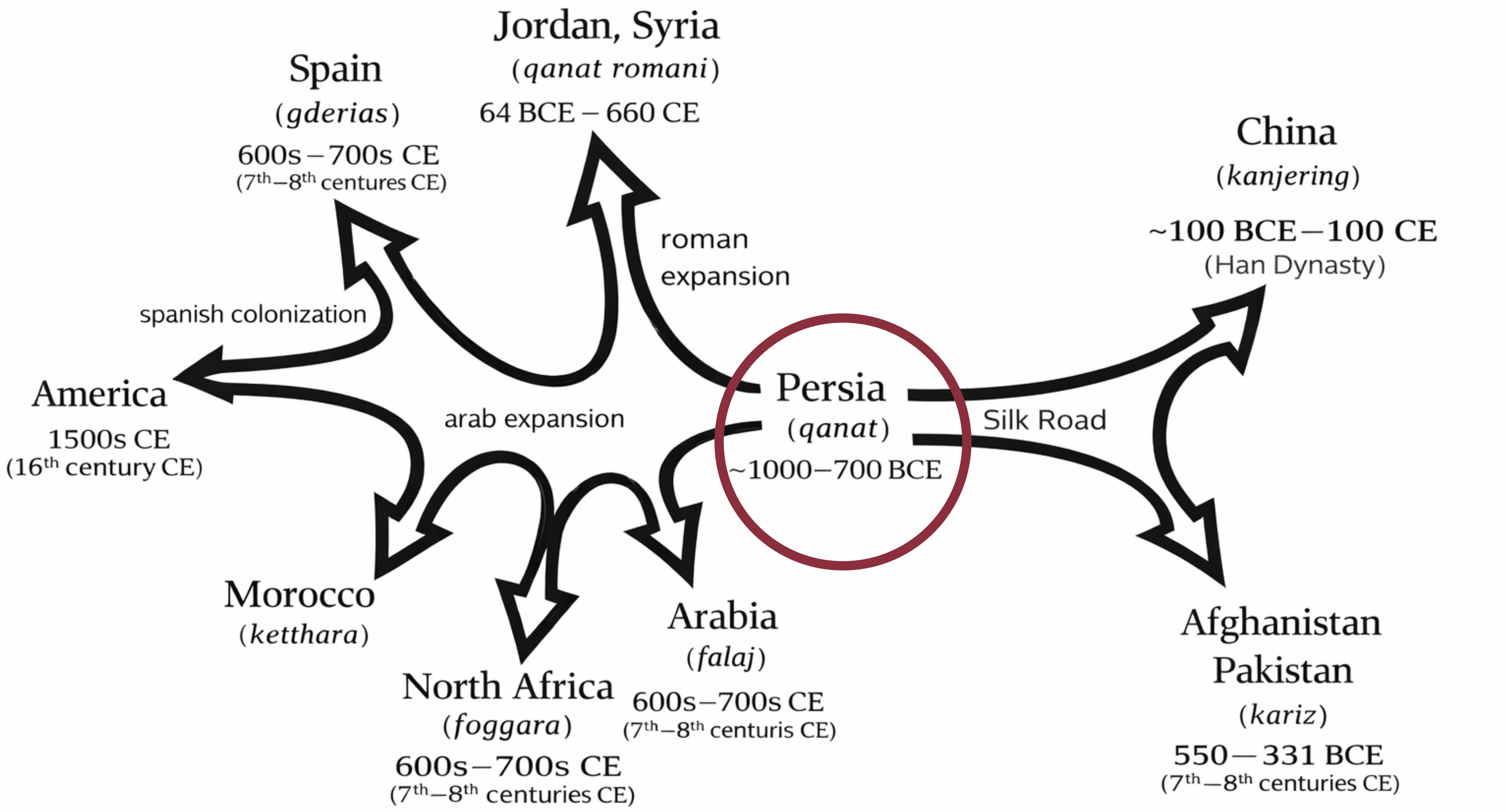
- HUMANS HAVE RECOGNIZED THE IMPORTANCE OF WATER AND HARNESSED ITS CONVEYANCE
- THE PERSIAN **QANATS** (550 – 331 BC):

  ***A MARVEL IN ENGINEERING: TAPPING ALLUVIAL AQUIFERS AT THE HEADS OF VALLEYS AND CONDUCTING THE WATER ALONG UNDERGROUND TUNNELS BY GRAVITY, OFTEN OVER MANY KILOMETERS***



***UNESCO.ORG***

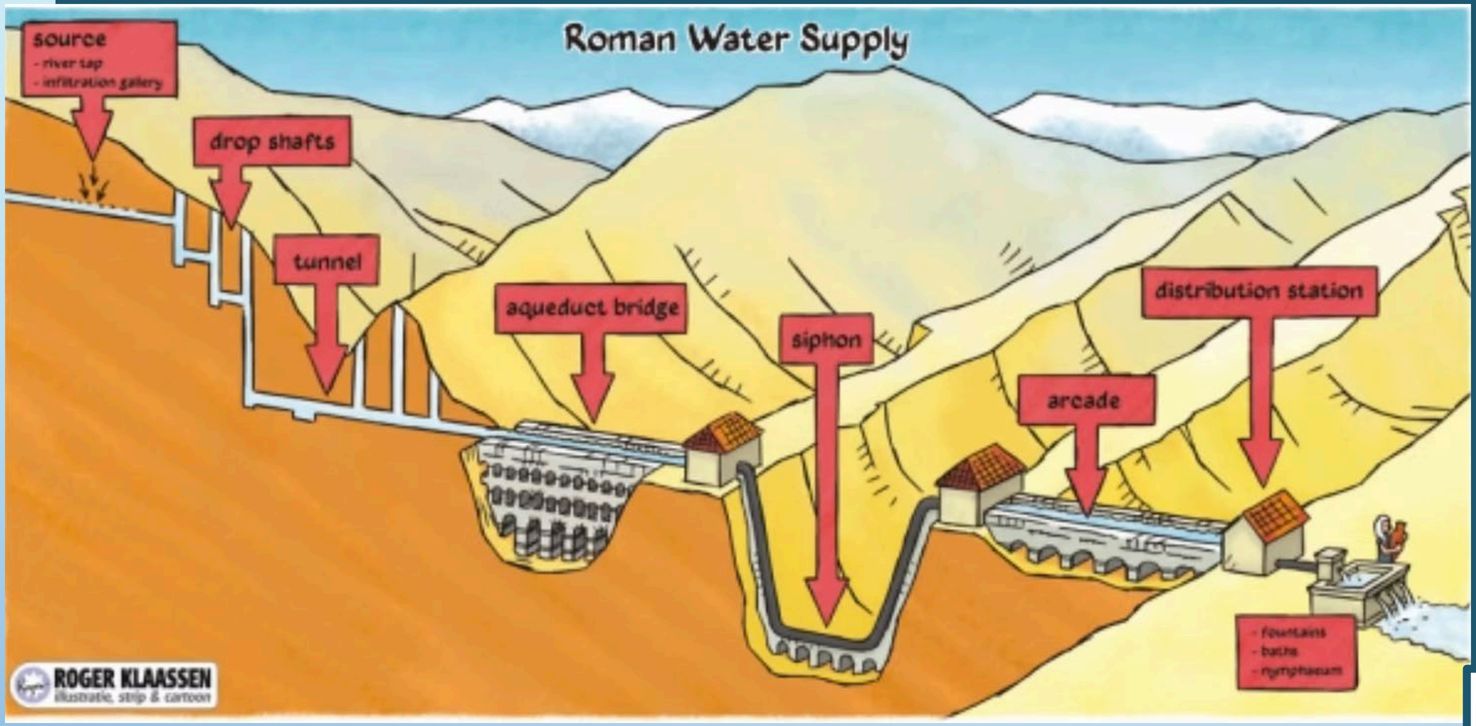
# DIFFUSION OF QANAT KNOWLEDGE




***BCE: "Before Common Era"***

*Environ. Eng. Res. 2013 June,18(2) : 57-63*

# THE GREEK **AQUEDUCTS**

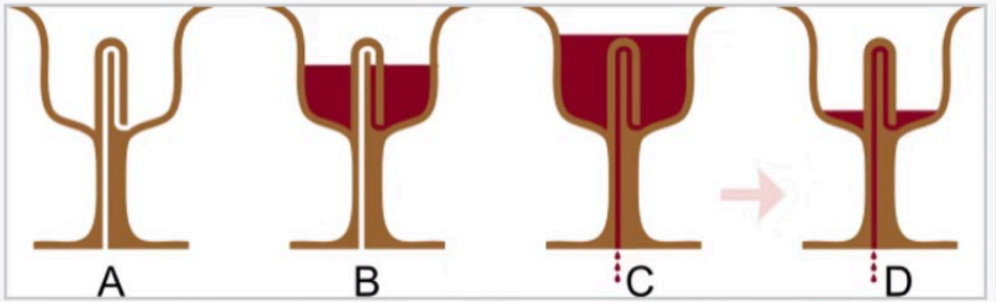



**Chantrou.net**

The Romans refurbished and expanded them:

***The Aqueduct of Constantinople is >300 km long and fetches Water from 100 km Distance***

*They gave us Siphons:*
*Tubes that connect two bodies of liquid and allow the liquid to flow upwards, thus defying gravity*

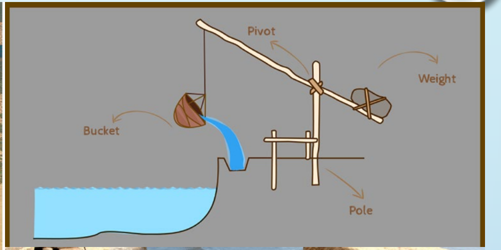



Cross section of a Pythagorean cup being filled: at B, it is possible to drink all the liquid in the cup; but at C, the siphon effect causes the cup to drain.

# AND AMAZING INGENUITY THROUGH TIME

Mesopotamia Irrigation Canals


Egyptians Managed Nile Floods for Irrigation



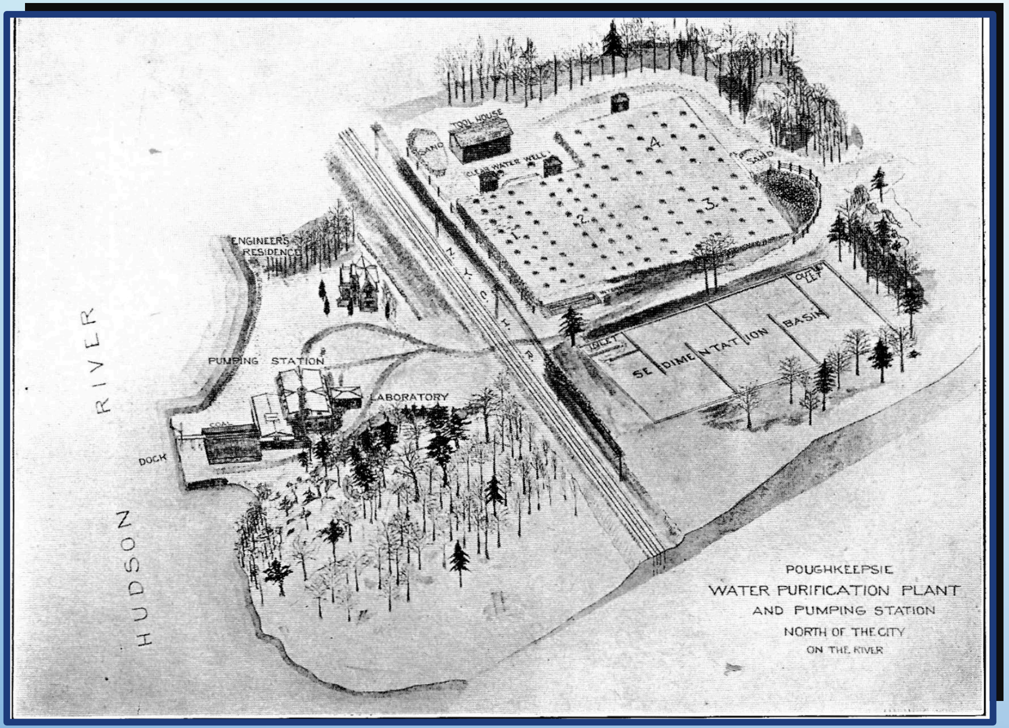

The Egyptian Shaduf and Nilometer

The Indus Pioneered Advanced Urban Water and Wastewater Engineering

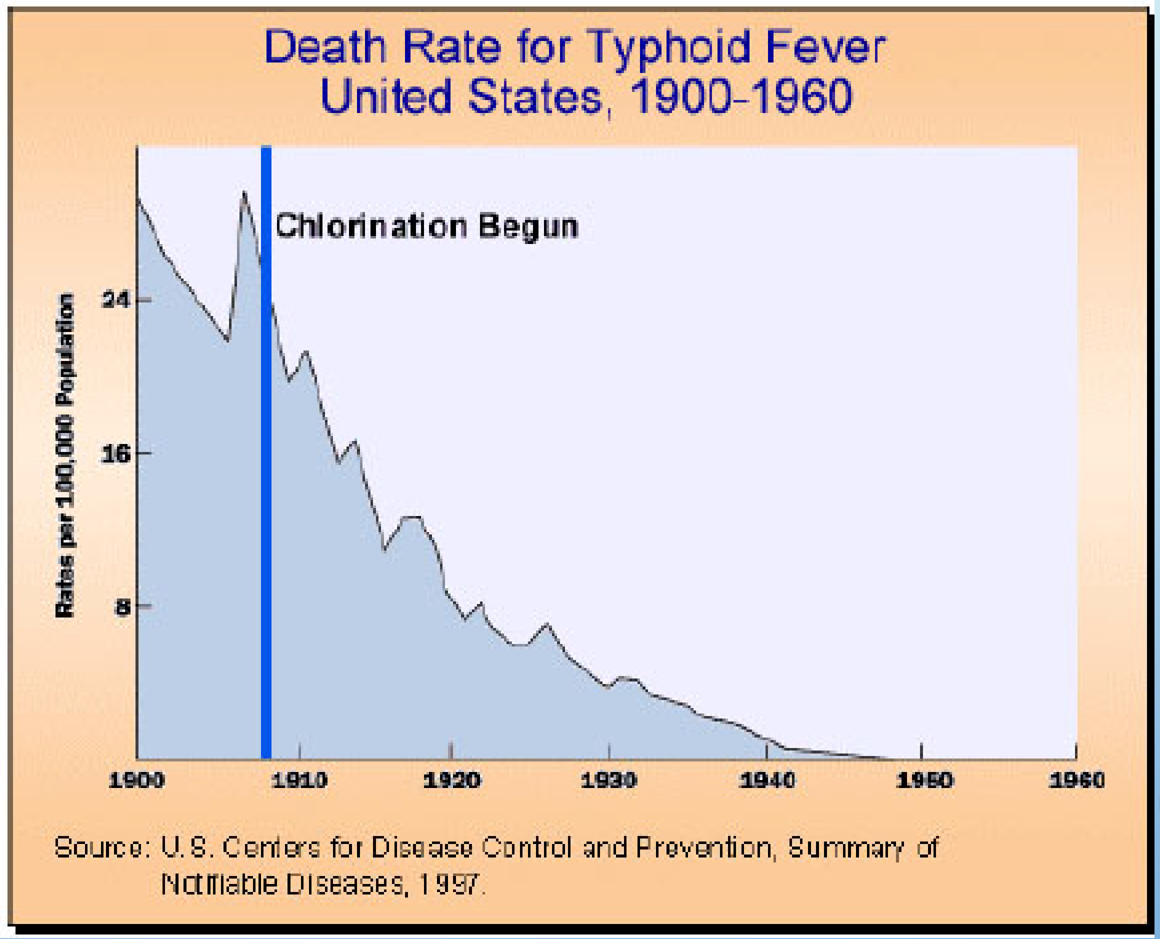


Mayans' Western First Filtration Systems

# FAST FORWARD: HERE IN THE US & IN MODERN TIMES




**First Filtration Water Treatment Plant**
**Poughkeepsie, NY (1872)**



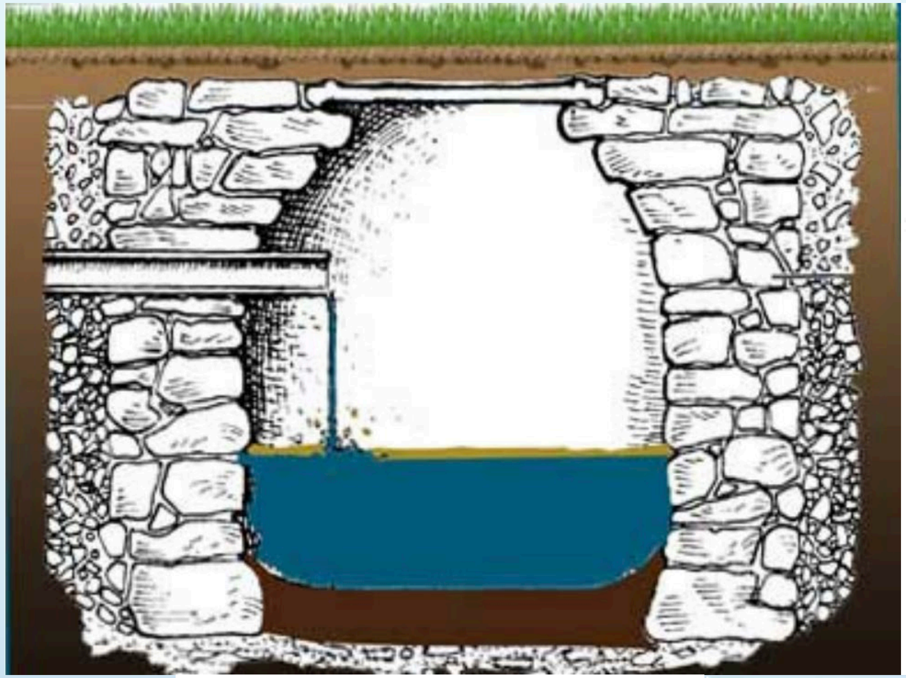

**First Chlorination System in Jersey City (1908)**

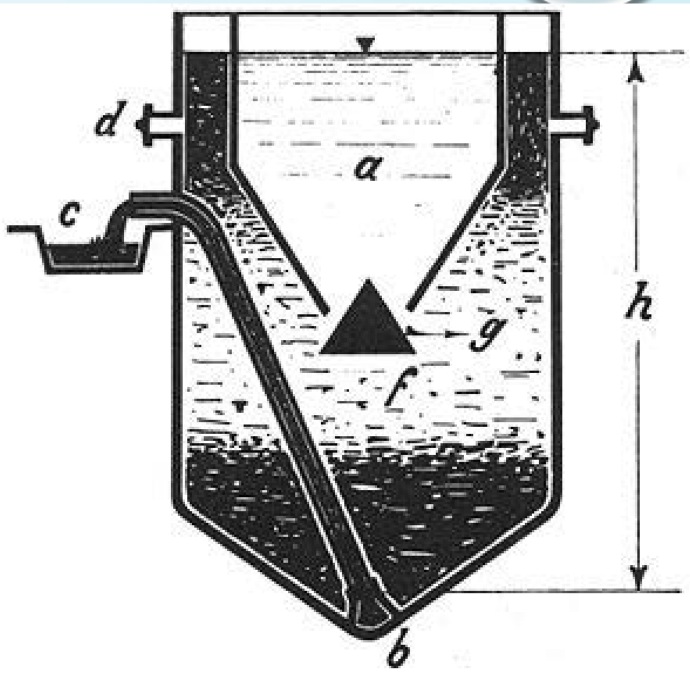
# WASTEWATER TREATMENT LED BY BRITAIN

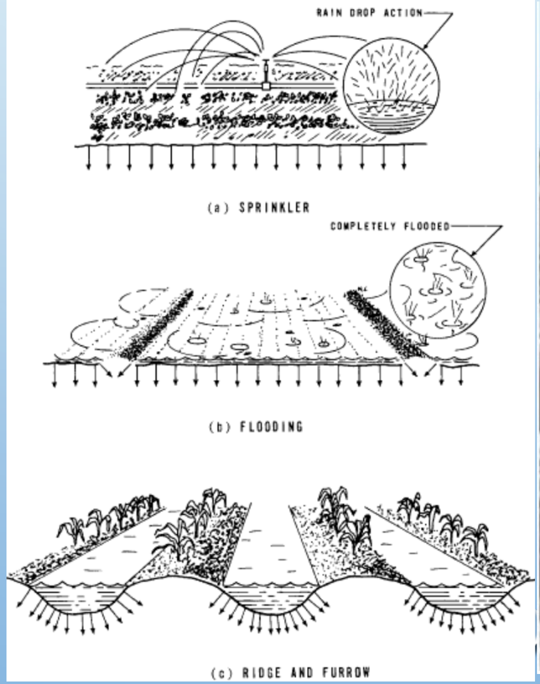
*Early industrialization combined with severe river pollution and cholera outbreaks in the 1800s Forced rapid innovation in sanitation*

## Biological Technologies

| | |
|---|---|
| 1865 | LAND APPLICATION |
| 1870s | INTERMITTENT FILTRATION |
| 1896 | SEPTIC TANK |
| 1892 | CULTIVATING FILTER |
| 1893 | TRICKLING FILTER |





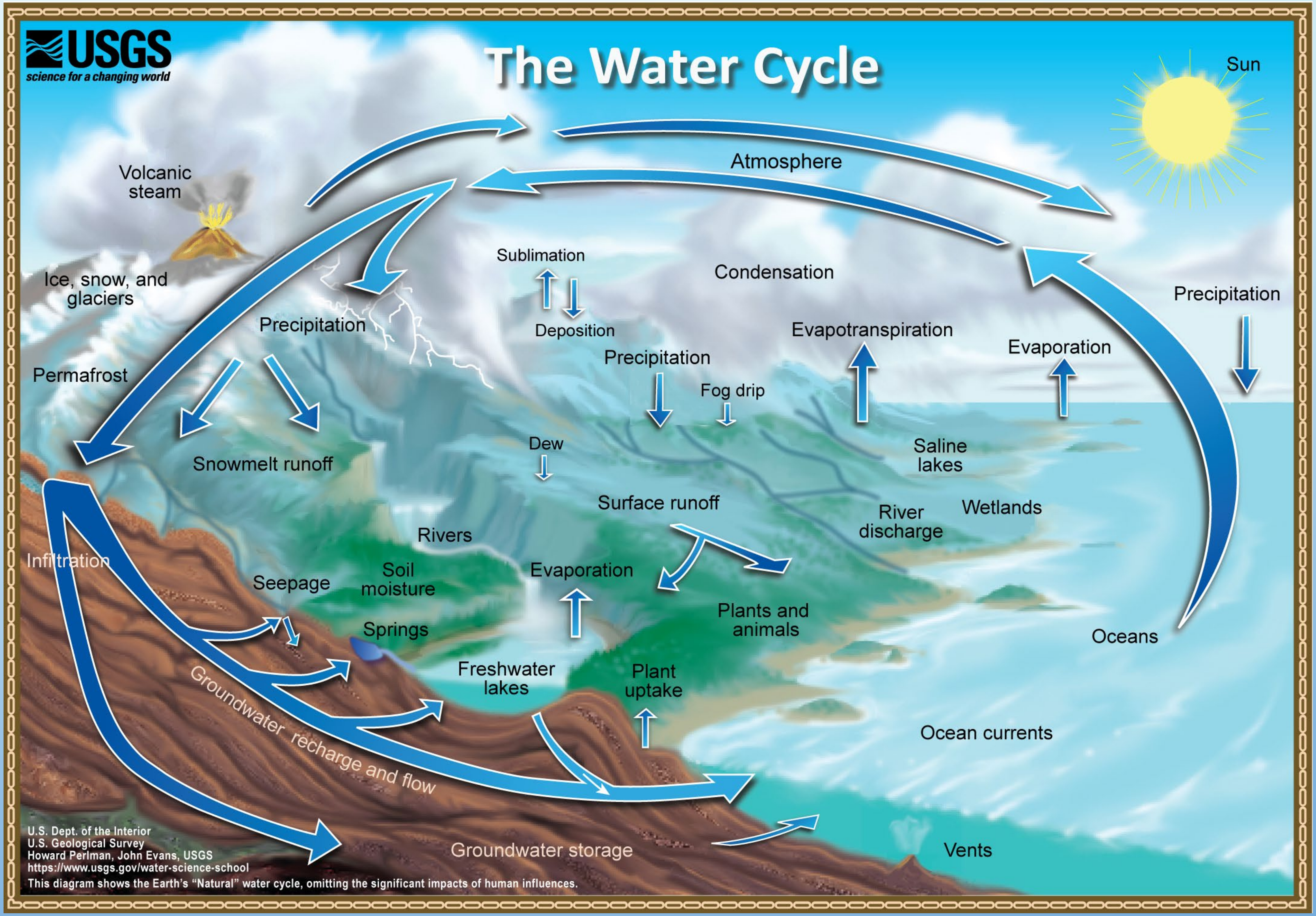




# *CHANGING THE CONVERSATION ABOUT WATER IN THE COMPUTE AGE*

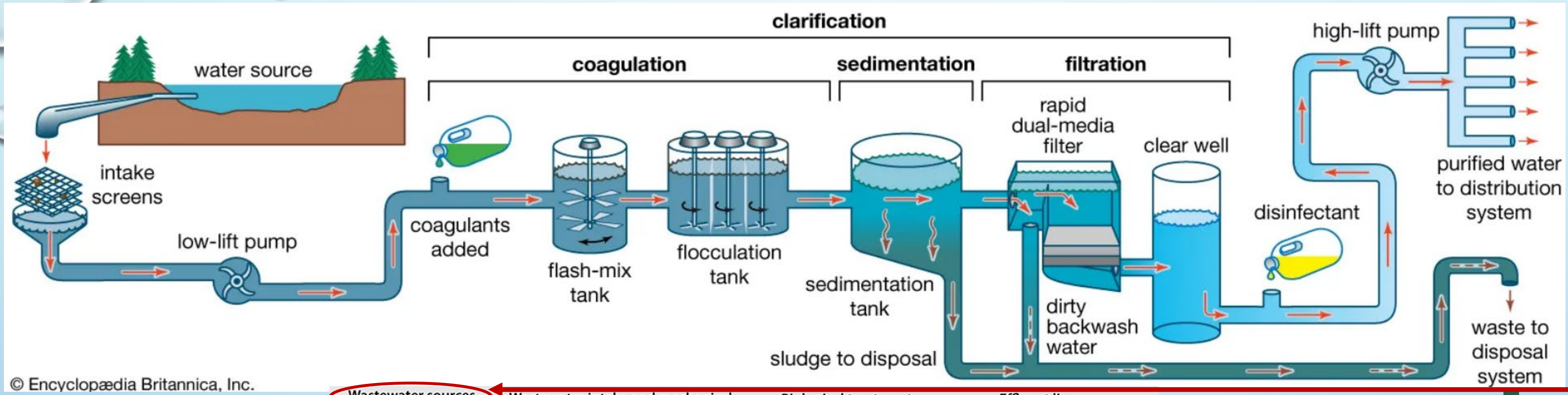
- NATURAL AND UNCONVENTIONAL SOURCES OF WATER
- CURRENT WATER DELIVERY MODEL (AND WASTEWATER TREATMENT)
- CHALLENGES WITH CONVENTIONAL WATER SOURCES AND DELIVERY MODEL
- ***THE TEXAS WATER STORY***
- THE US WATER ECONOMY
- ***DESALINATION — AN UNESCAPABLE WATER FUTURE?***
- WATER AND ENERGY NEXUS
- WATER AND PRODUCTIVITY NEXUS
- ***THE RIME OF THE FUTURE ENGINEER: NECESSITY IS THE MOTHER OF INVENTION***

# NATURAL AND UNCONVENTIONAL WATER SOURCES

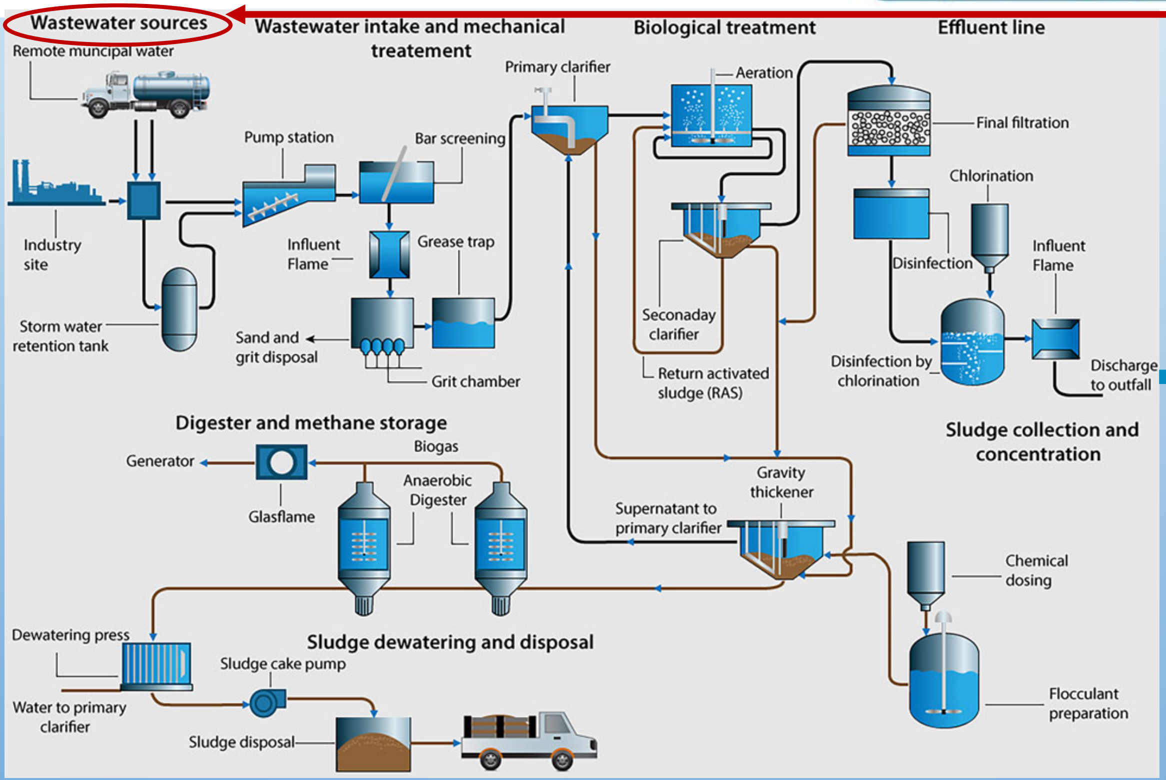
- SURFACE WATER (RIVERS, LAKES, STREAMS)
- GROUNDWATER (AQUIFERS, WELLS, SPRINGS)
- RAINWATER (PRECIPITATION)
- GLACIERS & SNOWMELT
- *RECYCLE – REUSE*
- *ATMOSPHERIC WATER (FOG, HUMIDITY)*
- *PRODUCED WATER*
- *SEAWATER (OCEANS)*



# CURRENT CONVENTIONAL WATER DELIVERY MODEL




**Complex Water Storage And Distribution Grid**




- Energy Intensive
- Consumes chemicals
- Ineffective for some pollutants
- Deteriorating Infrastructure
- Generates wastes

Settling Ponds
Wastewater Plants
Landfills
Land Applications

Rivers and Streams

# CHALLENGES WITH CONVENTIONAL WATER SOURCES AND DELIVERY MODEL

- COMPETITIVE USES POSE TECHNICAL, POLICY, MANAGEMENT, AND SOCIETAL CHALLENGES
  - WHO IS FIRST IN LINE IN TIMES OF DEFICIT? ***AGRICULTURE, INDUSTRY, MUNICIPAL, COMMERCIAL, ENERGY SECTOR, ENVIRONMENTAL, RECREATIONAL***
  - WHO BEARS THE COST OF DEVELOPING ***NEW WATER SOURCES?***
  - WHAT ABOUT EMERGING MEGA USERS: ***DATA CENTERS***
- CAN YOU SHARE-TRANSFER WATER-WATER RIGHTS: ***HAVE AND HAVE NOTS?***
- WHAT TO DO WHEN TOO MUCH OR NOT ENOUGH: ***THE EXTREMES***
- CAN WE CONSERVE ENOUGH? HARVEST DISTRIBUTED SOURCES: ***RAINWATER***
- WHAT ABOUT INFRASTRUCTURE RETROFITS TO ***REDUCE WATER LOSSES? CONSERVATION?***

The New York Times

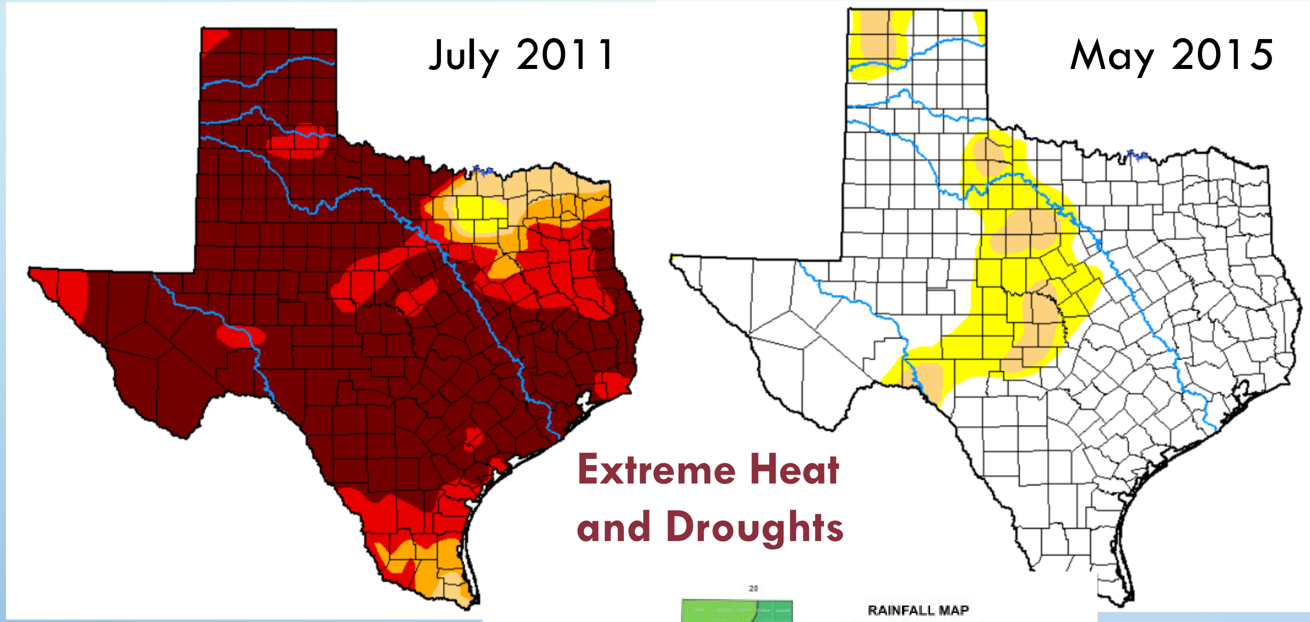
## Microsoft Pledged to Save Water. In the A.I. Era, It Expects Water Use to Soar.

Driven by the artificial intelligence frenzy, Microsoft is internally projecting that water use at its data centers will more than double by 2030 from 2020, including in places that face shortages.

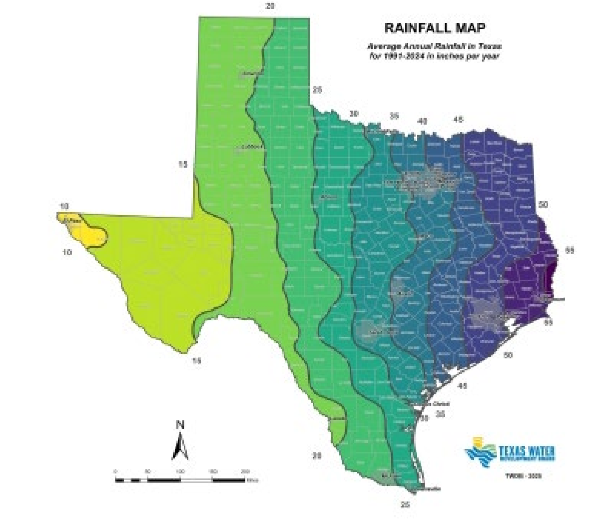
# THE TEXAS WATER STORY

## *TOO MUCH OR NOT ENOUGH*

## NOT *WHERE YOU WANT IT WHEN YOU NEED IT*

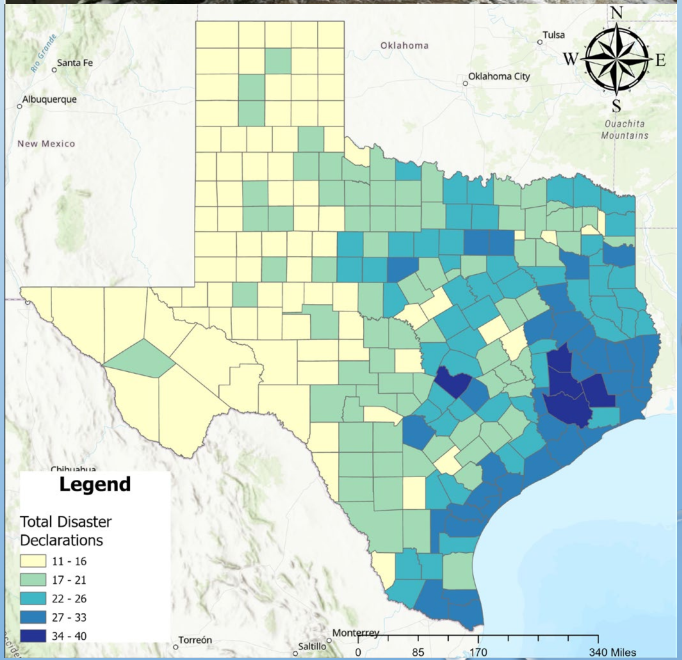



**Extreme Heat and Droughts**

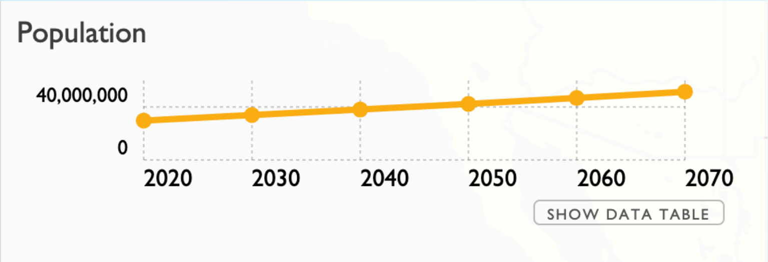



**Regional Rainfall Variability**

**Natural Hazards**

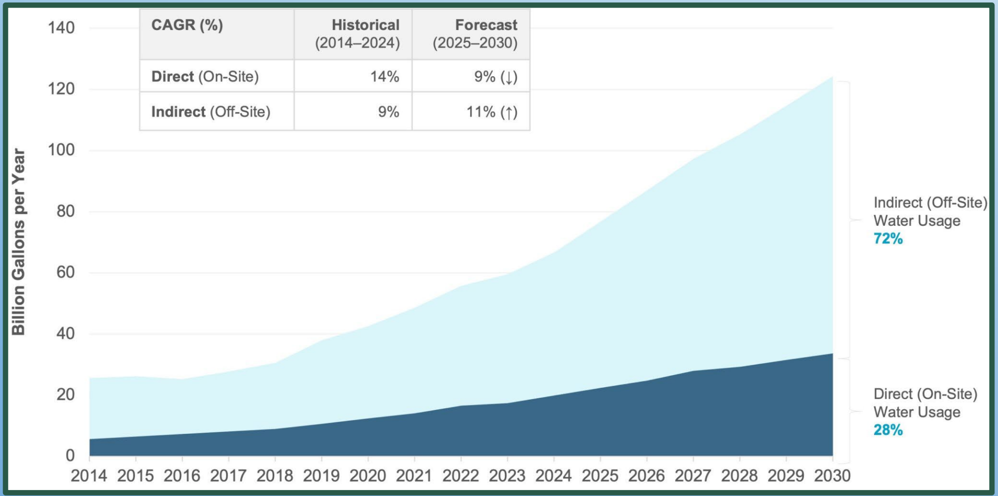



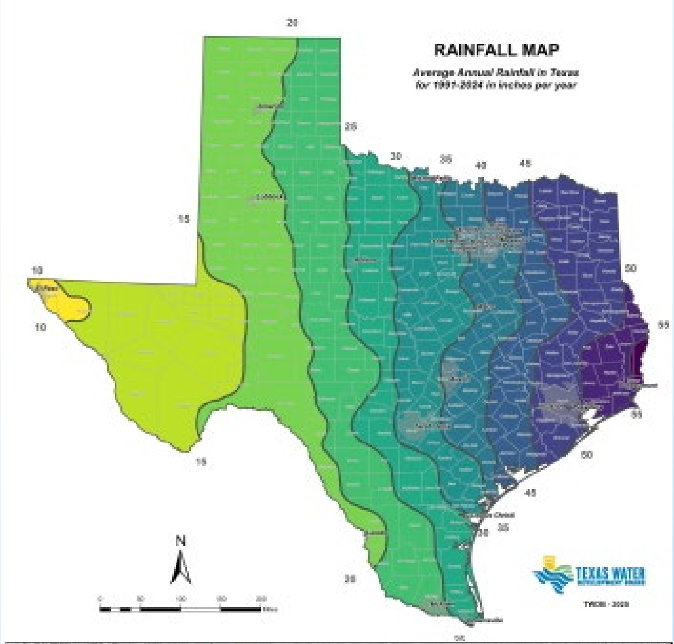
# TWO STRIKES FOR DATA CENTERS

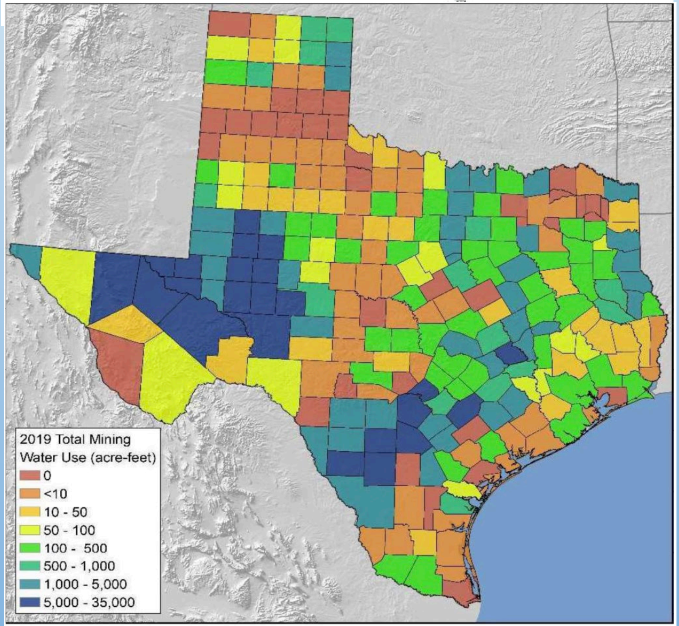


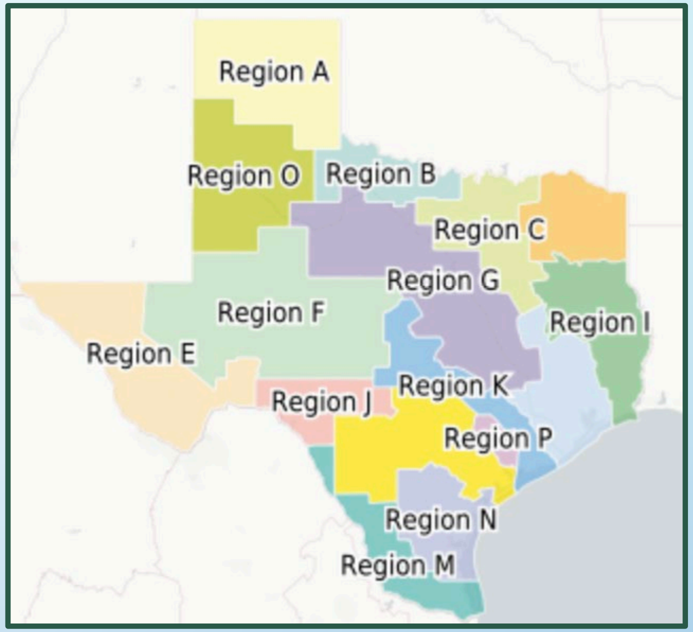

Data Center Electricity Demand Nearly Doubles to 8.9% by 2030, Shifting Water Risk from Cooling to Power Generation

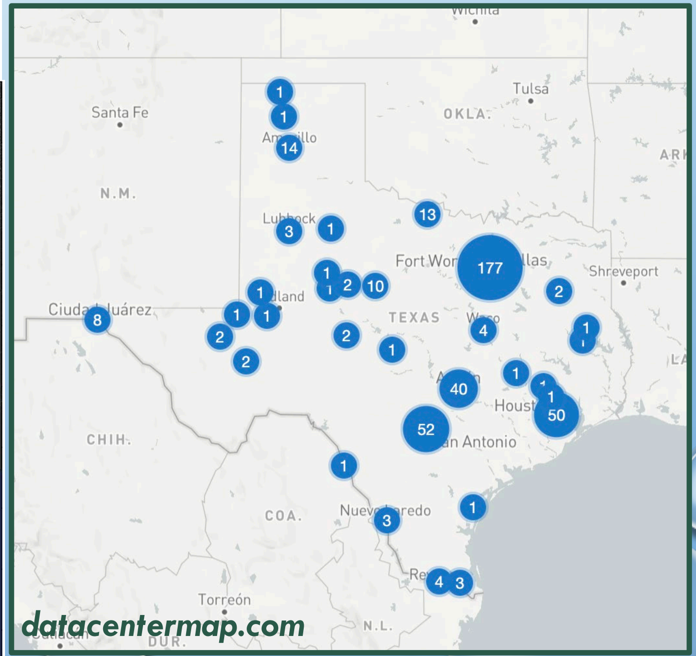
*Bluefield Research*



*125 Years of US Water Spending*

From Hand-Pumped Wells to a $170 Billion Annual Infrastructure System

# WATER

***Pricing it right will rightfully value it as:***

## The Resource of the Future

*Demand · Scarcity*

*Innovation · Circular Economies*

**0.15 gallon of gasoline equivalent for distilled water**

***$1-$2.50***

**0.000055 gallons of gasoline equivalent**

***< 5 cents***

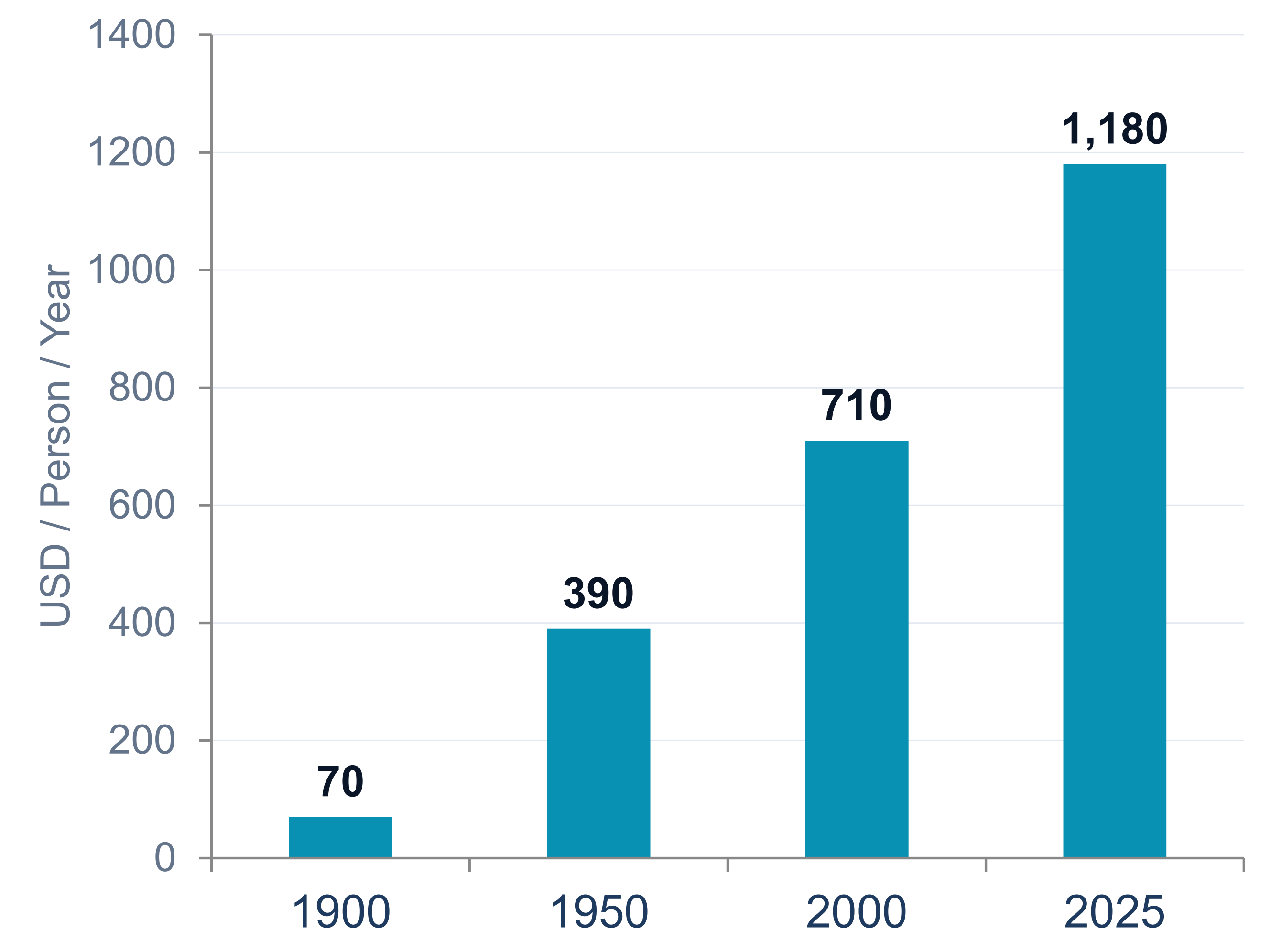
***The cost for water and wastewater in Houston for a family of 4 is one-fourth of this number based on 5,000 gallons consumption per month***

***~ $3.10***

$1,180 per capita annual US water cost • 2.2B people lack safe water • 40% of world faces water stress by 2050

# What Drove Costs Up?

*Four major forces reshaped US water spending over 125 years*




**1900–1950**
Federal dam & canal construction; subsidized irrigation

**1950–1980**
Urban pipe networks; postwar population boom

**1980–2000**
Clean Water Act & Safe Drinking Water Act mandates

**2000–2025**
Aging infrastructure + PFAS/lead removal requirements

# 1900: The Well & Ditch Era

*~$40–$100 per person per year in 2025 dollars*

## Water Access in 1900

60% of Americans relied on private wells, springs, and rivers at nearly zero monetary cost — but enormous physical labor.

40% in cities had piped water — primitive systems, little treatment, mostly private companies.

Irrigation was almost entirely private "ditch companies" — no EPA, no federal standards, no filtration requirements.

**$25–$65**
Drinking water & sewer / person

**$15–$35**
Irrigation infrastructure / person

**1902**
Bureau of Reclamation founded

# 1950: The Great Dam-Building Era

*~$300–$480 per person per year — peak federal water investment*

## The Postwar Water Boom

Federal government built Hoover Dam (1936), Grand Coulee (1942), and 100+ more. This era saw the largest real per-capita government water investment in US history.

Farmers received federally subsidized irrigation water at 5–10¢ on the dollar. Taxpayers covered the rest.

Municipal water systems expanded rapidly but wastewater treatment was still minimal — most sewage discharged raw into rivers.

**$150–$250**
Drinking water & sewer / person

**$140–$230**
Irrigation + dam infrastructure

**3–5×**
Increase from 1900 in real terms

# 2000: The Regulation & Treatment Era

*~$600–$825 per person per year — Clean Water Act drives costs upward*

## Environmental Law Changes Everything

The Clean Water Act (1972) and Safe Drinking Water Act (1974) mandated expensive treatment upgrades across 50,000+ water systems.

Federal dam building largely ended — but operation and maintenance costs of existing projects remained high.

Total government water/wastewater spending reached $80–$100 billion/year, or ~$280–$350 per capita in 2025 dollars.

**$325–$425**
Drinking water & sewer / person

**$270–$360**
Irrigation + infra / person

**6–8×**
Increase from 1900 in real terms

# 2025: The Aging Infrastructure Crisis

*~$975–$1,380 per person per year — and the need gap is growing*

## Deferred Maintenance Meets Rising Costs

Most US water pipe was built in the 1960s–80s and is now at or beyond its design life. Water main breaks occur 240,000 times per year.

EPA estimates a $625 billion drinking water infrastructure gap through 2041 — about $55/person/year in unmet needs on top of current spending.

The US needs $3.4 trillion in water infrastructure investment over 20 years. Federal share has dropped to just 8% of total; state/local governments now bear 92%.

**$550–$800**
Drinking water & sewer / person

**$425–$580**
Irrigation + infra / person

**10–14×**
Increase from 1900 in real terms

# Key Takeaways

1

### 10–14× Real Increase Since 1900

Water spending per person has grown from ~$70 to ~$1,180 in constant 2025 dollars — far outpacing inflation.

2

### Regulation Was the Biggest Driver Post-1970

Clean Water and Safe Drinking Water Acts transformed a simple distribution problem into a complex treatment and compliance system.

3

### The Federal Role Has Collapsed

Federal water infrastructure funding fell from ~50% of total (1981) to just 8% (2023). States and ratepayers now bear almost all costs.

4

### A $3.4 Trillion Infrastructure Gap Looms

Most US water pipes were built in the 1960s–80s and are now aging. The US needs ~$170B/year but is spending far less.

Sources: USGS, EPA, Congressional Budget Office, Bureau of Reclamation, Dallas Fed, Value of Water Campaign

# Water Demand: A Relentless Upward Trend

### Population Growth

Global population expected to reach 9.7B by 2050. Each additional person requires water for drinking, sanitation, food, and industry.

### Urbanization & Industry

As nations transition from farming to manufacturing to information technology, water demand per capita intensifies — factories, power plants, and cooling systems all require massive water inputs.

### Data Centers & AI

The digital economy is water-hungry. A single hyperscale data center can consume 3–5 million gallons per day for cooling. AI and quantum computing are accelerating this need.

By 2050, global water demand is projected to increase 55% above 2000 levels

# Water Sources: Tapped, Stressed & Untapped

## ⚠️ STRESSED SOURCES

- Groundwater — over-pumped in most major aquifers (Ogallala, Central Valley)
- Surface water (rivers & lakes) — over-allocated in arid basins
- Both sources face climate-driven drought risk
- Legal frameworks lag behind physical realities

## ✅ OPPORTUNITY SOURCES

- Rainwater harvesting — underutilized in much of the world
- Glacial & snowmelt — seasonal but currently uncaptured at scale
- Atmospheric water (fog collectors, humidity extraction)
- Seawater desalination — largest untapped resource globally

# Water Treatment: Emerging Contaminant Crisis

## From Infectious Disease to Chemical Contamination

Early wastewater treatment was driven by the urgent need to prevent cholera, typhoid, and dysentery. Today, treatment systems face a new class of challenges: persistent synthetic chemicals for which no cost-effective removal technology exists at scale.

*A critical pathway: biosolids spread on agricultural land carry these pollutants directly into the food supply.*

### PFAS

*"Forever Chemicals"*

Found in firefighting foam, non-stick coatings, and countless products. Linked to cancer, immune disruption. No standard removal at wastewater scale.

### Microplastics

*Ubiquitous Particles*

Present in virtually all water sources. Enter food chain through biosolids and irrigation. Long-term health effects poorly understood.

### 6PPD-Quinone

*Tire Chemical*

Byproduct of tire rubber, toxic to salmon and other aquatic life. Stormwater runoff pathway largely uncontrolled.

# Wastewater: From Nuisance to Intelligence Asset

## Historical Role

- Treatment driven by need to prevent infectious disease outbreaks
- Cholera, typhoid & dysentery controlled through sanitation
- Clean Water Act (1972) brought pollution control mandates
- Goal: protect downstream communities and ecosystems

## New Role: Disease Sentinel

- Wastewater epidemiology detects COVID-19, flu, RSV days before clinical cases appear
- Monitors opioid use, antibiotic resistance, and illicit drugs at population scale
- Low-cost public health early warning with no individual privacy concerns
- CDC & WHO expanding wastewater surveillance networks globally

# Expanding Supply Without New Sources

Significant water can be reclaimed through efficiency, reuse, and rehabilitation in addition to investing in costly new supply infrastructure.

### ♻️ Recycled & Reclaimed Water

Treated wastewater reused for irrigation, industrial cooling, and increasingly potable supply. Singapore's NEWater is a global model.

### 🌧️ Stormwater Capture

Urban runoff collected and treated reduces flooding while supplementing supply. Green infrastructure integrates capture into city design.

### 🛢️ Produced Water Recovery

Oil & gas wastewater increasingly treated to potable or agricultural standards. Texas, Colorado leading regulatory frameworks.

### 🔧 Infrastructure Rehabilitation

US water mains lose ~16% of treated water to leaks. Pipe repair and smart metering can reclaim billions of gallons annually.

### 💧 Greywater Reuse

Household sink and shower water reused for irrigation and toilet flushing. Reduces municipal demand 20–30% where permitted.

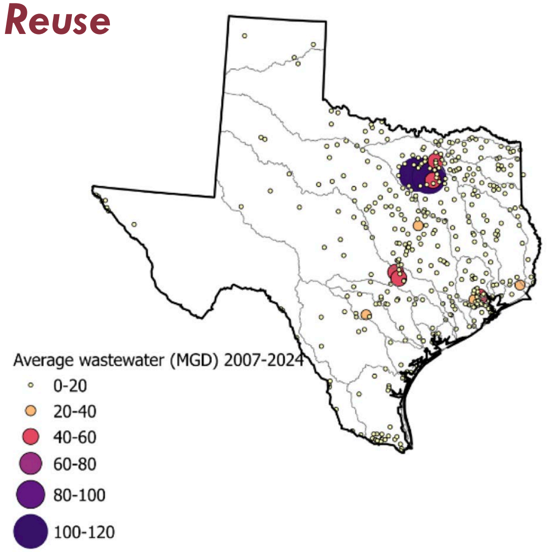
### 📉 Demand Conservation

Price signals, efficiency standards, and behavioral programs reduce consumption. Agricultural efficiency offers largest gain opportunity.

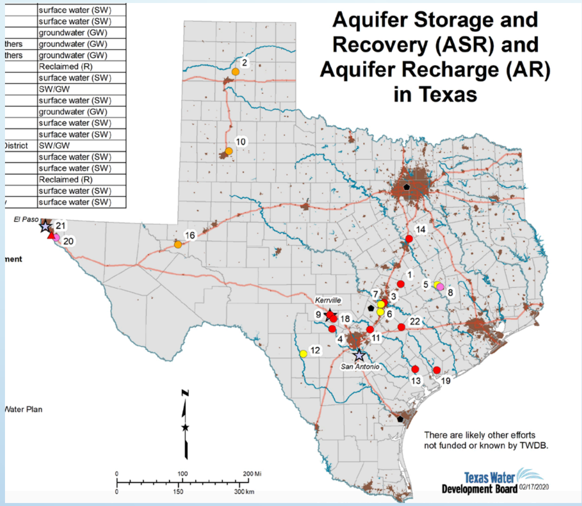
# TEXAS WATER PLANNING ($1 BILLION/YR FOR 20 YRS)

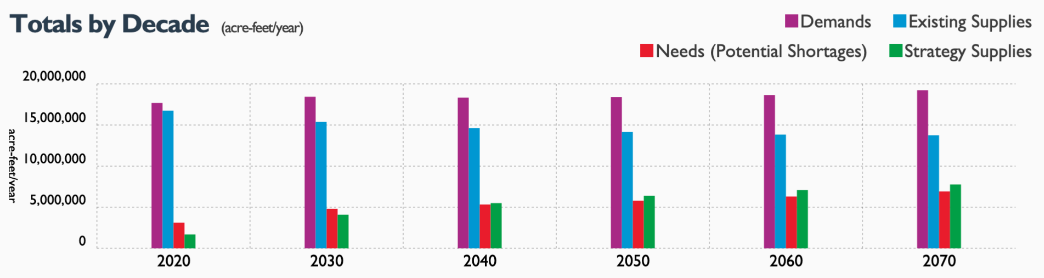
***No large municipal seawater desalination plants currently, several brackish inland desal plants***

## *Reuse*

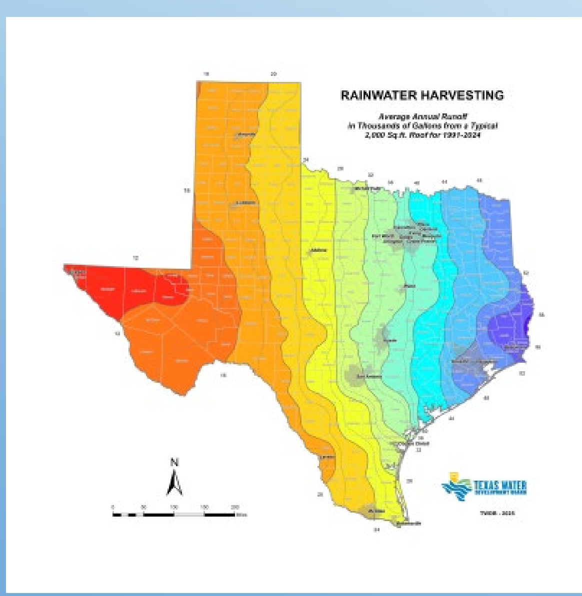



## *Managed Aquifer Recharge*

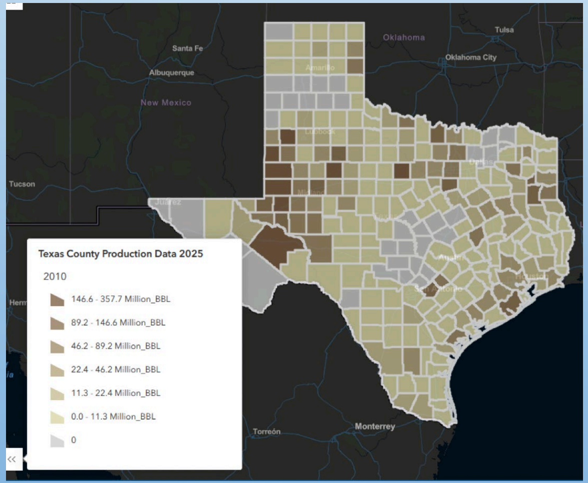


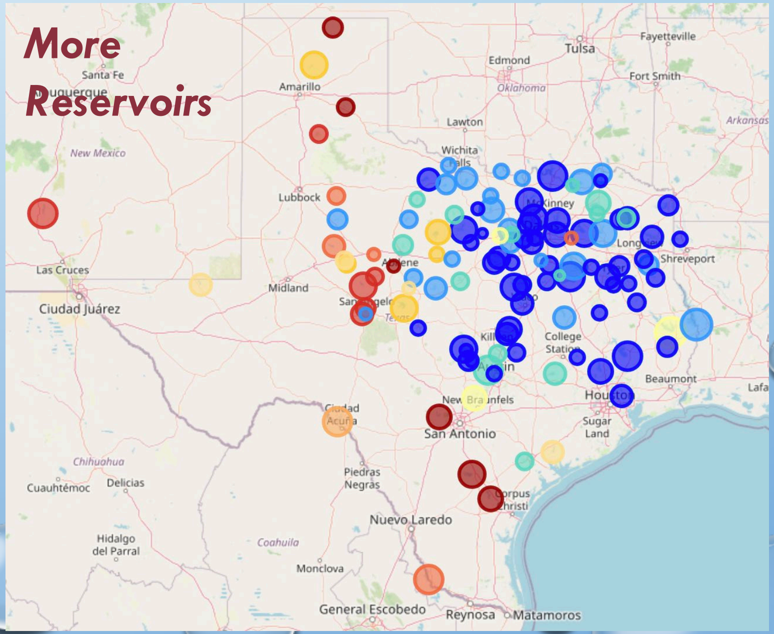

| | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 |
|---|---|---|---|---|---|---|
| Demands | 17,680,444 | 18,426,781 | 18,326,558 | 18,394,477 | 18,647,792 | 19,230,876 |
| Existing Supplies | 16,748,029 | 15,394,457 | 14,615,947 | 14,142,237 | 13,834,633 | 13,750,315 |
| Needs (Potential Shortages) | 3,116,143 | 4,802,730 | 5,339,768 | 5,798,441 | 6,307,209 | 6,917,609 |
| Strategy Supplies | 1,690,192 | 4,081,861 | 5,497,295 | 6,398,116 | 7,083,691 | 7,766,984 |




## *Treat Produced Water*




## *More Reservoirs*




***Tx Water Development Board***

# Seawater: The World's Largest Water Reserve

*Desalination offers the highest potential supply at declining cost*

**97%**

of Earth's water is in the oceans

Coastal populations: 44% of humanity lives within 150 km of the coast

## Why Seawater Wins

### Virtually unlimited supply

Oceans cover 71% of Earth — no depletion risk unlike groundwater

### Technology costs declining

Reverse osmosis costs fell 90% since 1980 — now \$0.50–\$1.00/$m^3$

### Location advantage

Most population growth near coasts where supply and demand align

### Climate-independent

Unlike rain or snowmelt, seawater is available regardless of drought

# Where Desalination Is — and Where It's Headed

Today's desalination map reflects water stress. Tomorrow's reflects climate migration toward temperate coastlines.

| Region / Country | Daily Capacity ($m^3$/day) | Primary Driver |
|---|---|---|
| Saudi Arabia & Gulf States | ~20 million | No natural freshwater |
| Israel | ~1.7 million | Water security strategy |
| United States | ~3 million | Coastal drought relief |
| Spain & Mediterranean | ~2.5 million | Agricultural & tourism demand |
| China & Australia | ~3 million combined | Coastal industrial cities & drought |

*Future growth: Climate migration will concentrate populations on temperate coastal fringes — driving desalination into Europe, US Pacific Coast, East Asia, and Southern South America.*

# The Core Challenges

## 01 Energy Cost

Desalination and long-distance water transport are energy-intensive. In many regions, energy scarcity is the binding constraint on water access. Affordable renewable energy is the key unlock.

## 02 Time to Implementation

Major water infrastructure takes 10–25 years from planning to operation. Climate shifts are outpacing our ability to adapt. Earlier investment and streamlined permitting are critical.

## 03 Delivery Where Needed

Water is heavy and expensive to move. Coastal desalination is useless to inland populations without costly pumping and conveyance infrastructure.

## 04 Climate Variability

Extended drought, extreme precipitation, and shifting snowpack patterns disrupt traditional water supply assumptions. Resilient systems must handle higher variance.

# The Water–Energy Nexus: A Symbiotic System

*Water and energy are inseparable — managing them together unlocks circular efficiencies*

## 💧 Water → Energy

- Hydropower — 16% of global electricity
- In-conduit power — turbines in water pipes
- Marine energy (tidal, wave, OTEC)
- Osmotic power (salinity gradient)

**CIRCULAR ECONOMY**

**Floating droplet electricity generator**

## ⚡ Energy → Water

- Solar-powered desalination
- Reclaim cooling water from power plants
- Electrolysis water recovery
- Heat-driven atmospheric water harvest

***The rime of the future engineer***

# Data Centers: A Circular Water-Energy Model

The AI computing boom has created both a challenge and an opportunity in the water-energy nexus.

## ⚠️ THE CHALLENGE

- Large data centers use 3–5M gallons/day for cooling
- Training one large AI model can use 700,000 liters of water
- Global data center water use projected to triple by 2030
- Mostly sited based on energy cost, not water availability

## ✅ THE OPPORTUNITY

- Co-locate with desalination: power data center with ocean wind, return treated freshwater
- Recover waste heat for industrial processes or district heating
- Recirculate cooling water to near-zero discharge
- Planned circular campuses combine data centers, renewables & water treatment

# Wealth Enables Water Technology

Nations with resources invest in advanced water infrastructure. Arid regions have pioneered transformative solutions out of necessity.

### IL Israel — Membrane Technology Leader

Largest per-capita desalination capacity globally. Over 85% of agricultural water is recycled. Transformed arid desert into fertile farmland through drip irrigation and advanced membranes.

### SA Saudi Arabia — Mega-Scale Desalination

Over 30 major desalination plants produce more than 7.5 million m³/day. Water is essential to survival — no natural rivers exist. Massive sovereign investment in water security.

### 🌍 Libya (GMMR) — Great Man-Made River

One of the world's largest engineering projects: 4,000 km of pipeline moving fossil groundwater from the Sahara to coastal cities. Provides 6.5M m³/day to 70% of the population.

### SG Singapore — NEWater & 4 Taps

Diversified supply strategy: imported water, rainwater catchment, reclaimed water (NEWater), and desalination. Now 40% water self-sufficient with target of 70% by 2060.

# Looking Ahead to 2055

*How much will Americans earn — and can they afford the water infrastructure they need?*

**Slow Growth**
1.0% / year

**AI-Driven Growth**
3.5% / year

*Productivity growth rate assumption drives an enormous divergence in living standards and infrastructure capacity*

Projections in constant 2025 dollars | Base: US per-capita NNI ~$63,000 (2025)

# Per-Capita Income in 2055: Two Scenarios

*US Net National Income per person — constant 2025 dollars*


**2025 Baseline: $63,000 / person**

**LOW GROWTH (1.0%)**

**$84,914 in 2055**

+35% above 2025

**HIGH GROWTH (3.5%)**

**$176,828 in 2055**

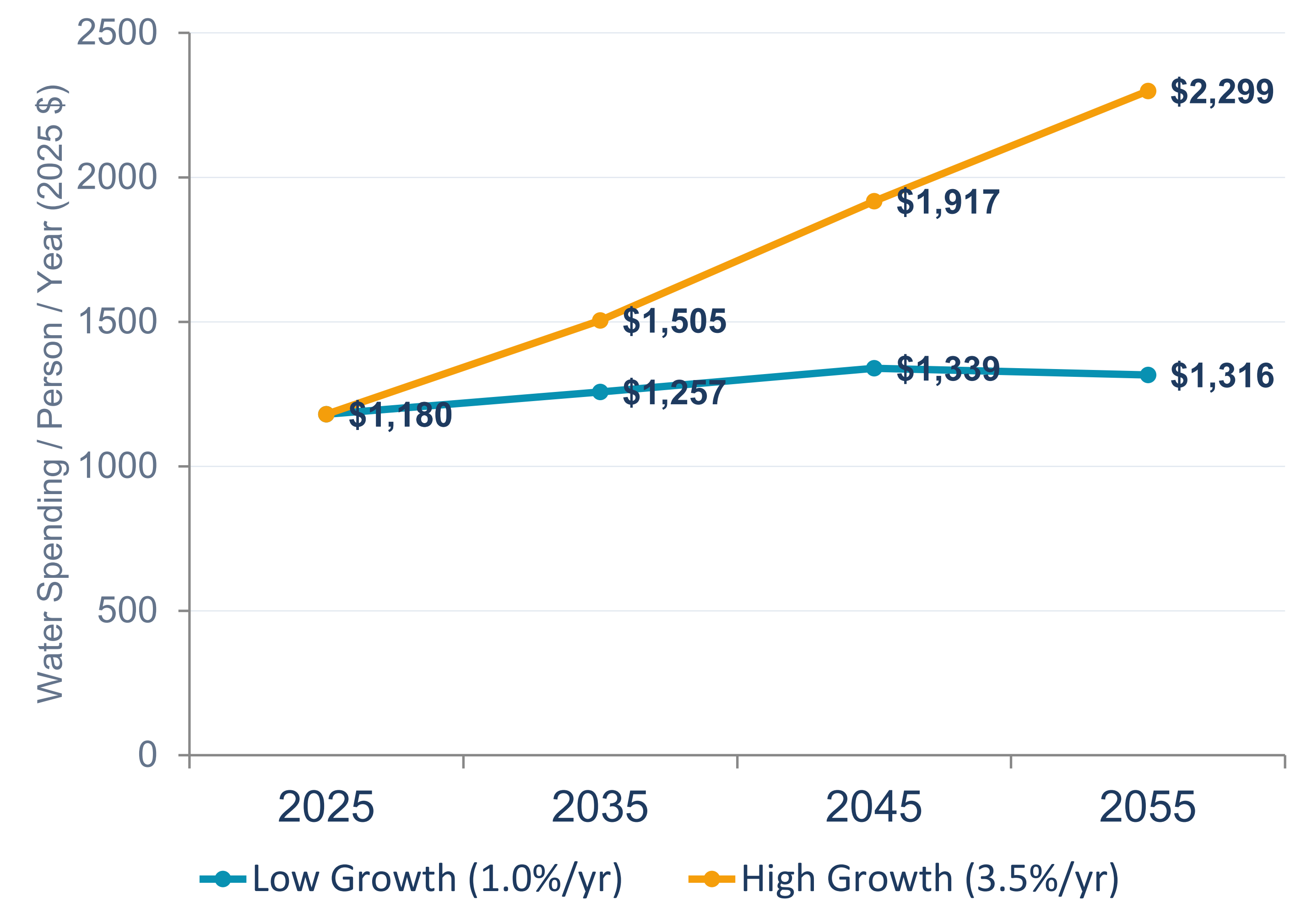
+181% above 2025

2.08× the low scenario

Formula: NNI per capita × (1 + growth rate)^30 | Constant 2025 dollars | Base NNI ≈ $63,000

# Water Spending Capacity in 2055

*High-growth income unlocks ability to close the $3.4 trillion infrastructure gap*




**TODAY (2025)**
~$1,180 / person
EPA gap: $55/person/yr unmet

**2055 LOW GROWTH**
~$1,316 / person
+$136 vs today
Infrastructure gap persists

**2055 HIGH GROWTH**
~$2,299 / person
+$1,119 vs today
EPA gap fully closeable

Water spending assumes ~1.3–1.55% share of per-capita NNI, consistent with historical affordability data

# The Productivity–Water Nexus: Synthesis

*Productivity scenario determines whether America can fund its water future*

**A**

**125 Years: Water cost 10–14× in real terms**

From ~$70/person (1900) to ~$1,180/person (2025) — driven by regulation, aging pipes, and treatment standards.

**B**

**The 2055 Fork: $85K vs $177K per capita**

1% vs 3.5% growth divergence compounds to a $92,000/year per-person income gap by 2055 — a 2.1× difference.

**C**

**High growth = $334B/year water headroom**

At 3.5%, national water capacity reaches ~$782B/yr — 4× the EPA's identified annual infrastructure need of $170B.

**D**

**Low growth = infrastructure crisis deepens**

At 1%/yr, water spending barely keeps pace with inflation. The $625B infrastructure gap widens and affordability stress persists.

Sources: USGS, EPA, CBO, Bureau of Reclamation, Goldman Sachs, Penn Wharton Budget Model, Dallas Fed | 2025 $

# A Brighter Future: The Circular Water-Energy Economy

*Integrating water supply, treatment, and energy into resilient interconnected systems*

## Integrated Planning

Water and energy agencies plan jointly. No new power plant without water reclamation plan. No desalination plant without renewable energy source.

## Distributed Systems

Move from centralized mega-infrastructure to resilient distributed networks. Local treatment, local energy, local storage reduces vulnerability.

## Nature-Based Solutions

Wetland restoration, urban forests, and permeable surfaces reduce flood peaks, recharge aquifers, and cool cities — simultaneously.

## Digital Intelligence

Sensors, AI optimization, and digital twins monitor leaks, predict demand, and manage complex distributed systems in real time.

# Water Security Is National Security

The choices made in the next decade — about desalination, water reuse, infrastructure investment, and energy integration — will determine whether the world's growing population has access to safe, reliable water.

Invest in water infrastructure now • Link water & energy policy • Embrace circular economy models • Deploy desalination at scale