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The path to investment in water infrastructure in low income and least developed countries: Obstacles and possibilities

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Rural communities in low-income countries rely on intermittent water supply, defined as access to water for less than 24 h a day. The path to continuous water supply requires electricity as well as water infrastructures, which in turn requires the necessary finance for investment. We show that a sample of 16 Least Developed Countries (as classified by the UN) do not yet meet the minimum conditions necessary to implement continuous water supply, mainly because they do not have the finance. Building up an infrastructure requires investments, using earned foreign exchange or loans, to build up electricity capacity, water treatment plants and a distribution pipe network. But once a country has the electricity infrastructure and the basic water mains, its remote areas can then be served through low-cost investment into a system called "trickle fill." Vietnam, having developed fast through export earnings, was able to increase its electricity production and expand its drinking water infrastructure. But there are still people in rural Vietnam without access to drinking water. We show that where there are water mains, continuous supply can be extended further through "trickle fill." We describe a freely available user-friendly decision-making tool for a feasibility study for a trickle fill solution and describe countries where this solution has been successfully implemented. For developing countries, we show that there is no shortcut to converting intermittent water supply to continuous water supply without adequate foreign exchange earnings which can then be invested in electricity and water infrastructure.

Key words: Foreign exchange, intermittent water, least developed countries, trickle fill, Vietnam.

INTRODUCTION

Rural communities in many parts of the world rely on intermittent water supply (IWS), defined as water supply for less than 24 h a day. Most residents of the least developed parts of sub-Saharan Africa and two-thirds of Latin Americans cope with intermittent water supply, while in parts of South East Asia over 90% of water supply systems are intermittent (Kumpel and Nelson, 2016; Simukonda et al., 2018). Table 1 shows details of

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the prevalence of IWS by the number of countries in each region; the number of utilities; population affected by IWS; and the mean duration of IWS in hours. About 23% of the population of low-income countries rely on water of unknown quality (Hannah and Roser, 2021).

Table 1 shows that the largest populations affected with the most severe interruption of water supply are in sub-Saharan Africa and Southeast Asia, or mainly the Least Developed Countries, which according to the United Nations classification, are countries with a per capita income of less than US $1018 in 2021. The time range of interrupted water supply is particularly alarming in sub-Saharan countries: the interruption can be as long as 23 and 1/2 h for worst affected locations, which can severely compromise the health of the population.

The main reason behind the dismal facts reported in Table 1 is that governments of such countries have a very limited tax base and typically have no other revenues to provide electricity and water infrastructure, except to one or two major urban centres. To make matters worse, rampant population growth has forced some of these countries to ration water quantity. But even the limited water supply is often contaminated with microbial, chemical and other contaminants. Inadequate maintenance has further compromised the water supply network. Hence, even the existing water infrastructure may be too old and/or beyond repair due to years of neglect and deferred maintenance.

There is a large literature that attempts to analyze the causes and consequences of intermittent water supply. But the path to continuous water supply requires as a precondition the creation of electricity and water infrastructures as part of a transition from low income to middle income status. As most developing countries do not have the industrial capacity to manufacture whole water treatment plants and water pipes, they must import these requirements from developed country corporations, who will demand payment in convertible currencies (US dollars, euros, Japanese yen, or Chinese yuan). Once the financial capability has been established, governments can commission engineering studies for specific water projects. A country typically requires a “backbone” of major water mains for distributing water and using electricity to pump the water to diverse regions of the country. The “backbone” of pipes connects large areas of the country. Once that is accomplished, any *remaining* rural areas could be served by converting an IWS system to one of continuous supply through low-cost investment into a system called “trickle fill,” which is a low diameter pipe connected to a water main to deliver drinking water to a consumer’s cistern (Janzen et al., 2022). But the condition of the existing pipes would have to be such that the additional investment is justified.

One country that has recently made a transition from low-income to middle income status is Vietnam. We show that Vietnam has not only made large strides in electricity production, but has been able to borrow funds from the Asian Development Bank and the World Bank to invest in and expand its electricity and water infrastructures. It has also successfully maintained its debt and interest repayment schedules as set by the two banks. Hence, it has the major water networks that could be used for trickle fill.

In most countries, it is the local authorities that plan and provide a public supply of water to a given population. In some cases, the water supply may come from a private corporation that may or may not be subject to some regulation as to water quality and price charged. In general, governments of low-income countries, both state level and at the local city or village level, face serious financial constraints on the supply of what we call “local public goods,” such as roads, education, electricity, and drinking water. It is not surprising that in the case of drinking water, it is only the highly developed rich countries that can guarantee to residents a continuous supply of treated drinking water in their homes for 24 h a day. In developing countries, it may be just the major cities that have such a reliable service. Regrettably, this means that the world may be far from being able to meet Sustainable Development Goal #6, which is adequate and safe drinking water for the global population by 2030. The objective of this paper is to describe the characteristics of an intermittent water supply and its disadvantages and then assess why least developed countries do not yet have the prerequisites to consider the possibility of continuous water supply which are: an adequate nation-wide electricity grid, and an adequate water infrastructure. To support this objective, we present a case study of Vietnam, on how it managed to develop and, in the process, continued to invest in both electricity and drinking water treatment plants, as well as a functioning network of water distribution pipes. Once a country has the main “backbone” of water mains, it then has the potential to extend its water supply through what is known as “Trickle Fill,” which is a low-cost alternative whereby an existing intermittent water supply can be converted to a continuous water supply that is both reliable and equitable (Janzen et al., 2022).

Problems of intermittent water supply

It was stated earlier that intermittent water supply systems exist all over the world. Their location is asshown in Figure 1, which should be read in conjunction with Table 1. Some of these systems supply water daily, while others supply less than 7 days a week, with supply durations ranging from 1 to more than 19 h on supply days in both cases (Sashikumar et al., 2003, Ingeduld et al., 2008; Danilenko et al., 2014). Even as developed as North America, there are isolated indigenous communities who have been under boil water advisories for years and hence do not have access to continuous water supply in the same manner as other citizens of Canada and the US.

Some communities have been plagued with water-

Table 1. Intermittent water supply (IWS) by number of countries, utilities, population and duration of IWS.

Parameter	Number of Countries with IWS IWS/Total	Utilities with IWS out of total IWS/Total	Population with IWS Millions	IWS Duration (h) Mean hours	IWS Time range (h)
East Asia & Pacific	9 out of 32	54 out of 479	15.0	16.7	1 to 23
Europe & Central Asia	17 out of 41	162 out of 960	25.4	13	0.2 to 23.7
Latin America	8 out of 21	79 out of 1403	28.4	16	2 to 24
Middle East & North Africa	1 out of 2	12 out of 13	4.6	3	N/A
South Asia	5 out of 6	104 out 107	116.6	7.2	0.3 to 23
Sub-Saharan Africa	19 out of 40	249 out of 314	118.8	12.8	1 to 23.5
Total	59 out of 142	660 out of 3276	308.9	12.5	12.5 to 24

Source: Kumpel and Nelsen (2016); IBNET database.

Figure 1. The global location of intermittent water supply.
Source: Galaitsi et al. (2016).

borne disease outbreaks, resulting in deaths (Dore, 2015).

Other communities, even in Canada, rely on water delivered by trucks due to water quantity and/or water quality problems. Further, communities who have instead relied on their own water wells often receive poor quality water and residents use in-home treatment to improve the water used directly for drinking (Janzen et al., 2022). Some need to use "point-of-use" treatment devices to make the water potable.

Two recent articles review the state of the world's intermittent water supply (Galaitsi et al., 2016; Simukonda et al., 2018). Galaitsi et al. (2016) review 129 articles on intermittent water supply, with 109 empirical case studies. They find the "causal consequential pathways" that characterize these IWS. Some of these pathways are: low prices that lead to inadequate cost recovery; overstretched networks that necessitate water rationing; insufficient funding resulting in poor data management; and inadequate treatment of water that leads to serious health concerns. In the final analysis, lack of finance is usually the problem, but sometimes it is also lack of training for water operators. In some cases, the intermittency of water supply is predictable whereas in others even the intermittency is either irregular or the water delivery totally unreliable (Galaitsi et al., 2016). They offer an interesting illustrative case: In response to statements from the president of the European Parliament regarding Israeli water policies affecting Palestinian consumers, Malcolm Lowe writes, ". . . wastage of water from leaky pipes and plain theft of water are rampant . . . A friend who just came back from a West Bank town reported hearing from the locals that there nobody pays water bills or even municipal taxes" (Lowe and Shulz, 2016).

Next, we proceed to the second excellent review article on intermittent water supply, by Simukonda et al. (2018). This review adds that population growth in developing countries has led to increases in water demand, and failing to meet this growing demand has ultimately meant water scarcity. A common characteristic of African countries is unplanned increase in urbanization, as rural populations search for paid employment in the peri-urban suburbs and shanty towns close to cities, leading to demands for water and sanitation services beyond the existing infrastructure capacity (Seetharam and Bridges, 2005; Le Blanc, 2008). These developments are then compounded by (a) poor local governance; (b) hydrological regime changes due to land-use changes and climate change; (c) poor system management and operation; (d) lack of skilled personnel, and (e) inadequate and poorly run electrical utilities, where power is critical for pumping water supplies. Simukonda et al. (2018) neatly summarize the "root causes" of intermittent water supply, which revolve mainly around inadequate funding and lack of planning.

In summary, the percentage of population of low-income countries having access to different qualities or types of water has been estimated to be (Hannah and Roser, 2021): Safely managed drinking water, 28.8%; Basic water, 30.3; Limited access to water, 17.8; Unimproved water, 17.1; No access (surface water only), 6.0/100.

MATERIALS AND METHODS

It has been shown that intermittent water supply systems have a large number of associated problems. In addition, it must be noted that IWS systems are very heterogeneous, they range from a simple one delivery pipeline to a system with a complex system of pumps, pipes of varying size and quality, with or without a storage tank, some conforming to national standards and some built without authorization by private entrepreneurs.

How can any given IWS be converted to a continuous supply system, comparable to water distribution normally seen in the most developed countries of Europe and North America?

A necessary precondition for expanding an existing IWS is that the main water transmission is in good working order and has adequate pressure, and pressure requires electricity. Water demand management is another crucial factor in moving from IWS to continuous water supply, as demonstrated by an important case study in Nagpur (India) in which IWS was converted to continuous water supply in order to learn lessons on how this exercise can be replicated in the rest of the country (Hastak et al., 2017). This study also shows that adequate pressure is a necessary part of supply management, which in turn requires a reliable electricity supply.

Prerequisite for expanding water supply: Finance first

Let us consider a sample of 16 Least Developed Countries and assess their potential for implementing continuous water supply, based on critical development and capacity factors, which are (1) GDP per capita, (2) potential to obtain foreign exchange through trade or borrowing, (3) the existence and size of electricity production, and (4) the existence of a skeletal network of pressurized water pipes that present the opportunity for extension by connecting additional small diameter pipes to this network.

Table 2 gathers together some basic data that can be used to assess the potential for continuous supply, either by a simple enrichment of the existing water infrastructure or by means of adding trickle fill systems to the skeletal network of water pipes. For this table, we have chosen countries with high populations that are getting by with erratic and irregular water supply, and in many cases with water sources that are unsafe. That should be clear from the last two columns of Table 2. While this is a one-year snapshot, the problem is chronic low per capita income, chronic lack of foreign exchange, chronic unsafe water, and continued deaths year after year due to unsafe water.

In order to assess the financial capacity to engage in infrastructure expansion, we collect two types of data: (1) we show, in the third column of Table 2, Exports minus Imports, to assess if the country has NET export earnings, which can be used to finance the purchase of water treatment plants, pipes and pumps; in the fourth column we show if a country has a "Current Account" surplus, which brings in other flows besides exports and imports of goods, such as net remittances of nationals working abroad, who send their money to their "home" country, to support other members of their families. The

Table 2. Assessing the potential for continuous water supply based on critical capacity factors.

Least developed country	GDP USD per capita, 2020	Exports minus Imports, 2020 USD millions	Current account balance/GDP % (latest year)	kWh Electricity Production per capita, 2019	Percent of population with access to safe drinking water (latest year)	Share of deaths (%) due to unsafe water in 2019	Debt/ GDP ratio (%)
Bangladesh	1,957	-19,199	0.34	489	58.5	3.73	30.1
Burkina Faso	809	+255	0.49	61	N.A.	5.7	27.0*
Burundi	254	-747	-17.29	30	N.A.	6.9	21.9*
Cambodia	1,605	-1,916	-11.46	460	27.8	1.3	22.5
Cameroon	-	-1,979	-5.33	337	N.A	4.6	34.7*
C. African Republic	479	-477	-8.11	32	6.2	9.5	38.1*
Chad	674	-52	-7.27	14	5.6	10.1	36.7*
Djibouti	3,264	-504	-1.00	42	N.A	3.3	-
D.R. Congo	529	+7,459	-2.31	127	19.0	4.1	12.9*
Eritrea	581	-420	-7.55	148	N.A.	6.7	175.6*
Ethiopia	812	-9,857	-2.91	130	12.6	6.5	28.4*
Ghana	2,202	2,043	-3.12	397	41.4	2.4	44.3*
Malawi	548	-2,053	-15.57	77	N.A.	5.2	28.4*
Mali	875	-954	-2.03	200	N.A.	6.8	36.3*
Mauritania	1,678	+86	-7.10	189	N.A.	4.7	73.1*
Niger	566	-1,380	-7.11	25	N.A.	8.2	34.9*
Contrast with a growing successful economy: A Success Story							
Vietnam	2,763	+20,105	+4.64	2,160	90	0.22	

*Countries identified as “highly indebted poor country” by the World Bank; they may be eligible for debt relief, if they meet certain criteria. N.A. means “not available.”
Sources: UNCTAD 2020 Report; World Bank Data, 2021; Hannah and Roser (2021); WHO and UNICEF (2020).

current account surplus means that the country has “hard currency” balances in foreign banks, which it can spend. If the current account balance is negative, it means that the country is in debt, or that its foreign exchange reserves abroad are falling or turning negative. A current account surplus usually indicates that the foreign earnings can be spent on buying foreign goods, like water treatment plants, pumps and pipes.

The overall negative balance on the current account year after year means a continual increase in external debt, with growing difficulties in servicing the debt. Hence, Table 2 should be read as the repetition of very similar grim data, year after year, for the last two or three decades for the Least Developed Countries (Easterly, 2001). That means growing external debt. We note that with the exception of Bangladesh and Cambodia (and of course Vietnam), all countries in Table 2 are classified as “highly indebted poor countries.” It is recognized that these countries will not be able to repay their debts; so, the IMF and the World Bank have initiated programs by which a great deal of the external debts may be partially or wholly cancelled, provided the country meets specified conditions.

Table 2 shows that this sample of 16 Least Developed Countries (taken from a UN list of 39) do not yet have the potential to earn enough foreign exchange through international trade to be able to import water treatment equipment and install a network of water infrastructure pipes. In addition, foreign aid will not help these countries as they do not have adequate electricity supply (Table 2, column 5) to carry out a program of water infrastructure expansion.

The lessons of economic development show that when countries have developed and climbed out of poverty, it has been through domestic income growth, implementing domestic production and import substitution, accompanied by earning foreign exchange through exports. This has been the path followed by Japan, China, Taiwan, and South Korea. Indeed, that is also the path that Vietnam has followed, as shown subsequently.

A SUCCESSFUL CASE STUDY: INFRASTRUCTURE EXPANSION IN VIETNAM

Vietnam has a population of 97.3 million (IEA, 2019). Over the past 3 decades it has progressed from a low to middle income country; its rate of poverty fell from 94.3% in 1992 to 22.4% by 2018 (Macrotrends, 2022). In December 1986, the government adopted the “Doi Moi” (open door) policy, shifting from a centrally planned economy to a market oriented one. Vietnam’s transformation from a largely agricultural to an increasingly industrial economy has turned the country, once considered one of Asia's poorest, into one of its fastest growing. It has emulated China in becoming an export-oriented economy (bottom row in Table 2).

The Asia Development Bank (ADB) has been a major partner in assisting Vietnam in urban water supply and sanitation. It has provided around $430 million (slightly less than 50% of the total external assistance in the sector) to Vietnam since 1993 (Asia Development Bank, 2009). The ADB has evaluated the implementation and performance of three loans and all were deemed to be satisfactory. Other loans from the World Bank for expanding water infrastructure have also been successfully used and all interest and loan repayments have been fulfilled on schedule. The adoption of market orientation meant the commercialization of all water and sanitation services for all urban areas. Decree 117 in 2007 mandated that all services move to full cost recovery, and provincial water utilities receive no operating subsidy. By 2010 most water supply companies were recovering their operation and maintenance costs, but budgets were typically set so low that service quality suffered, contributing to widespread problems of poor water quality, low pressure and intermittent supply. To date few, if any, utilities have achieved full cost recovery. A critical obstacle here has been the reluctance of People's Party Committees to raise tariffs to commercially viable levels. Nevertheless, great strides have been made, especially first in urban areas.

Vietnam began to set national targets for rural water supply and sanitation in 1999. In 2000, a 20-year plan, the first National Strategy for Rural Water Supply and Sanitation was adopted, and a second Plan was issued for 2006-2010. The total annual investment requirement, according to the Water Supply Program of the World Bank 2014 report, was as follows: rural water supply: $520 million, of which only a third had been secured by 2014; urban water supply: $1.04 billion, of which one-eighth had been secured by 2014. Nevertheless, as can be seen from the evidence given subsequently, Vietnam is credit worthy; and the borrowing agent is the Bank of Vietnam, which has always met its interest paying due dates on time, right up to 2022.

The Second Economic Development Plan of 2006 to 2010 proposed a major expansion of water infrastructure; doubling of water supply capabilities for industry and urban areas; provision of drinking water to 80% of urban residents and 60% of rural residents; reduction of flooding in the rainy season and an ensured water supply in cities; and provision for the increasing disposal of solid and liquid waste in the cities.

Electricity and water in Vietnam

A pressurized water distribution network, required as a precondition to expansion of the network through trickle fill will need adequate electricity. This is a brief review of evidence of the adequacy of electric power supply in Vietnam.

The state-owned Vietnam Electricity (EVN) was formed in June 2006 by converting the vertically integrated former Electricity of Vietnam into a holding company structure. EVN's operating units, consisting of power plants, regional power distribution companies, and power transmission system operator, have been converted into independent subsidiaries. According to the International Energy Agency (2019), electricity production in Vietnam in 2019 increased by 228.5% from 1990 (Figure 2). As shown at the bottom of Table 2 (last row), per capita electricity production in 2019 was 2,160 kWh. That row also shows a very large trade surplus (exports minus imports) in 2020, and a healthy current account surplus (last row, column 4), which means that Vietnam has adequate foreign exchange for needed imports of water treatment plants and import (or local manufacture) of the necessary water pumps and pipes.

Since its creation in 1996, EVN has had profitable operations. It has financed the rapid expansion of Vietnam's electricity sector without resorting to significant fiscal subsidies. Key financial performance indicators, such as the debt service coverage ratio, the self-financing ratio, and receivables, have been maintained at prudent limits.

According to the WHO/UNICEF joint monitoring program 2020 report, Vietnam is likely to be on track to achieve universal basic water and sanitation services by 2030 with an increase at the annual rate of 0.8 and 1.9%, respectively. In 2020, 90% of the population had improved water on their premises and 89% had improved sanitation facilities. However, there is a gap between urban and rural areas and among regions. According to a UNICEF report (2021) nearly 2.5 million people in the rural areas do not have access to clean drinking water, and 10 million people, mainly in rural areas, still cannot access basic sanitation facilities (UNICEF, 2021). But that too is being addressed by the adoption of the *National Strategy in Rural Water Supply and Sanitation by 2030, with a vision to 2045.* The objective of this Strategy is to ensure that over 62 million rural people have access to safely managed water supply and sanitation services.

However, many challenges remain. According to Vietnam's Ministry of Agriculture and Rural Development, only 51% of rural households have access to water that meets the Ministry of Health's water quality standard and that 44% of household water supplies that were tested in the study were found to have *E. coli* contamination. To reduce impacts of unsafe water and sanitation in the rural population, the National Strategy has set new goals for 2045: 100% of rural people will have access to safe and sustainable clean water and sanitation; 50% of rural residential areas will have domestic wastewater collection

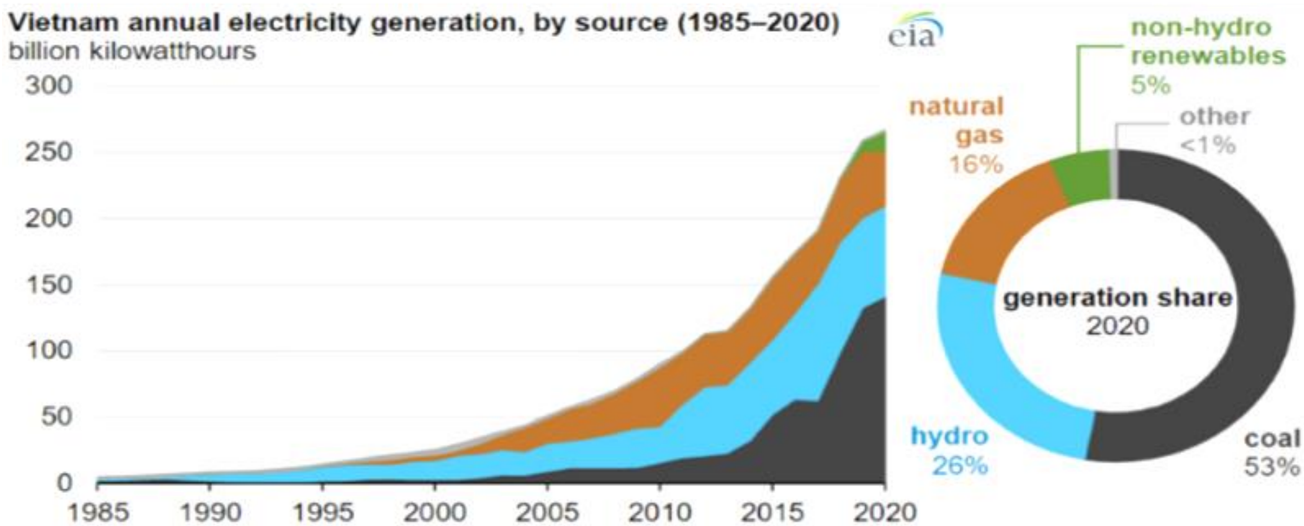

Figure 2. Electricity production in Vietnam, 1985-2020. Evidence of the adequacy of electric power supply in Vietnam, a precondition to expansion of the network through trickle fill. Reproduced from: U. S. Energy Information Administration, 2021 - Vietnam annual electricity generation by source in 1985 through 2020.

systems; 30% of domestic wastewater will be treated; 100% of livestock households and farms will have livestock waste treatment (UNICEF, 2021).

But note that surrounding the major cities are rural populations where the National Strategy in Rural Water Supply is being implemented. For example, for the Central Region, a rural supply project loan of US $50 million was obtained from the Asian Development Bank. A total of around 190,000 people in 48,000 households had been provided with piped water by 2017. Also 33 communes also received piped water. The number relying on dug or drilled wells in the communes fell from around 71,000 to 31,000. The ADB evaluation in 2019 showed that this project was a success (Asian Development Bank, 2019). Progress in implementing the strategy continues and the 2030 targets are likely to be met, project by project. Nevertheless, there is scope for optimizing the use of the major water trunk lines through investment in a larger trickle fill network, similar to the one in the City of Hanoi.

THE TRICKLE FILL SYSTEM FOR OPTIMIZING THE USE OF EXISTING WATERMAINS

A trickle fill system consists of *high-density polyethylene* (HDPE) piping with the appropriate size and pressure rating being connected to a watermain (Langford et al., 2012). For a water supply line that must meet the requirements of putting out fires, it is recommended that the HDPE pipe has a minimum diameter of 150 mm (6"); for other mainlines without the need for firefighting, a minimum diameter of 50 mm (2") would be adequate (Figure 3, for a schematic representation of a trickle fill system). The system requires that all end-users have on-site potable water storage tanks, called cisterns, as well as their own on-site pressure systems, where necessary. The water is delivered from a reservoir or high-pressure transmission line to a given community by a low-pressure, smaller diameter HDPE pipe main and, eventually, via branches to each individual customer cistern as shown in Figure 3.

To obtain an understanding of how a conventional property is connected to a municipal water treatment plant, considering Figure 4a, which shows water coming to a property *directly* from a municipal water treatment plant. To compare this with a property with a trickle fill connection (Figure 4b), in which an individual property has its own cistern or water holding tank that mimics a standard cistern in a conventional toilet, except that it is larger. In contrast to the full pressure municipal system, the end-of-the-line pressure of the low-pressure system constantly or "trickle" into each cistern, typically at a rate of approximately 2.3 L/min (0.5 imperial gallons/min) or 1.14 m^3/day (300 imperial gallons per day) (Langford et al., 2012). Usually, these systems are designed to maintain a minimum operating pressure of 138 kPa (20 psi) to mitigate the risk of ingress of contaminates from outside sources, especially in the event of a pipeline break (MPE Engineering Ltd, 2005).

Daily flow demands are satisfied over the course of the day from the holding tank rather than flowing instantaneously from a municipal water treatment plant. Since the cisterns' storage capacities provide for the only needs to be such that it allows the water to flow peak flows, the trickle fill distribution piping can be sized for average flow, translating to smaller pipe diameters, and thus, lower costs (Janzen et al., 2017). Langford et al.

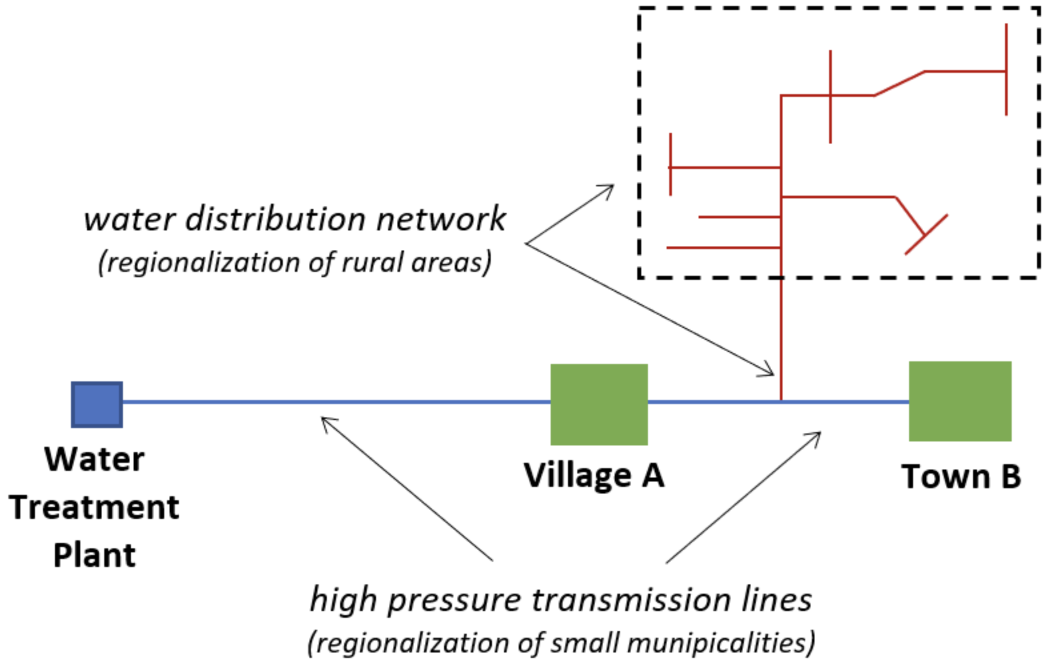

Figure 3. Trickle fill network connected to high pressure transmission line between Village A and Town B.

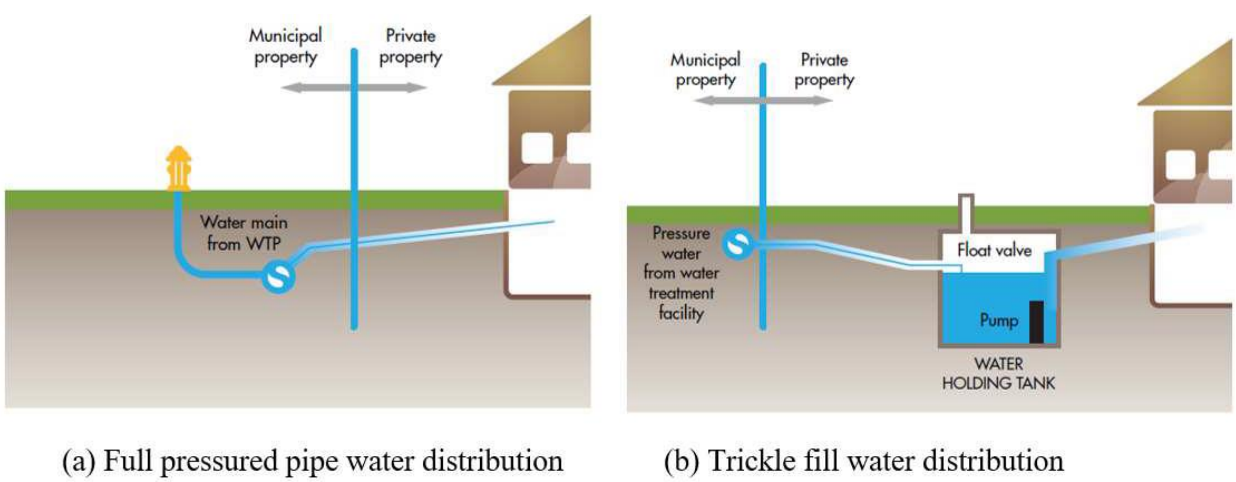

Figure 4. Supply from Municipal Water Treatment Plant Versus Trickle Fill from Holding Tank. Source: Regional Municipality of Wood Buffalo (2018).

(2012) recommend that the minimum piping diameter for the trickle fill branches be 50 mm (2 inch) in order to support future development and zoning changes. Most of the existing trickle fill pipes in Alberta have diameters ranging between 40 mm (1.5 inch) and 150 mm (6 inch) (MPE Engineering Ltd, 2005).

Furthermore, each customer's cistern is equipped with a flow emitter assembly (Figure 5) which moderates the intake: when the float drops, the float valve opens and allows the water to flow in at a rate dictated by the flow restricting orifice; when the float rises to the top, the valve closes and stops the inflow of water (Regional Municipality of Wood Buffalo, 2018). Typically, the water is distributed throughout each home by an automatic booster pump, often located in the bottom of the cistern. Each cistern should be sized such that it can provide the household peak demand which depends on factors such as the number, age, gender, and behaviors of the

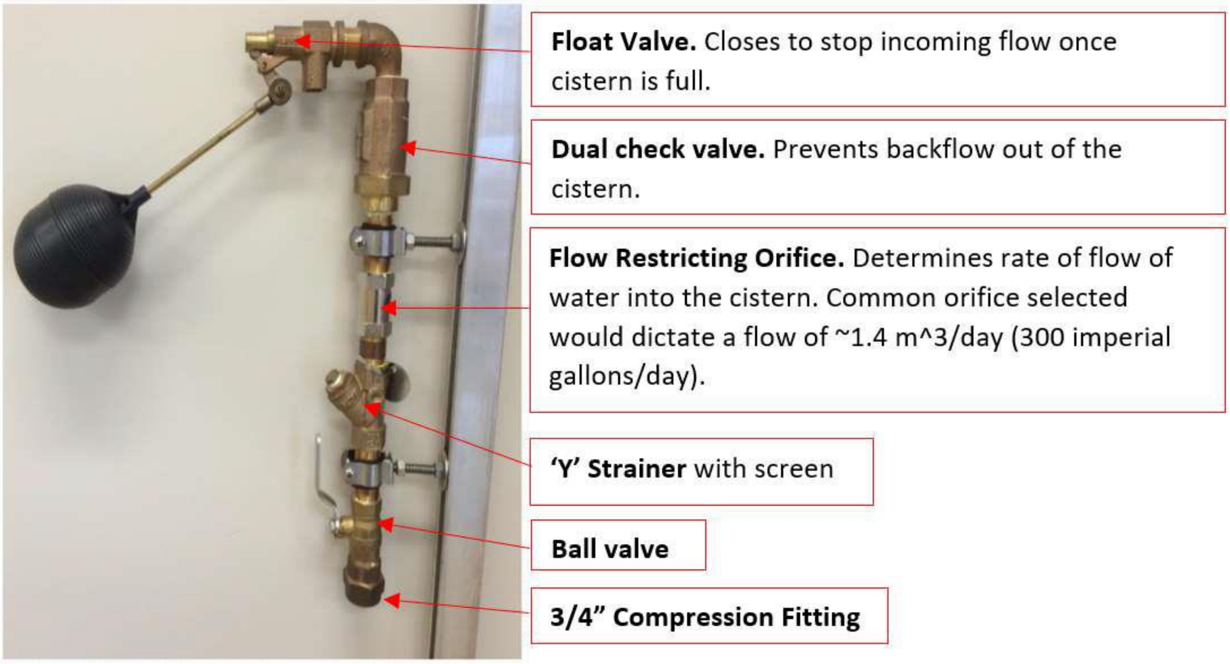

Figure 5. A flow emitter assembly for a cistern in a trickle fill system.
Source: Irwin (2018).

residents as well as the home's plumbing fixture characteristics.

Some valves and booster pumps for pressure control may also be required on a low-pressure system, depending on factors such as geography and expected loading; however, less of these will be required than on a conventional full-pressure system. Furthermore, installing flow restrictors onto household services could also reduce overall water demand and therefore allow the water system to stay pressurized. Instead of a system that allowed "maximum water quantity," a water utility could allow a fixed water quantity, a set amount per day regulated through a flow restrictor. This would reduce overall water demand and allow systems to stay pressurized, and hence facilitate continuous water supply and avoid interruptions. It is clear that a demand management strategy should be an integral part of the policy of eliminating IWS and replacing it with continuous water supply.

Some trickle fill systems in Alberta and Ontario

Drinking water trickle fill systems have been implemented in multiple places throughout Alberta including in Kneehill, Wheatland, Newell, Stettler, Starland, Lacombe, Lethbridge, and Cypress Counties. In approximately 20% (15 out of 72) of the rural counties and districts in Alberta, residents have connected to regional systems by implementing the trickle fill design (Roulston, 2017; Alberta Municipal Affairs, 2017). The Province of Alberta (Canada) continues to be a good candidate for using trickle fill as a way of optimizing the use of existing water treatment plant capacities, which tend to be "over-dimensioned" in order to meet peak water demands in the high summer when drought conditions are possible. As shown in Janzen et al. (2022), Alberta has a good network of main regional transmission pipes, with adequate pressure and uninterrupted power supply.

A similar trickle fill system also exists in Carlsbad Springs, in the rural outskirts of the City of Ottawa, which uses treated water from the City of Ottawa from a single watermain (Figure 6). The HDPE pipe used was of 2-inch diameter and no provision was made for firefighting. The original design was for 775 individual connections in the trickle fill system. While the majority of the connections supply water to single family homes, the capacity of the system allowed for a small number of large water users, such as a school, a hotel, a residential complex for seniors, a small apartment building, a golf course, and a recovery centre. As a result, the system was designed to accommodate a total of 829 "equivalent units", each limited to a tank re-supply rate of 2.7 m^3/day. No provisions were made for any growth beyond the 829 equivalent units (Ottawa City Infrastructure Policy Group, 2014).

The South Pacific Island country of Kiribati (Albetis and Lenehan 2003) and South Africa also have trickle fill systems in use (Scott and Tipping, 2001). The Carlsbad Trickle Feed System is perhaps one of the largest in

Figure 6. The 44 residential units of Carlsbad springs with trickle fill water supply, obtained from a single watermain from the city of Ottawa, Ontario, Canada.
Source: Ottawa City Infrastructure Policy Group, 2014, Page 12.

Canada. Its continuing success demonstrates not only the technical feasibility but also indicates social acceptance of trickle fill systems in provinces as diverse as Alberta and Ontario. Their success indicates that there is an existing knowledge base regarding the development and operation of trickle fill systems.

Hence, countries where an existing intermittent water supply is in a reasonably good state of repair and has adequate pressure, or where an upgrading pumping station either exists or is planned, could consider the use of a Trickle Fill Water Supply System, using the existing network as a nucleus.

Evidence of trickle fill systems in Vietnam

It should also be noted that a version of trickle fill already exists in the city of Hanoi, but with a slight difference. In Hanoi the trunk pipes have lower pressure (10 m, or 98.7 kPa), which is about one-third of the average pressure in US water treatment pipes (Derrible et al., 2022).

However, the cisterns in the Hanoi residents' homes fill up when the variable water supply and pressure are both available and are adequate. Hence, an adequate inventory of water is carried by the Hanoi households themselves. The cistern water can then be disinfected as and when required, using "point of use" filtration systems.

Incidentally, Vietnam is also innovating. Saldarriaga et al. (2020) report that the Hanoi reservoir, from which pipes emanate, has a constant pressure of 10 m (98.7 kPa), which is much lower than pressure in North American water networks. The whole Hanoi network comprises 34 pipes and 31 nodes configured in 3 loops. Apart from Hanoi, the major cities of Vietnam all have successful water utilities.

In urban centres of Vietnam there is the possibility of using cisterns and flow restrictors to manage demand and reduce peak water usage, allowing systems to maintain continuous water supply. In rural areas there is a possibility of using trickle fill to supply water to areas where the groundwater wells have been contaminated.

Given the availability of adequate electricity in Vietnam, all the remaining rural population could potentially receive continuous water supply through the implementation of a trickle fill system. That would accelerate Vietnam's current water supply plans, and may be cost-saving. Of course, the actual implementation of any particular rural area is location specific and a *pre-engineering* assessment of a given rural population can be carried out by the tools and a template covered in Irwin (2018) and published in Janzen et al. (2022), which show free web access to the socio-economic, pre-engineering assessment tools. The decision-making tool incorporates three main aspects: (a) economic feasibility, (b) energy requirements, and (c) environmental impacts, which include the *change* in the carbon footprint. A detailed explanation on how the template can be used is made freely available by the authors, and may be accessed via the University of Calgary's manuscript vault (Irwin, 2018) (https://prism.ucalgary.ca/handle/1880/109762).

Of course, before any actual investment occurs, the preliminary assessment must be followed with a *site-specific engineering* study to validate or refute any potential positive preliminary assessment.

Conclusion

The objective of this paper was to consider preconditions for expanding water infrastructure, improve access to drinking water and/or convert intermittent water supply to continuous water supply in homes and work places. Table 1 shows the problem of intermittent water supply was most severe in the (UN classified) Least Developed Countries. There are 39 countries under this classification. We considered a sample of 16 such countries with the objective of assessing their current capacity to make the transition to continuous water supply. These 16 countries have low per capita income and little or no foreign exchange that would be required to import, and no steel industry to manufacture locally, water infrastructure components, including water treatment plants, pumps and pipelines. Their plight is one of unsafe water and alarming numbers of associated deaths. They also do not yet have the electricity infrastructure that would be needed as a prerequisite for an extensive water network for continuous water supply. But *before an engineering study is commissioned to build a water treatment plant,* it is important to determine if the necessary finance is available to pay for it. When there is no domestic steel industry, it would be necessary to buy the treatment plant and pipes from abroad, that is, from a developed country supplier. That supplier will have to be paid in foreign currency. We know that foreign currencies are earned by exporting more than importing, or by maintaining a Current Account Surplus, or surpluses, to build up foreign reserves. For a developing country, it will be necessary to invest first in a "backbone" of water supply mains pipeline. This backbone can then be extended, by adding small diameter high- density polyethylene pipes that are called "trickle fill," to maximize the utilization of the backbone of the network, which typically maintains good pressure. Thus, a trickle fill addition, coupled with a demand management strategy, could eliminate supply interruptions and achieve continuous water supply.

Some countries have successfully transitioned out of 'least developed' status and one such country is Vietnam. There is hope that soon at least some of the 16 countries will show enough income and export growth to leave "Least Developed" category. For example, Bangladesh and Cambodia, with strong and growing export performance over the *next* decade, could emulate the example of Vietnam.

As far back as 1986, Vietnam adopted the principles of a market economy, and embarked on a policy of export led growth. It has successfully raised loans, and established long term development plans to bring continuous water to the cities. For rural areas, it adopted a Rural Water and Sanitation Strategy for the delivery of continuous water supply to rural areas by 2030, and at least by 2045. But in 2021, some 4% of the rural population was without access to continuous and safe water. Of course, the government's Rural Water Strategy Plan may include the usual approach to expanding water infrastructure, but in this paper, we suggest that an alternative lower cost approach be considered, and that alternative is Trickle Fill, in which existing pressurized pipes are connected to low diameter high density polyethylene pipes, with cisterns at the rural households, as in Hanoi, but extend it to other parts, mainly rural residents not too far from a water main. The Trickle fill solution, already adopted successfully in many parts of the world, would be worth considering not only in rural Vietnam, but also in other developing countries that have once invested in adequate electricity supply network.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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