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Upgrading Domestic-Plus Systems in Rural Senegal: An Incremental Income-Cost (I-C) Analysis

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ABSTRACT: There is growing evidence that rural and peri-urban households depend on water not only for basic domestic needs but also for a wide variety of livelihood activities. In recognition of this reality, an alternative approach to water service planning, known as multiple-use water services (MUS), has emerged to design water services around households' multiple water needs. The benefits of MUS are diverse and include improved health, food security, income generation, and women's empowerment. A common argument put forth by WASH sector professionals in favour of upgrading existing water systems is that productive water uses allow for income generation that, in turn, enhances the ability to pay for services. However, there has been limited rigorous research to assess whether the additional income generated from productive use activities justifies water service upgrading costs. This paper describes an income-cost (I-C) analysis based on survey data and EPANET models for 47 domestic-plus water systems in rural Senegal to assess whether the theoretical financial benefits to households from additional piped-water-based productive activities would be greater than the estimated system upgrade costs. The paper provides a transparent methodology for performing an I-C analysis. We find that the potential incremental income earned by upgrading the existing domestic-plus systems to provide intermediate-level MUS would be equivalent to the funds needed to recover the system upgrade costs in just over one year. Thus, hypothetically, water could pay for water. A sensitivity analysis shows that even with a 55% reduction in household income earned per cubic meter of water, the incremental income is still greater than the upgrade costs over a ten-year period for the majority of the systems.

KEYWORDS: Domestic-plus systems, intermediate-level MUS, multiple-use water services, rural water supply, incremental I-C analysis, Senegal

INTRODUCTION

Rural livelihoods depend on water. People use water for productive activities such as agriculture, gardening, horticulture, livestock-raising, car-washing, arts, ice-making, brick-making, pottery, butchery, and other small-scale commercial activities (van Koppen et al., 2009; Smits et al., 2010). Renwick et al. (2007) estimate that between 60-70% of the rural poor have some asset that relies on water, such as livestock, a small agricultural plot, or a small enterprise. Women are especially dependent on access to water for their homestead-based livelihood activities. Water provided for women's productive activities gives them an opportunity to diversify their livelihood activities and earn income from activities over which they have greater control (van Koppen et al., 2009; van Houweling et al., 2012). However, water supply programmes typically focus on providing water for a single use, either for basic domestic needs or for irrigation purposes (Faures and Santini, 2008; van Koppen et al., 2009; van Koppen et al., 2014).

Multiple-use water services (MUS) constitute an alternative approach to planning, designing, and managing water services to meet people's multiple water needs (Moriarty et al., 2004; van Koppen et al., 2006; Renwick et al., 2007). The MUS approach uses a participatory process to provide water services for rural and peri-urban people with diverse agriculture-based livelihood strategies, the majority of whom are poor (van Koppen et al., 2006; van Koppen et al., 2014). MUS do not necessarily require new technology, but rather call for the enhancement and integration of existing water technologies to make greater quantities of water available in a way that is best suited to the needs of rural households (Smits et al., 2010).

The extent to which households take up productive water uses depends on their level of water access as defined by variables such as water quality and quantity, reliability of supply, and distance (Katsi et al., 2007; van Koppen et al., 2009; Smits et al., 2010). These characteristics of access can be expressed in the form of a *water service ladder* (Renwick et al., 2007; van Koppen et al., 2009). At the basic domestic level, water is within one kilometre or a 30-minute round trip of the household (Renwick et al., 2007). The 10-25 litres per capita per day (lpcd) provided at this level only serves a few domestic needs. Basic-level MUS provide 15-50 lpcd within a 15-minute round trip walk for some livestock or for small gardens in addition to most domestic needs. Intermediate-level MUS meet all domestic needs and serve livestock, gardens, trees, or small enterprises by providing 40-100 lpcd within a 5-minute round trip from the household. Highest-level MUS provide water directly to households and serve all domestic and small-scale productive needs with more than 100 lpcd.

The growing body of research speaking to the benefits of MUS systems has attracted the interest of NGOs and other organisations seeking to provide water more equitably, sustainably, and efficiently. However, one key knowledge gap that remains is whether the additional benefits of increasing the quantity of water supplied for productive activities justify the costs of upgrading existing systems. Related questions concern the repayment period based on average annual financial benefits less annual recurrent costs and how to target high potential MUS markets. This information is critical to scaling up MUS in a sustainable manner.

One of the most comprehensive studies conducted on upgrading water supply systems to support MUS was based on a review of existing research and field observations of MUS in South Asia and sub-Saharan Africa (Renwick et al., 2007). This study concluded that there is a high benefit-cost ratio, especially for systems upgraded to support intermediate-level MUS (i.e. systems that provide improved access to 40-100 lpcd). They found that the costs of upgrading services to intermediate MUS levels can be repaid from the extra income generated within 13-30 months (Renwick et al., 2007). Another study conducted in two areas of the East Haraghe zone in Ethiopia by Adank et al. (2008) also found that there were high benefit cost ratios, and that, with relatively small additional costs, existing water supply systems could be upgraded to accommodate multiple uses. More recent research finds MUS to be a cost-effective way to provide water in almost all cases (Butterworth et al., 2013; van Koppen et al., 2014).

The study presented here contributes a methodology for assessing the financial benefits and costs of upgrading existing piped water supply systems in rural Senegal to support intermediate-level MUS. Using data from a large-scale study of 47 piped water supply systems, this paper addresses the question of whether the additional water provided can (theoretically) pay for itself.

The 47 systems studied in Senegal accessed groundwater using electric pumps powered by generators. Pumped water is stored in an above-ground water tank and distributed under gravity to the community via a piped distribution network. The systems were originally designed to support the productive use of water. For example, 43 of the 47 systems had at least one cattle trough. Of the remaining four systems, two had at least one water tank intended to provide water for small-scale agriculture (known locally as a 'bac jardin'). Thus, with the exception of two systems, the majority of communities surveyed could be considered to be served by domestic-plus systems. Given the existing quantities of water supplied, these systems can be classified as providing basic-level MUS. This study, therefore, focuses on upgrading these domestic-plus systems (i.e. systems that provide improved access to 15-50 lpcd) to provide intermediate-level MUS.

This study is unique because the financial benefits were calculated using data from the income module of a household survey which included all household-level water- and non-water-based activities. The costs of upgrading the systems to support intermediate-level MUS are based on EPANET models that consider water availability in Senegal. Thus, the financial analysis in this study is grounded in the local context leading to a reliable assessment of whether upgrading domestic-plus systems to support greater levels of productive activity is a worthwhile endeavour.

The following section describes the research methodology and outlines each step of the incremental I-C analysis. The results are then presented, followed by a discussion of the main findings and conclusion.

METHODOLOGY

Research design and sample frame

The data analysed in this paper were collected as part of an empirical study of the extent to which and conditions under which the productive use of rural piped water occurs in Senegal (van Houweling et al., 2012; Hall et al., 2014). The study targeted rural reticulated (i.e. piped) water systems that accessed groundwater via boreholes.

The research selected four administrative regions in the northern (St. Louis and Matam) and central (Diourbel and Kaffrine) zones of Senegal based on an assessment of the agricultural and livestock activity occurring within these regions. The southern zone was not selected due to its different geographical, hydrogeological, and climatic characteristics.

A database was created to document all of the rural piped water systems in these four administrative regions that had a functioning water committee – known as an ASUFOR (*Associations d'usagers de forage;* Associations of borehole users). For each system, preliminary data were developed on the extent of agricultural and livestock activity undertaken by households using a combination of existing public sources, data held by the in-country partner IDEV-ic (formerly known as Senagrosol), reconnaissance visits to each region, and phone conversations with ASUFOR members.

A stratified random sampling process was used to select 47 systems – 14 in Diourbel, 12 in Kaffrine, 10 in Matam, and 11 in St. Louis – based on varying levels of productive activity occurring in each region. This variation was necessary to identify the conditions under which high levels of productive activity occurred (Hall et al., 2014).

The fieldwork was completed from June to July, 2009, during which the following research activities were completed:

- 1860 household surveys;
- 47 community leader interviews;
- 46 water committee interviews;
- 44 water operator interviews;
- 15 focus groups with women; and
- 47 rapid (one-day) engineering assessments of the existing water systems.

The analysis in this paper draws primarily on data from the household surveys and the engineering assessments.

Household characteristics and community water sources

The typical household in our sample had a median of 11 persons living within a compound. The majority of respondents (86%) had lived in their community for over 20 years and nearly all (97%) owned their home. Education levels were low among the survey respondents and 86% had no formal education. Household median monthly income was US$121.00.[1] With regard to household assets, only a small number of households owned a bicycle (4%), television (18%), or motorcycle (3%), but eight out of ten (83%) households had a mobile phone. More than half of all households owned a plow (56%) and/or wooden cart (55%). Approximately one-third (31%) of the survey respondents were female.

Nine out of ten (89%) households surveyed used water from the piped system, from public and/or privately owned taps. Of these users, one-third (33%) used piped water for domestic uses only, 63% used the piped water for livestock, and 2% used piped water for crops. In addition to the piped system, public wells were utilised by 36% of households, rainwater collection by 15%, handpumps by 8%, and surface water by 7%.

The household survey revealed that 97% of all households undertook at least one form of productive activity (e.g. gardening, agriculture, livestock, commerce, services, and/or manufacturing). Three-quarters (74%) of households used water to support this productive activity with one-half (54%) using piped water (Hall et al., 2014).

EPANET hydraulic models

Using data from the 47 engineering assessments of the piped water systems, it was possible to create an EPANET hydraulic model for each system.[2] Data on the operation of the existing systems (e.g. hours of pumping) were used in the models to develop a daily flow rate for each system. This daily flow rate provided an estimate of the volume of water that should be available to each person living in the community. The purpose of these models was to replicate the existing water supply situation in each community.

The existing water supply for each system was then compared against a productive-use design flow (described in the following section) that was developed for each region. The productive-use design flows were created using data from the household survey and from a rural water supply project undertaken by the Directorate of Rural Water in Senegal (the Ministère de l'Agriculture et de l'Hydraulique) (PELTS, 2004).

The demand for additional water was confirmed from women's focus groups in 15 communities and household survey data. The focus groups revealed a demand among participants for increased water for productive activities, while at the same time acknowledging other constraints that limited their ability to scale up their water-based activities (van Houweling et al., 2012). In the household survey, among the 43% of households that identified water as a priority concern for government, two thirds (67%) reported insufficient water for domestic use, one-third (35%) reported insufficient water for livestock, and one-quarter (24%) reported insufficient water for crops. Based on these data, the

[1] The conversion rate used in this paper was USD 1.00 to 450 FCFA, which was the prevailing exchange rate at the time the analysis was undertaken.

[2] EPANET is a public domain water distribution system model that was developed by the U.S. Environmental Protection Agency (EPA). The hydraulic model can be used to simulate pressurised pipe networks of any size over extended periods and provides information such as pipe flows and pressure at junctions. For additional information, see www2.epa.gov/water-research/epanet.

productive-use design flows were set to levels that should enable households to satisfy *all* of their water demands using water from the piped system. This approach meant the design volumes were tailored to regions included in the study, rather than setting theoretical values that may not be suitable for local conditions.

If the volume of water provided by an existing system fell below the productive use design flow, an assessment was undertaken to identify the most cost-effective way to increase the flow of water to meet the design flow. System upgrades consisted of operational changes (e.g. additional hours of pumping) and/or system improvements (e.g. increasing the diameter of pipes, adding additional public taps/cattle troughs, etc). All the system upgrades were modelled in EPANET to ensure the piped water networks would function from a hydraulic perspective.

The cost of upgrading the existing systems is one component of the incremental I-C analysis. The second component is an estimate of the potential productive income that could be generated from the additional piped water provided.

The following section describes the process of calculating the productive-use design flows and how these were used to estimate the costs of upgrading the existing domestic-plus systems. The subsequent section provides information on how the incremental income from the additional piped water was calculated.

Developing the productive-use design flows

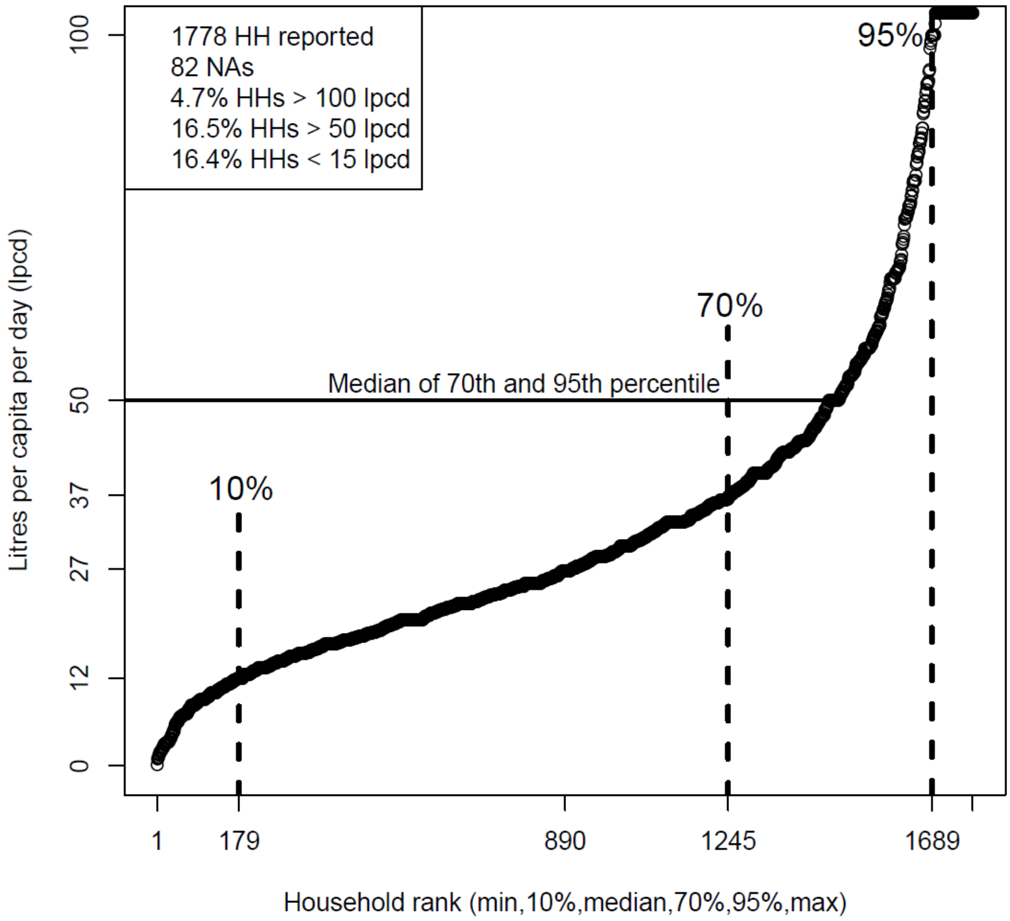
Figure 1 provides a graphical display of the total water volume (measured in lpcd) used by households from all sources.[3] The figure shows a continuum of low to high water use.[4] The median volume of water used by households *from all sources* in the 70-95 percentile range was exactly 50 lpcd – the value set for the productive-use design flow. This value represents a high level of water use in rural Senegal. Only 16.5% of the 1,778 households surveyed in Senegal use more than 50 lpcd (82 households had missing values for volume of water used). The median volume of water used by households from the piped water supply in the 70-95 percentile range was 36 lpcd.

With reference to the MUS water ladder, the existing piped water systems surveyed in Senegal can be described as providing basic-level MUS. This level of service is considered by Renwick et al. (2007) to support basic domestic activities including some combination of livestock raising, gardening, and possibly some small-scale enterprises. Setting the productive-use design flow in Senegal to 50 lpcd increases the level of service provided by these systems to intermediate-level MUS. The intermediate level of service is intended to provide greater access to improved and reliable water (in the range of 40-100 lpcd) that is close to the household (<5 minutes round trip, <150 m). The alignment between Renwick et al.'s (2007) MUS water ladder and the empirical analysis in this paper lends support to their level of service descriptions/categories.

[3] The 'all sources' variable includes water obtained from public/private taps, public/private wells, public/private handpumps, and water vendors, which were the dominant water sources in the communities included in the study. No data were collected in the household survey on the volume of water obtained from lakes, rivers, or rainwater.

[4] This general pattern is also reflected at the system level – i.e. within each of the 47 systems there is a continuum of low to high water users that follows the general shape of Figure 1.

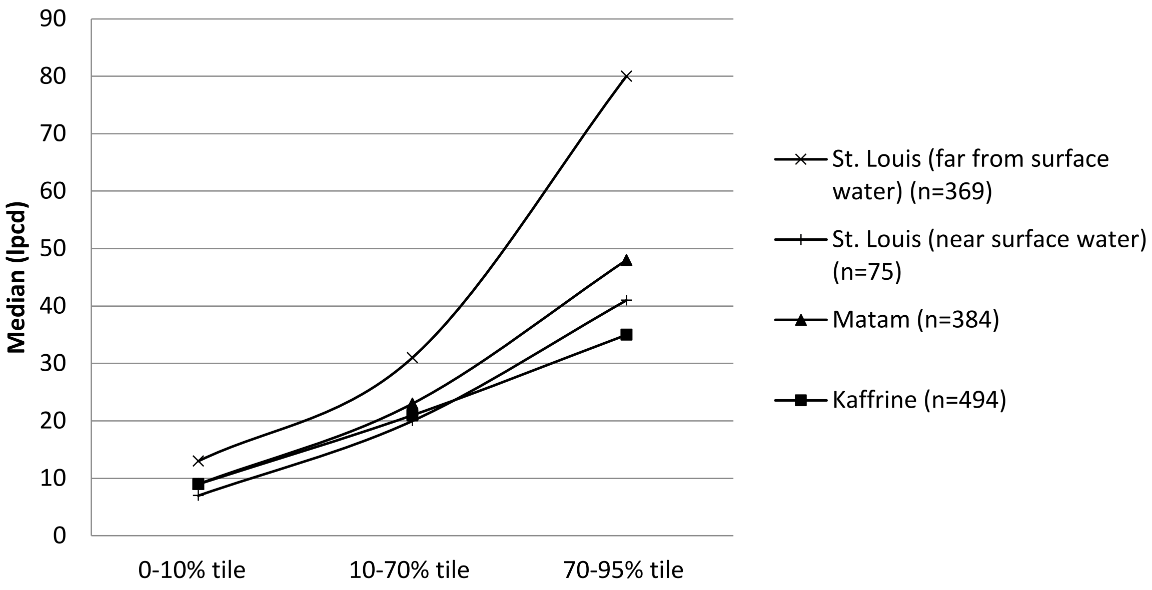
Figure 1. Volume of water used by each household (from all sources, lpcd).



An analysis of water consumption by region revealed an important difference between those systems located far from surface water in St. Louis and those systems located near surface water in this same region. The systems in the former group use significantly larger volumes of water from all sources (80 lpcd, Figure 2) and from the piped system (51 lpcd, Figure 3), when compared to the latter group (and all other regions). One explanation for this difference is the significant level of livestock activity that occurs in the St. Louis region. Around 90% of the households surveyed in St. Louis owned livestock compared to 52% in Kaffrine, 63% in Diourbel, and 75% in Matam. Further, the number of livestock units (LSU) owned by households in St. Louis was greater than in the other three regions.[5] Those households supported by systems located near surface water in St. Louis had the option of watering their livestock using nearby surface water sources. This option did not exist for households in systems located far from a surface water source, making these households more reliant on the piped water system to support their livestock, increasing their piped water consumption. If the systems in St. Louis located far from surface water are excluded, the water volume used by *high-water-use* households (i.e. households in the 70-95 percentile range of water use by volume) from the piped water system is consistent across all regions at around 33 lpcd (Figure 3).

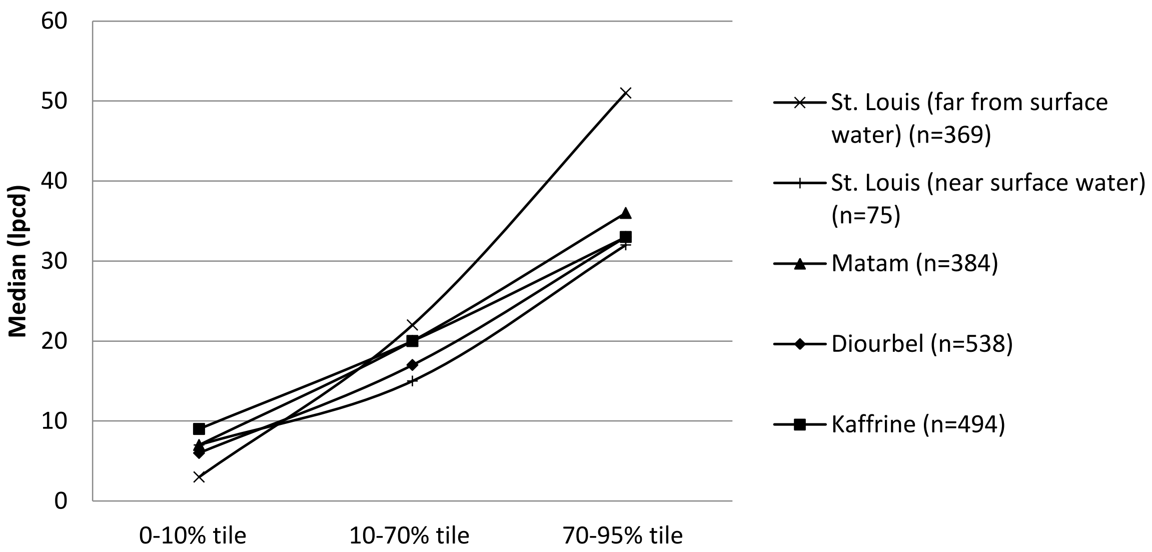
[5] For example, 84% of households in St. Louis had two or more cattle (or an equivalent number of LSU), compared to 44% in Kaffrine, 55% in Diourbel, and 59% in Matam.

Figure 2. Household median water consumption (lpcd) from *all sources* by percentile range.



Note: The data for Diourbel and Matam fall along the same line, except for the 0-10%tile range where the median lpcd values for Diourbel and Matam were 7 and 9, respectively. The Diourbel data is not shown on Figure 2.

Figure 3. Household median water consumption (lpcd) from *piped water* by percentile range.



Based on the above analysis, the following productive use design flows were set for each of the four regions:

- Diourbel, Kaffrine, Matam, and St. Louis (systems *near* surface water): 50 lpcd
- St. Louis (systems *far* from surface water): 80 lpcd

By comparing the productive-use design flow with the quantity of water provided by the existing system, it was possible to calculate how much additional water was needed to reach the design flow. This analysis revealed that 42 of the 47 systems required some form of improvement to increase the volume of water supplied.[6] Each of the 42 systems was assessed by experienced rural water system engineers at iDEV-ic (our in-country research partner) to find the most cost-effective way to upgrade its capacity. The system improvements included a combination of capital upgrades (such as the addition of public taps, the replacement of narrow pipes, or the installation of a more powerful water pump) and operational changes (such as increasing the hours of pumping). The determination of what capital upgrades were needed was based upon the ratio of the design flow to the existing flow. For example, if the productive-use design flow was 1.4 times the existing flow of a system, this factor was used to increase the number of public and private taps and cattle troughs connected to the piped network by approximately 40%. The EPANET models were also used to assess what other system upgrades were needed to supply the greater volume of water. The capacity upgrades were complicated by the need to proportion the quantity of water provided to public/private taps and cattle troughs. This issue was addressed by allocating 70% of the increase in supply to households and 30% to the cattle troughs distributed throughout the system. This division of water to household and livestock activities is consistent with water use patterns in rural Senegal (PELTS, 2004).[7]

Upon completing the above analysis, each of the 42 systems had two EPANET models. The first captured the existing water supply situation and the second modelled the upgraded system supplying the productive-use design flow. These models provided a detailed inventory of system components and operating procedures. The difference between the two models was used to develop a reasonable estimate of the likely system upgrades needed to increase the flow of water to meet the productive-use design flow. It should be recognised, however, that the EPANET models only provide a representation of the existing and upgraded systems. If the systems included in the study were actually targeted for an upgrade, a more detailed and time-intensive engineering assessment would be required to carefully document the site. Given this limitation, the cost of upgrading the existing systems was estimated by subtracting the cost of building the existing systems from the cost of building the upgraded systems (Table 1). See the Appendix to this paper for the system-level data that are summarised in Table 1. Regional-specific unit cost data provided by iDEV-ic were used to estimate the costs of building the systems.

[6] The water supply provided by four systems in St. Louis and one system in Matam were found to exceed the productive-use design flow – i.e. all households in these five systems could increase their level of productive activities and subsequent demand for water to 50 or 80 lpcd (depending on the productive-use design flow for the system) without any change to the existing configuration or operation of the piped water systems.

[7] The PELTS (2004) project found that rural households typically use around 25 lpcd from the piped water system to support domestic and productive activities. This figure falls in-between the volumes of water used by the *medium-* (10-70%tile) and *high-water-use* (70-95%tile) groups of households (see Figure 1). The PELTS (2004) project also found that around 70% (~17 lpcd) of the water used by rural households from the piped system was directed at household use (which can include household-based productive activities), with 30% (~8 lpcd) used to support livestock. Comparable data were obtained from the household surveys conducted for this research. For example, the median piped water consumption during the dry and wet season was 24 lpcd and 21 lpcd, respectively. Further, data from the income module of the household survey revealed that 6.6 lpcd (90% trimmed mean) of piped water was used to support livestock, which is around 30% (28% for the dry season and 31% for wet) of the total piped water volume consumed by households. Thus, designing piped water systems to ensure a 70:30 ratio of water for households (including domestic and productive activities) vs. livestock was considered a suitable approach for rural water systems in Senegal.

Table 1. Estimated incremental capital and O&M costs of upgrading systems to provide the productive-use design flows.

	Cost of building existing system (USD)	Cost of building existing system (USD per capita)	Annual O&M for existing system (USD)	Cost of building upgraded system (USD)	Cost of building upgraded system (USD per capita)	Annual O&M for upgraded system (USD)	Marginal capital costs (USD)	Marginal capital costs (USD per capita)	Marginal annual O&M (USD)
Median	326,976	102	16,003	357,105	114	21,583	28,403	7	3,517
Mean	390,050	128	18,776	438,158	139	24,813	48,108	11	6,037
St. Dev	239,084	108	14,533	290,381	109	17,822	64,203	11	7,567
N	47	47	47	47	47	47	47	47	47

Calculating the potential incremental income from the supply of additional piped water

The potential incremental income generated from providing additional water to households was calculated from the sample households' current level of productive income. The household survey included an income module that collected information on a wide range of water- and non-water-related income generating activities. If a household stated that it used water to support an income-generating activity, all of the reported income was included in one of the two productive income variables described below:

- *Productive Income (all sources)* = Productive income from *all water sources* (USD) (trimmed mean) / Volume of water used from all sources (m^3) (trimmed mean)
- *Productive Income (piped water)* = Productive income from *piped water* (USD) (trimmed mean) / Volume of water used from the *piped* system (m^3) (trimmed mean)

Both variables are reported in units of USD/m^3 (see Table 2). Trimmed mean values for the productive income and water volumes were used to limit the potential impact of outliers.

Table 2. Potential incremental income from the productive use of water (USD/m^3).

	Mean productive income (all sources) (USD/m^3)	Mean productive income (piped water) (USD/m^3)
All regions (n=47)	4.08	1.63
Diourbel (n=14)	2.53	2.12
Kaffrine (n=12)	1.06	0.92
Matam (n=10)	2.28	1.52
St. Louis (n=11)	10.98*	1.90
Near surface water (n=7)	10.87	0.89
Far from surface water (n=4)	11.05	3.66

* Households in St. Louis reported owning a large number of livestock units and generated significant levels of income from these activities. Since it was not possible to collect data on the volume of surface water consumed by livestock, the water consumption variable (the denominator) is likely to be underestimated, inflating the USD/m^3 value in this region.

Since the upgraded piped water systems should be able to meet *all* the potential household water demands, the *Productive Income (all sources)* variable could be considered a more appropriate estimate of the potential income that could be earned from the additional piped water. The lower level of income generating productive activities supported by piped water systems (when compared to income generating activities supported by all sources) means that the *Productive Income (piped water)* variable is generally a more conservative estimate.

Incremental income-cost (I-C) analysis

The objective of the I-C analysis was to determine whether the incremental income that could be generated from the supply of *additional* water for productive activities was greater than the estimated incremental costs associated with providing this water.

Table A2 in the Appendix presents data on the daily volume of water supplied by the existing and upgraded systems, and the difference between these two values. Five of the systems (27, 37, 40, 42, and 46) already (theoretically) provided sufficient water quantities for productive use activities and required no system upgrades. By multiplying the additional volume of water provided to each system by the productive use income variable for that system, it was possible to calculate the theoretical annual incremental income from water. The *net* annual incremental income was then calculated by subtracting the incremental annual Operation and Maintenance (O&M) (or recurrent) costs from the incremental annual income. The incremental annual O&M costs are the costs associated with providing the *additional* volume of water.

The analysis was then extended to determine whether the estimated net incremental income would be sufficient to cover the incremental capital costs over a ten-year period. For this analysis several assumptions were made. First, it was assumed that the system upgrades would continue to provide benefits for ten years beyond the year of the study. The mean age of the water systems in the sample was 17 (st. dev. 9), so it was assumed that the average system would be 27 years at the end of its working life. Since this estimate is likely to underestimate the longevity of the water systems in the study, it can be considered a conservative estimate of the future stream of financial benefits. To ensure that the results were consistent with similar assessments, a discount rate of 10% was selected (Renwick et al., 2007). Population growth was not considered in the calculation.

RESULTS

Can water (theoretically) pay for water?

The results from the initial I-C analysis indicated that, of the 42 systems that required some form of upgrade, only one had a negative net annual benefit when the *Productive Income (all sources)* variable was used, and six had a negative net annual benefit when the *Productive Income (piped water)* variable was used (see Table A3 in the Appendix to this paper).[8] This means that for the majority of the

[8] When looking at the results for the *Productive Income (all sources)* variable, System #17 is the only system where the annual O&M costs exceeded the potential productive income, making it impossible to generate any net annual financial benefit. Hence, the income-cost ratio was set to NA (not applicable). In addition to System #17, six systems (12, 15, 17, 25, 41, and 45) under the (more conservative) *Productive Income (piped water)* variable have an income-cost ratio of less than one. One reason for these poor income-cost ratios is that the range of values for the *Productive Income (piped water)* variable for these systems is low – i.e. from $0.02/m^3 to $0.61/m^3 (Table A2) compared to $1.63/m^3 for the sample-level *Productive Income (piped water)* variable (Table 2). This difference can be attributed to lower levels of income-generating productive activity supported by piped water on these systems when compared to the other systems.

upgraded systems,[9] the unadjusted incremental annual income would be greater than the incremental annual O&M costs. Thus, in this context, water could (theoretically) pay for water.

Table 3 presents the results as a ratio of incremental income to costs (I-C ratio). An I-C ratio < 1.0 indicates that the net annual financial benefits over ten years are less than the marginal capital costs. In contrast, an I-C ratio > 1.0 indicates that the theoretical financial benefits are greater than the theoretical marginal costs.

Table 3. Incremental cost analysis – repayment periods and income-cost (I-C) ratios.

		Productive Income (all sources)		Productive Income (piped water)	
		Repayment period (months)	I-C Ratio	Repayment period (months)	I-C Ratio
All systems	Median	12.6	5.9	16.1	4.6
	Mean	54.2	16.8	73.8	9.0
	St. Dev.	138.5	50.2	171.9	16.1
	N	41	41	36	36
Diourbel	Median	11.4	6.5	9.6	7.7
	Mean	23.8	7.4	80.3	7.1
	St. Dev.	32.3	4.4	211.2	4.8
	N	14	14	13	13
Kaffrine	Median	22.8	3.2	46.3	1.6
	Mean	134.3	3.8	103.9	3.4
	St. Dev.	251.1	3.2	217.6	3.1
	N	11	11	9	9
Matam	Median	7.2	10.3	10.9	6.7
	Mean	12.2	17.7	21.4	10.1
	St. Dev.	14.8	21.0	19.6	13.0
	N	9	9	9	9
St. Louis	Median	23.1	3.2	28.8	2.6
	Mean	43.0	54.8	97.3	21.6
	St. Dev.	58.5	118.2	142.1	39.4
	N	7	7	5	5

Assumptions: Discount rate = 10%. Duration of incremental benefits = 10 years. The financial return on the additional activities will be equal to the returns realised by current activities documented in the household survey (see the sensitivity analysis below).

The median I-C ratio for the sample is 4.6 when considering only productive income from piped water or 5.9 when taking into account productive income from all water sources; the mean I-C ratios are substantially higher due to the four systems having I-C ratios ranging from 36 to 320. At the regional level, the systems studied in Diourbel and Matam have, on average, a higher I-C ratio than the systems in Kaffrine and St. Louis. This result is primarily due to the higher piped-water-based income-generating activities of households in Diourbel and Matam (see the *Productive Income [piped water]*) column in Table A2, Appendix).

[9] Table 3 indicates that the incremental annual income was greater than the incremental annual O&M costs in 41 systems for the analysis using the *Productive Income (all sources)* variable and 36 systems for the analysis using the *Productive Income (piped water)* variable. The total number of systems selected for potential system enhancements was 42.

By dividing the incremental capital costs by the net annual incremental income, it was possible to obtain an estimate for the monthly repayment period associated with the system improvements (Table 3). That is, if all of the potential net annual incremental income were directed to repaying the incremental capital costs, how long would it take to recover the capital expenditure? The results of this theoretical analysis show that, for median income and cost values across the entire sample, the incremental capital costs of system upgrades could be recovered in just over one year (excluding those systems for which the net annual incremental income was negative).

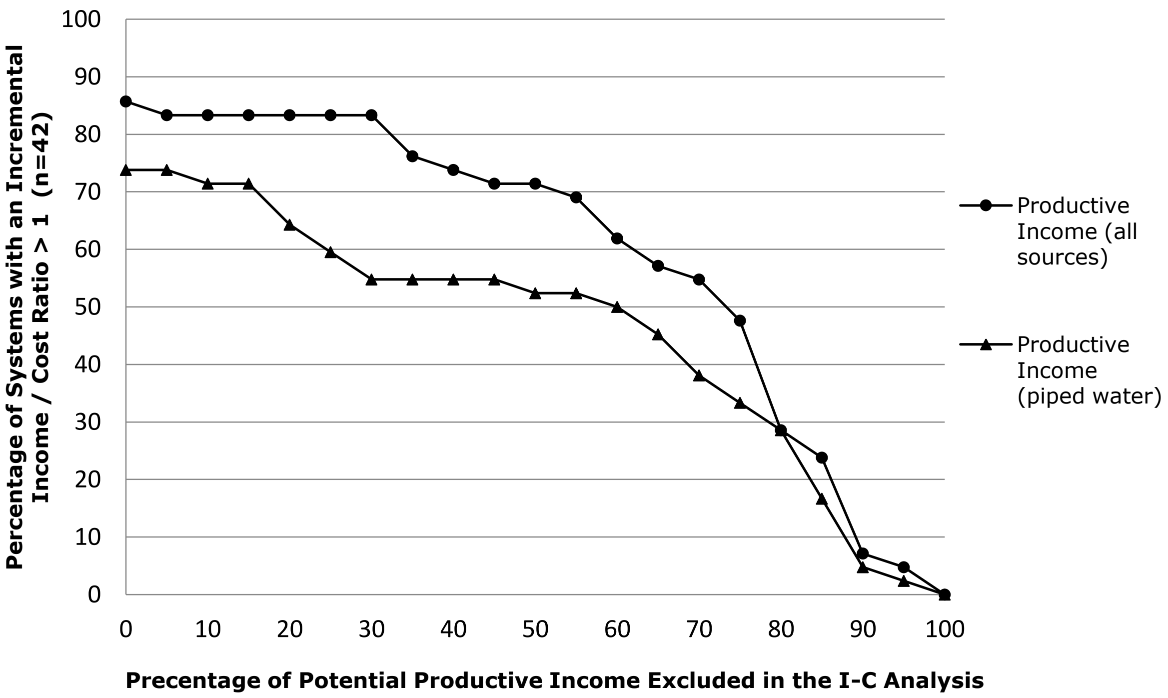
While this analysis is theoretical, it does indicate that the systems studied in Diourbel and Matam would be good candidates for piped water system improvements targeted at supporting productive activities.

Sensitivity analysis of the productive income variables

To focus the analysis on the potential for cost recovery within the water systems, the costs and benefits were limited to financial variables in order to reduce the uncertainty associated with the findings. However, in an effort to take into account the broad range of factors that could reduce the income variables – such as the availability of food for livestock or household credit to scale up productive activities – a sensitivity analysis was undertaken to determine how a reduction in the income variables might impact the I-C ratios. That is, what happens to the I-C ratio if the financial return on the additional productive activities is significantly less than the returns currently realised by households using water for income-generating activities?

Figure 4 shows how the percentage of systems with an I-C ratio > 1 changes as the value of the potential productive income (from all sources or piped water only) is reduced (n=42). As expected, the I-C analysis based on the *Productive Income (all sources)* variable, which accounts for all water-based income, has a higher percentage of systems with an I-C ratio > 1. The analysis shows that the majority of systems can tolerate a reduction of 55% in the value of both income variables before the number of systems that have an I-C ratio > 1 begins to fall.

Figure 4. Sensitivity analysis of the income-cost ratios.



DISCUSSION

While much research has documented the extent of productive water use in rural communities and the benefits of these activities, there are few studies on the financial viability of expanding water services to support increased levels of productive activity. This research builds on the multiple-use water service model by demonstrating that the incremental income generated from productive uses is likely to be greater than the incremental upgrade costs in areas where most households rely on productive use activities. Even with a 55% reduction in the income generated per cubic metre of water, over one-half of the systems still had a positive incremental I-C ratio.

This research provides empirical evidence that the water service ladder developed by Renwick et al. (2007) is a useful proxy for considering how different levels of service might align with greater engagement in productive activities. Using the water service ladder terminology, the domestic-plus systems studied in Senegal can be described as providing basic-level MUS (15-50 lpcd). The productive-use design flows developed for Senegal would increase the level of service to intermediate-level MUS (40-100 lpcd). The alignment between Renwick et al.'s (2007) study and this empirical analysis makes it possible to compare the results.

The I-C analysis highlights two findings that are broadly consistent with Renwick et al.'s (2007) analysis. First, the median I-C ratios (see Table 3) indicate that the scale of the incremental income is around five times that of the incremental costs over a ten-year period (with a 10% discount rate). Second, the incremental costs could be repaid in around one year if all the incremental productive income was used for this purpose. However, caution should be taken in interpreting these findings. The analysis is not meant to imply that water users will bear the full burden of cost recovery and payment for services, which may lead to the exclusion of the poorest groups (van Koppen et al., 2014). Rather, it is meant to provide some insight into the scale of productive income that could be generated, and how this compares with the cost of system upgrades.

The I-C analysis assumes that the *additional* water provided to households could be directly translated into additional productive income – i.e. that households would simply scale up their current productive activities in proportion to the additional water provided. This assumption follows Renwick et al.'s (2007) analysis where garden area and other productive activities were calculated based on a linear relationship with the quantity of water provided. Though this is a useful assumption for the analysis, there are constraints that can prevent households from scaling up their activities.

A household's ability to scale up its activities is likely to be affected by its access to resources (Jordans and Zwarteveen, 1997; Sijbesma et al., 2009; van Houweling et al., 2012). For example, women in Senegal reported that poor access to animal food and fodder, land, high-quality seeds, fertilisers, fencing, and other items prevented them from engaging at the level they desired (van Houweling et al., 2012).

The I-C analysis also assumes that there will be a market for the goods and services generated from the additional productive activities (i.e. the financial return on the additional activities will be equal to the returns realised by current activities documented in the household survey). In addition, the analysis is based on the premise that households would continue pursuing the same activities with the additional quantities of water provided. Therefore, an important question is whether the existing markets could absorb an increase in the availability of goods and services without seeing a significant decline in the prices households could command for their goods/services. A review of the market reveals there is likely to be growing consumer demand for additional products/services from productive activities, especially livestock products, but it is uncertain whether households could supply this demand due to inherent problems with the current market structure (IMF, 2007; Roland-Holst and Otte, 2007; SWAC-OECD and ECOWAS, 2008). Thus, any effort to scale up productive activities should be part of a wider initiative to improve market access and supply chains.

A sensitivity analysis was used to account for the uncertainties related to the productive income variable.[10] This analysis revealed that if households could generate only 45% of their existing water-based income from each additional unit of water, the incremental productive income generated would be greater than the incremental system upgrade costs for the majority of systems over a ten-year period.

Furthermore, this study has focused on the financial, rather than the full economic costs and benefits of domestic-plus systems. Including economic benefits such as those related to time savings,[11] improved health, food security, and social equity could significantly increase the benefit cost ratio. The economic benefits also do not include the averting of costs from non-planned uses and conflict (van Koppen et al., 2014). A full economic analysis would also need to take the opportunity cost of water into account, which could be significant in water-scarce areas.

The analysis in this paper assumed that all of the productive-use design flows would be provided through the rural piped water network. Under this scenario communities would be fully dependent on the rural piped water system. While this may be true in some cases, it is likely that many communities will have access to other (free) sources of water, such as artesian wells, ponds, and streams. Thus, while the results from the I-C analysis are informative, any action to promote productive use within communities needs to evaluate how multiple water sources could be used for different purposes.

One-fifth (20%) of the households surveyed in Senegal were found to *exclusively* use non-piped water to support their productive activities (Hall et al., 2014). Similar observations were found in comparable research undertaken in rural communities served by piped water systems in Colombia and Kenya (Hall et al., 2013). Further, focus group research with women in the study communities in Senegal highlighted the importance of traditional open wells and surface water sources for productive activities (van Houweling et al., 2012).

Given the existing use of non-piped water sources, it is important to consider how piped *and* non-piped sources can be better integrated into a multiple-use water service approach. By doing so it may be possible to reduce the volume of the productive-use design flows provided through the piped water network, reducing the needed incremental capital and O&M costs.

While it was necessary to constrain this analysis to answer the question of whether water can pay for water, the inclusion of the *Productive Income (all sources)* variable was intended to highlight the additional potential economic value of productive activities supported by non-piped water. Table A2 (Appendix) shows that for three quarters (74%) of the systems studied, the productive income generated from all water sources was greater than the income generated from piped water only. This means that the *Productive Income (all sources)* variable had the best performance in the I-C analysis (see Table 3 and Figure 4). The implication of this analysis is clear: any initiative focused on enhancing productive activities needs to include non-piped (traditional) water sources to realise the full economic impact that could be generated from productive activities.

[10] As mentioned under Table 2, the *Productive Income (all sources)* variable in St. Louis is considered to be inflated since it was not possible to collect data on surface water consumption by livestock. In contrast, the *Productive Income (piped water)* variable for St. Louis is considered to be more reliable since data were collected on piped water consumption by livestock. Since four systems in St. Louis (systems 37, 40, 42, and 46 – see Table A2, in the Appendix) with very high *Productive Income (all sources)* values were excluded from the analysis (because they did not require any system enhancements), the impact of these values on the analysis is limited.

[11] In several of the EPANET models for upgraded systems, additional water access points were added to a system to ensure it could function from a hydraulic perspective. While the majority of households would need to make additional trips to existing public taps to increase their levels of water consumption, the time burden for other households may be reduced if a new public tap were installed near their property. An assumption was made in the analysis that households would be able to find a way to increase both water use and income-generating activities at the household level.

Notwithstanding these issues, the I-C analysis provides an upper limit to the design of the water service where *all* the water is provided by the piped system. If this assumption is relaxed and additional water can be obtained from non-piped (traditional) sources at limited or no cost, the cost of the piped water system upgrades could be reduced. This reduction in the incremental costs could have a significant positive impact on the I-C analysis if the level of incremental productive income is sustained. Put differently, if the results from the I-C analysis are positive, it provides a signal that increasing the supply of water for productive activities – and moving communities from basic- to intermediate-level MUS – is worth further exploration.

CONCLUSION

This paper provides empirical evidence that the theoretical financial benefits from additional piped-water-based productive activities are greater than the estimated system upgrade costs for the majority of domestic-plus water systems studied in rural Senegal. That is, if *all* of the incremental productive income earned from the additional piped water supply were used to pay for the estimated incremental O&M and capital upgrade costs, the incremental income would be greater than the incremental costs for the majority of systems, even with a 55% reduction in the expected level of income from productive activities. This finding demonstrates only that the scale of the incremental income is likely to be greater than the incremental costs and does not address whether these costs should be covered by the water users, community, or local/national government. The analysis also revealed how the extent of productive activity undertaken by households varies by region, implying that any programme designed to scale up MUS in Senegal may need to be tailored to expand existing, or initiate new, productive activities.

The results from this analysis are broadly consistent with those from Renwick et al.'s (2007) study of MUS. For example, the I-C analysis and Renwick et al.'s (2007) study both indicate that upgrading water services from basic- to intermediate-level MUS could generate sufficient productive income to theoretically repay the incremental costs within approximately one year. In addition, the development of the productive-use design flows showed that Renwick et al.'s (2007) water services ladder provides a useful framework for categorising different levels of MUS.

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APPENDIX

Table A1. Incremental capital and O&M costs of systems to provide the productive use design flows.

ID	Cost of building existing system (USD)	Cost of building existing system (USD per capita)	Annual O&M for existing system (USD)	Cost of building upgraded system (USD)	Cost of building upgraded system (USD per capita)	Annual O&M for upgraded system (USD)	Marginal capital costs (USD)	Marginal capital costs (USD per capita)	Marginal annual O&M (USD)
1	1,384,970	107	24,315	1,671,141	129	35,248	286,170	22	10,933
2	842,675	77	39,426	973,024	89	52,582	130,349	12	13,156
3	997,462	89	18,704	1,037,567	93	21,583	40,105	4	2879
4	230,588	113	5838	267,605	131	11,554	37,017	18	5716
5	352,030	38	7415	406,078	44	9209	54,048	6	1794
6	224,316	152	5541	243,105	165	8545	18,790	13	3004
7	774,599	74	18,463	1,076,312	103	31,343	301,713	29	12,880
8	339,275	125	8796	357,105	131	11,259	17,830	7	2462
9	338,075	154	6345	358,352	163	7211	20,277	9	867
10	443,972	114	8119	512,616	132	13,309	68,644	18	5190
11	493,455	117	10,441	576,556	136	20,907	83,102	20	10,467
12	313,254	133	7828	347,321	148	11,345	34,068	14	3517
13	696,380	125	16,328	886,948	159	39,935	190,568	34	23,607
14	294,231	100	4563	339,965	115	8530	45,733	15	3967
15	562,629	28	29,127	671,717	34	54,739	109,088	5	25,611
16	213,524	47	16,003	219,955	49	17,332	6430	1	1329
17	342,300	62	32,273	370,703	67	40,487	28,403	5	8214
18	460,226	96	33,267	499,366	104	37,190	39,140	8	3923
19	564,683	104	19,885	618,041	114	25,624	53,358	10	5739
20	224,843	112	14,190	232,490	116	16,614	7647	4	2425
21	399,606	54	14,284	437,791	59	19,038	38,185	5	4755
22	218,733	139	8257	292,391	186	8765	73,658	47	508
23	404,758	90	18,721	429,625	95	22,920	24,867	6	4198
24	577,584	71	15,039	674,670	83	22,911	97,086	12	7871
25	318,995	53	40,959	325,354	54	44,519	6358	1	3560
26	423,153	134	7706	453,445	144	10,678	30,292	10	2972
27	329,068	54	26,359	329,068	54	26,359	0	0	0
28	234,564	40	18,893	257,865	44	25,937	23,301	4	7044
29	386,978	87	22,933	448,625	101	24,384	61,646	14	1451
30	326,976	44	18,077	379,527	51	26,784	52,551	7	8708
31	442,862	25	39,428	487,201	27	47,825	44,339	2	8396
32	282,202	66	21,824	303,508	71	29,743	21,307	5	7919
33	325,048	65	10,901	369,039	74	13,490	43,991	9	2589
34	218,590	73	7619	228,366	77	10,324	9776	3	2706
35	228,494	79	9919	238,294	83	12,086	9800	3	2167
36	316,521	113	5435	331,440	118	6579	14,919	5	1144
37	633,692	423	51,019	633,692	423	51,019	0	0	0
38	168,983	155	31,023	171,256	157	33,168	2273	2	2145
39	158,605	135	12,512	185,367	158	26,500	26,762	23	13,988
40	420,022	507	17,832	420,022	507	17,832	0	0	0
41	219,479	157	28,365	229,184	164	38,410	9705	7	10,044
42	176,113	342	75,296	176,113	342	75,296	0	0	0
43	219,149	64	37,717	253,493	74	77,919	34,344	10	40,202
44	265,337	102	5470	290,482	112	7047	25,145	10	1577
45	130,789	295	2407	150,661	339	3830	19,871	45	1422
46	134,581	471	6123	134,581	471	6123	0	0	0
47	277,968	229	1474	296,394	244	2182	18,426	15	708

Table A2. Water supply from existing and upgraded water supply systems.

ID	Region	Pop. served	Existing system supply		Upgraded system supply		Additional water provided (m^3/day)	Prod. income (all sources) (USD/m^3)	Prod. income (piped water) (USD/m^3)
			m^3/day	lpcd	m^3/day	lpcd			
1	DIOURBEL	12,946	400	31	647	50	247	5.10	0.17
2	DIOURBEL	10,904	400	37	545	50	145	1.03	0.52
3	DIOURBEL	11,159	480	43	558	50	78	1.54	2.11
4	DIOURBEL	2049	40	20	102	50	62	3.44	3.55
5	DIOURBEL	9288	300	32	464	50	164	1.70	1.34
6	DIOURBEL	1477	40	27	74	50	34	1.75	2.14
7	DIOURBEL	10,415	185	18	521	50	336	2.45	2.64
8	DIOURBEL	2721	96	35	136	50	40	1.95	2.47
9	DIOURBEL	2200	90	41	110	50	20	2.69	2.09
10	DIOURBEL	3879	100	26	194	50	94	4.41	3.74
11	DIOURBEL	4226	95	22	211	50	116	0.49	0.60
12	DIOURBEL	2353	70	30	118	50	48	0.42	0.15
13	DIOURBEL	5580	85	15	279	50	194	6.73	6.94
14	DIOURBEL	2955	60	20	148	50	88	1.67	1.23
15	KAFFRINE	20,000	480	24	1,000	50	520	0.15	0.07
16	KAFFRINE	4500	196	44	225	50	29	0.45	0.26
17	KAFFRINE	5500	220	40	275	50	55	0.38	0.38
18	KAFFRINE	4814	200	42	241	50	41	2.58	2.15
19	KAFFRINE	5425	198	36	271	50	73	3.03	3.34
20	KAFFRINE	2001	80	40	100	50	20	2.10	1.48
21	KAFFRINE	7363	240	33	368	50	128	0.53	0.28
22	KAFFRINE	1574	70	44	79	50	9	0.60	0.57
23	KAFFRINE	4505	175	39	225	50	50	0.79	0.58
24	KAFFRINE	8152	240	29	408	50	168	0.55	0.54
25	KAFFRINE	6024	270	45	301	50	31	0.59	0.29
26	KAFFRINE	3153	100	32	158	50	58	0.93	1.10
27	MATAM	6060	300	50	300	50	**0**	2.04	1.98
28	MATAM	5879	200	34	294	50	94	1.36	1.40
29	MATAM	4424	200	45	221	50	21	2.16	1.91
30	MATAM	7500	240	32	375	50	135	1.59	1.87
31	MATAM	18,000	648	36	900	50	252	5.34	3.46
32	MATAM	4277	150	35	214	50	64	1.61	1.34
33	MATAM	5000	200	40	250	50	50	1.52	1.01
34	MATAM	2984	100	34	149	50	49	3.34	1.24
35	MATAM	2888	110	38	144	50	34	1.48	0.37
36	MATAM	2797	100	36	140	50	40	2.37	0.59
37	ST. LOUIS	1499	520	347	520	347	**0**	18.56	5.12
38	ST. LOUIS*	1090	80	73	87	80	7	8.06	2.63
39	ST. LOUIS*	1171	40	34	94	80	54	0.94	1.28
40	ST. LOUIS	828	180	217	180	217	**0**	23.94	0.11
41	ST. LOUIS*	1395	80	57	112	80	32	0.93	0.61
42	ST. LOUIS	515	450	874	450	874	**0**	13.90	0.35
43	ST. LOUIS*	3428	125	36	274	80	149	33.54	10.12
44	ST. LOUIS	2599	84	32	130	50	46	0.77	0.15
45	ST. LOUIS	444	6	14	22	50	16	3.13	0.02
46	ST. LOUIS	286	30	105	30	105	**0**	15.26	0.00
47	ST. LOUIS	1216	45	37	61	50	16	1.78	0.46

* Systems in St. Louis located far from surface water.

Table A3. I-C ratios and repayment periods (months) relating to system enhancements for each productive income variable.

		Productive income (all sources) variable				*Productive income (piped water)* variable			
		Annual potential productive income from additional water volume (USD)	Annual potential NET productive income from additional water volume (USD)	Repay-ment period (months)	I-C ratio	Annual potential productive income from additional water volume (USD)	Annual potential NET productive income from additional water volume (USD)	Repay-ment period (months)	I-C ratio
1	DIOURBEL	460,440	449,506	7.6	9.65	15,359	4426	775.9	0.10
2	DIOURBEL	54,389	41,233	37.9	1.94	27,802	14,646	106.8	0.69
3	DIOURBEL	43,813	40,934	11.8	6.27	60,072	57,192	8.4	8.76
4	DIOURBEL	78,319	72,604	6.1	12.05	80,808	75,092	5.9	12.46
5	DIOURBEL	101,853	100,058	6.5	11.38	80,125	78,331	8.3	8.91
6	DIOURBEL	21,617	18,612	12.1	6.09	26,435	23,430	9.6	7.66
7	DIOURBEL	300,180	287,300	12.6	5.85	323,575	310,695	11.7	6.33
8	DIOURBEL	28,571	26,109	8.2	9.00	36,124	33,661	6.4	11.60
9	DIOURBEL	19,621	18,755	13.0	5.68	15,290	14,423	16.9	4.37
10	DIOURBEL	151,268	146,078	5.6	13.08	128,252	123,062	6.7	11.02
11	DIOURBEL	20,587	10,121	98.5	0.75	25,417	14,951	66.7	1.11
12	DIOURBEL	7746	4229	96.7	0.76	2759	*Negative*	NA	NA
13	DIOURBEL	476,824	453,217	5.0	14.61	491,633	468,026	4.9	15.09
14	DIOURBEL	53,626	49,660	11.1	6.67	39,252	35,286	15.6	4.74
15	KAFFRINE	27,631	2020	648.1	0.11	13,053	*Negative*	NA	NA
16	KAFFRINE	4778	3449	22.4	3.30	2804	1475	52.3	1.41
17	KAFFRINE	7552	*Negative*	NA	NA	7531	*Negative*	NA	NA
18	KAFFRINE	38,399	34,476	13.6	5.41	31,990	28,067	16.7	4.41
19	KAFFRINE	81,003	75,264	8.5	8.67	89,166	83,427	7.7	9.61
20	KAFFRINE	15,387	12,962	7.1	10.42	10,845	8420	10.9	6.77
21	KAFFRINE	24,815	20,060	22.8	3.23	13,129	8374	54.7	1.35
22	KAFFRINE	1899	1391	635.4	0.12	1804	1296	681.9	0.11
23	KAFFRINE	14,492	10,294	29.0	2.54	10,624	6425	46.4	1.59
24	KAFFRINE	33,824	25,953	44.9	1.64	33,020	25,149	46.3	1.59
25	KAFFRINE	6764	3204	23.8	3.10	3338	*Negative*	NA	NA
26	KAFFRINE	19,531	16,558	22.0	3.36	23,082	20,110	18.1	4.08
27	MATAM	0	0	NA	NA	2164	0	NA	NA
28	MATAM	46,757	39,712	7.0	10.47	48,123	41,079	6.8	10.83
29	MATAM	16,690	15,239	48.5	1.52	14,811	13,360	55.4	1.33
30	MATAM	78,333	69,626	9.1	8.14	92,305	83,597	7.5	9.77
31	MATAM	490,934	482,537	1.1	66.87	318,642	310,245	1.7	42.99
32	MATAM	37,619	29,700	8.6	8.57	31,271	23,352	10.9	6.73
33	MATAM	27,729	25,140	21.0	3.51	18,440	15,851	33.3	2.21
34	MATAM	59,897	57,191	2.1	35.95	22,206	19,501	6.0	12.26
35	MATAM	18,590	16,423	7.2	10.30	4690	2523	46.6	1.58
36	MATAM	34,459	33,315	5.4	13.72	8610	7466	24.0	3.08
37	ST LOUIS	0	0	NA	NA	0	0	NA	NA
38	ST LOUIS	21,188	19,043	1.4	51.48	6921	4776	5.7	12.91
39	ST LOUIS	18,459	4471	71.8	1.03	25,156	11,168	28.8	2.56
40	ST LOUIS	0	0	NA	NA	0	0	NA	NA
41	ST LOUIS	10,754	710	164.0	0.45	6984	*Negative*	NA	NA
42	ST LOUIS	0	0	NA	NA	0	0	NA	NA
43	ST LOUIS	1,827,147	1,786,944	0.2	319.71	551,148	510,946	0.8	91.41
44	ST LOUIS	12,909	11,332	26.6	2.77	2,469	891	338.5	0.22
45	ST LOUIS	18,500	17,078	14.0	5.28	132	*Negative*	NA	NA
46	ST LOUIS	0	0	NA	NA	0	0	NA	NA
47	ST LOUIS	10,283	9576	23.1	3.19	2,668	1960	112.8	0.65

Note: A '*Negative*' result means that the annual potential productive income from the additional water provided was less than the annual incremental O&M (or recurrent) costs of providing this water.