A Well Construction Cost-Benefit Analysis (CBA): For Water Supply Well Guidelines for use in Developing Countries

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Abstract

This report is an economic cost-benefit analysis that considers the differences between properly and inferiorly constructed and maintained groundwater wells in developing countries, using rural Kenya as a case study. Factors of influence include the lifespan of the well, the number of beneficiaries, project expenses, environmental and health consequences, and other economic factors. The results highlight the importance of the role of proper construction, operation, and maintenance in realizing the full benefits potential of a new water well. Even if inferior construction methods do not cause more serious issues, the typical reduction in lifespan means only 30 percent of the potential benefits are provided. With the prospect of groundwater contamination and aquifer damage, the benefits may even be reduced to zero. This paper argues that saving a few thousand dollars up front, as tempting at it may be, is not worth this risk. Well construction approaches that provide cost savings should be carefully assessed to avoid (1) increasing associated environmental and health risks and (2) reducing the anticipated lifespan of the project.

About the Author

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Introduction

The objective of this paper is to discourage taking shortcuts to 'save money' on well projects in developing countries. This will be accomplished by illustrating the value of clean water provided by a properly constructed and maintained drinking water well in comparison to alternative shortcut scenarios. The method used is an economic cost-benefit analysis (CBA) with project variables for the quality of construction and maintenance. CBA is commonly employed for analysis of project alternatives, particularly for organizations with a public service orientation. This is because CBA goes beyond cash-flow accounting to include additional project costs and benefits, such as environmental damage or health improvements. Although CBA cannot provide definitive answers, it can be useful when taken for what it is – one tool in the decision making toolbox. Countless organizations use CBA regularly, including the World Health Organization and the World Bank.

For this CBA, values employed are largely based on literature values. Because the magnitude of cost and benefit estimates can vary by locale, this analysis will consider a project to construct a drinking water well fitted with a handpump in rural Kenya. However, the methods presented should be easily transferred to other comparable contexts. The first thing to set is the number of beneficiaries of the proposed project. The number of people served by a well depends on the yield of the well, the population density surrounding the location of the well, and the availability of water from other sources. This analysis uses the widely accepted norm for a pipe tap or hand pump of 250 people per source (Reed, 2005, p. 3; World Health Organization, 2004, p. 16).

The steps of an economic cost-benefit analysis (CBA) include identifying what alternatives will be analyzed, deciding which costs and benefits to include, predicting those costs and benefits over the life of the project, monetizing impacts, and discounting to obtain present discounted values as necessary. Rogers, Bhatia, & Huber (1998) provide the framework for assessing water as a socioeconomic good that will be used in this paper. They suggest the consideration of the following costs: Capital Charges, Operation and Maintenance (O&M) Cost, Opportunity Cost, Economic Externalities, and Environmental

Externalities. Meanwhile, benefits include the Value to Users of Water, Net Benefits from Return Flows, Net Benefits from Indirect Uses, Adjustment for Societal Objectives, and Intrinsic Value. All of these terms are described in more detail in Table 1. Figures 1 and 2 further illustrate the full array of costs and benefits.

Table 1 - Descriptions of the CBA components (Rogers et at., 1998)

Potential Costs	
Capital Charges	These include the up-front costs for the project and may or may not incorporate depreciation.
O&M Cost	These are the operation and maintenance costs for running the system. Examples include electricity, labor and materials, and management.
Opportunity Cost	This accounts for the fact that resources dedicated to the project under consideration could be used for something else. One example is use of water for one purpose that detracts from another use (water for drinking reduces the amount available for agriculture). Another example is uncompensated time spent on the project by beneficiaries when they could otherwise be earning an income. It can also be referred to as the social marginal cost.
Economic Externalities	Externalities are costs that are not otherwise accounted for. Economic Externalities are those which directly impact the economy, such as an upstream diversion that limits access to water for a downstream business. Note that externalities can be positive or negative.
Environmental Externalities	Externalities are costs that are not otherwise accounted for. Environmental externalities are those which affect public health and/or ecosystems. Note that externalities can be positive or negative.
Potential Benefits	
Value to Users of Water	This is what the water is worth to the project beneficiaries.
Net Benefits From Return Flows	Return flows are water that is diverted back into the hydrologic system, such as irrigation water that recharges groundwater.
Net Benefits from Indirect Uses	These are secondary benefits that are not the primary objective of the project, such as livestock use of an irrigation system.
Adjustment for Societal Objectives	These are gains to society beyond the value to users of water. Examples are poverty alleviation, public health, employment, and food security.
Intrinsic Value	These include non-use based value, such as the desire for aesthetically pleasing water views or environmental stewardship.

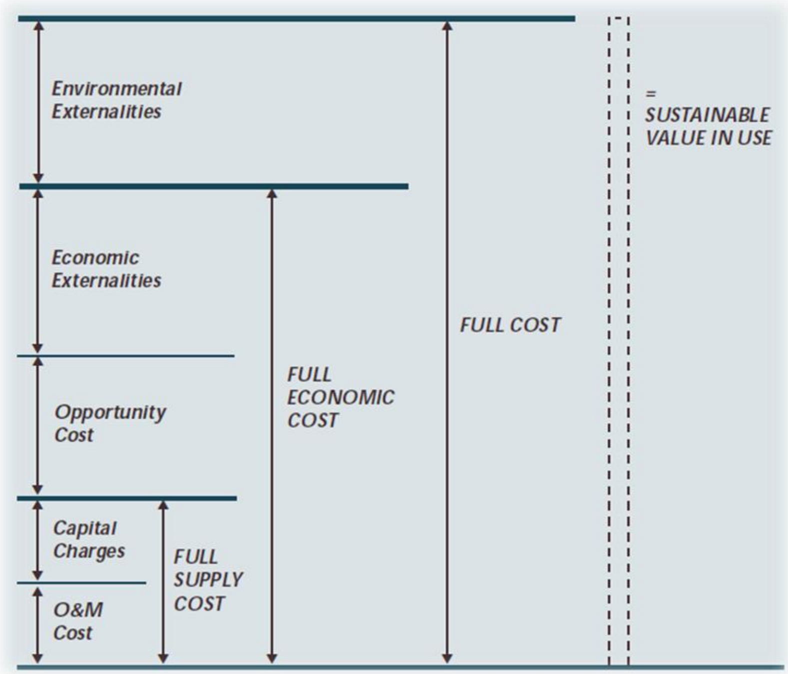

Figure 1 - Potential Costs (Rogers et al., 1998, p. 7)

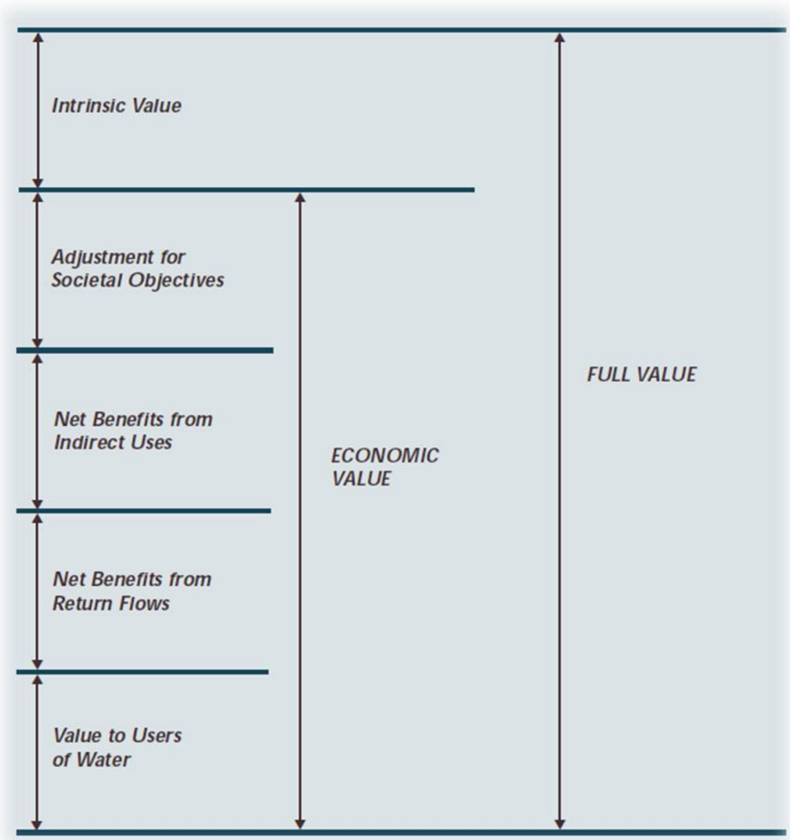

Figure 2 - Potential Benefits (Rogers et al., 1998, p. 13)

This CBA will begin by completing the cost analysis first and the benefits analysis second. Throughout the analysis, the concept of Present Discounted Value (PDV) will be important to understand. PDV accounts for the time value of money (i.e. interest). Planned future costs or benefits must be 'discounted' to be represented as a present day value. This CBA will use a discount rate of 3 percent, which is commonly used by the World Health Organization (Cameron, Hunter & Jagals, 2011, p. 21). PDV is calculated as follows, where *D* is the expense amount, *r* is the discount rate, and *t* is time:

$$PDV = \sum_{t=0}^{n} \frac{D_t}{1+r^{\ t}}$$

Once all of the potential costs and benefits have been considered, a final net present value (NPV) can be calculated. The NPV of the project is ultimately determined by subtracting the PDV of the costs from the PDV of the benefits as follows: $NPV = PDV_{Benefits} - PDV_{Costs}$. All monetary values in this paper are in current US Dollars (USD). The format of this report is to complete the cost analysis first, followed by the benefits analysis, and then a conclusion that presents the CBA summary.

Cost Analysis

First, consider the project costs. The first aspect includes what are also known as the accounting costs of the project – the Capital Charges and the Operation and Maintenance (O&M) cost. Together these encompass the tangible cash outflows that occur to complete and sustain the project over its lifespan. For well pricing, the cost of well construction, development and the pump must be included. The estimated cost of drilling a well in rural Kenya was estimated by Doyen (2003) at $11,850[1], including siting and supervision. The estimated cost for a typical lever-style hand pump (e.g., Afridev, India Mark II) is $1,800 installed (EWB-OSU, 2012). These are the assumed costs for proper construction. The price

[1] Adjusted from Doyen’s 2003 value of $9,500 using the United States Bureau of Labor Statistics Consumer Price Index Inflation Calculator.

of the pump is not likely to vary, but the amount of money allocated to well construction and development is where shortcuts are possible. For inferior construction, this analysis assumes a 25 percent reduction in the investment made toward well construction and development, so $8,888.

Next, consider the O&M costs for the well. There are two components to this estimate, (1) the expected lifespan of the project and (2) the annual recurring expenses. According to the Rural Water Supply Network (2012), inferior wells are often abandoned after 3 to 5 years even with O&M. Abandonment could be due to an issue with the pump or the borehole. Additionally, inferiorly constructed wells are more susceptible to failures due to lack of O&M. On the other hand, with proper construction, development, and O&M, it is not unreasonable to assume that a well could have a lifespan of at least 20 years (Cameron et al., 2011, p. 157). The following lifespans[2] are assumed for this analysis:

- Properly constructed well with O&M = 20 years
- Inferiorly constructed well with O&M = 5 years
- Properly constructed well without O&M = 4 years (20% of 20 years)
- Inferiorly constructed well without O&M = 1 year (20% of 5 years)

As for O&M expenses, a rule of thumb for these costs is 10 percent of capital charges (Cameron et al., 2011, p. 157), but in this case the only the cost of the hardware (i.e., the pump) should be used for this calculation because a properly constructed borehole should not require regular O&M investment. Considering this reasoning, the annual O&M cost is estimated to be $180 per year, which as a recurring expense needs to be projected into the future, over the anticipated life of the project[3]. The resulting O&M cost is $2,578 for a properly constructed well, $669 for an inferiorly constructed well, and $0 for a well with no O&M.

[2] It is the opinion of the author that these lifespans provide an adequately conservative analysis.
[3] A table of PDV computations is available in the appendix.

Opportunity cost is the next component of this analysis. Simply defined, opportunity cost is the next best use of an input, so all project inputs must be considered. The capital expenses for the well have been assessed at competitive market prices. Given that the competitive market price for a private good is equivalent to the opportunity cost, assuming no influence from minimum wage, the production expenses already include associated opportunity costs. Another aspect is that beneficiaries of a well project are likely to participate in several hours of related technical training and health education. This should be accounted for as an opportunity cost, because it is time that could be spent otherwise, such as participating in income generating activities.

This paper assumes the total time investment required is equivalent to one working day per person at the time of well construction. As a proxy, the gross national income (GNI), adjusted for purchasing power parity (PPP), is used to monetize all time-based measurements in this paper. According to the World Bank (2012), this value for Kenya is $1,720, leading to an estimated daily income of just under five dollars per day per capita. Because GNI is a gross measure by definition, the opportunity cost estimated in this paper is higher than it is in actuality since rural areas have lower incomes in comparison to urban areas. However, because the same value is used for all aspects of the CBA it will not change the final ranking of alternatives. The total PDV[4] for opportunity cost is estimated at $1,178 for all scenarios.

The final aspect of the cost analysis is to determine applicable externalities. These are economic and environmental costs that are not otherwise accounted for – direct impacts to the economy, public health, ecosystems, etc. Externalities can be negative or positive, but one should be careful to avoid double counting (e.g. counting health improvement as a positive environmental externality cost AND an adjustment for societal objectives benefit). For this reason, this analysis focuses on possible negative externalities and leaves the positive externality of improved health for the benefits section. Without knowing more about the constraints of the groundwater resource, there are no foreseeable negative economic externalities for constructing a well, so a value of $0 is used for this analysis. If the new well

[4] A table of PDV computations is available in the appendix.

could restrict the amount of water available to income-producing activities (e.g., local agriculture and businesses), the resulting negative economic externality should be evaluated and included in the analysis.

Next, there are possibly significant environmental externalities associated with raw materials and construction that are not accounted for in the market price for those goods. The environmental externalities worth exploring are those for cement, steel, PVC, fuel, and water. These are present regardless of the quality of construction. The estimated values are based on a combination of data available from various literature sources as noted in Table 2. While these values turned out to be relatively small, it is still important to consider them; in some situations the same externalities could be much more substantial. The total per well is only $48. A summary of the Cost Analysis thus far is shown in Table 3.

Table 2 - Environmental externalities (calculated per well constructed)

Well Construction Environmental Externalities				
Cement	*Steel*	*PVC*	*Fuel*	*Water*
500 kg cement per well (based on 10"x6" annular seal to 5 meters and standard well pad)	100 kg steel per well (related to pump, pump rod, and hand operating mechanism)	100 kg PVC per well (for casing and riser pipe)	200 liters of gasoline per well (for transportation and drilling rig, pump, etc.)	1000 liters water used per well (for drilling, clean up, flush, mix cement, etc.)
1100 kg CO_2 per 1000 kg cement (US EPA, 2005)	0.50 kg CO_2 per kg steel (Worrell et al., 1999, p. 3; units converted to kg)	2.16 kg CO_2 per kg PVC (UPC, 2009, p. 57)	2.4 kg CO_2 per liter of gasoline (NRC, 2009)	1000 liters = 1 cubic meter
$36.77 per 1000 kg of CO_2 (US DOE, 2010; inflation adjusted)	$36.77 per 1000 kg of CO_2 (US DOE, 2010; inflation adjusted)	$36.77 per 1000 kg of CO_2 (US DOE, 2010; inflation adjusted)	$36.77 per 1000 kg of CO_2 (US DOE, 2010; inflation adjusted)	$0.70 per cubic meter (Rogers et al., 1998, p. 17; inflation adjusted)
$20.22	**$1.84**	**$7.94**	**$17.65**	**$0.70**

Table 3 - Cost Analysis Summary (A)

CBA Project Alternatives:		Proper Construction; With O&M	Inferior Construction; With O&M	Proper Construction; No O&M	Inferior Construction; No O&M
Costs	**Descriptions**	**Well Value Estimates**			
Capital Charges	well construction & development	$11,850	$8,888	$11,850	$8,888
	pump components & installation	$1,800	$1,800	$1,800	$1,800
O&M Cost	PDV, assumes 10% pump cost as proxy for annual O&M cost	$2,578	$669	$0	$0
Opportunity Cost	time spent for training (1 day per beneficiary)	$1,178	$1,178	$1,178	$1,178
Economic Externalities	negative economic impacts	$0	$0	$0	$0
Environmental Externalities	negative environmental impacts	$48	$48	$48	$48
Total PDV Costs		**$17,455**	**$12,583**	**$14,876**	**$11,914**

There are additional negative environmental externalities that could arise with poor quality construction such as groundwater contamination and aquifer damage. These externalities can be accounted for by estimating the cost to reconcile the damages (if possible). Note that unresolved, these damages can also lead to reduced benefits. Various scenarios could play out with respect to groundwater contamination and aquifer damage. An entirely separate analysis could be conducted to evaluate a variety of possible externalities, such as drilling through two aquifers and dewatering one or contaminating an entire aquifer that is used by many neighboring communities so that people who used to have clean water are now getting sick. This analysis will focus on localized groundwater contamination as there is data to support valuation and it will result in a conservative estimate.

Table 4 - Cost Analysis Summary (B)

CBA Project Alternatives:		**Proper Construction; With O&M**	**Inferior Construction; With O&M**	**Proper Construction; No O&M**	**Inferior Construction; No O&M**
Costs	**Descriptions**	**Well Value Estimates**			
Capital Charges	well construction & development	$11,850	$8,888	$11,850	$8,888
	pump components & installation	$1,800	$1,800	$1,800	$1,800
O&M Cost	PDV, assumes 10% pump cost as proxy for annual O&M cost	$2,578	$669	$0	$0
Opportunity Cost	time spent for training (1 day per beneficiary)	$1,178	$1,178	$1,178	$1,178
Economic Externalities	negative economic impacts	$0	$0	$0	$0
Environmental Externalities	negative environmental impacts	$48	$48	$48	$48
Total PDV Costs		**$17,455**	**$12,583**	**$14,876**	**$11,914**

The value of groundwater contamination will be determined by estimating the expense required for treatment sufficient to return the quality to its pre-contamination state. While it may be possible to provide less expensive, more appropriate treatment to make the water safe to drink, this assessment is trying to get at the value of the damage done. Assuming 10 liters per user per day need to be treated (Reed, 2005); each user will need 3,650 liters treated per year over the lifespan of the well. Rogers et al.

(1998) estimate water treatment at $0.70 per cubic meter. Given these values and discounting future expenses, the estimated environmental externality contribution is $753,310 if the lifespan is 5 years (i.e., inferior construction with O&M) and $159,736 if the lifespan is 1 year (i.e., inferior construction with no O&M). Table 4 displays Cost Analysis for alternatives that include these externalities and Table 5 summarizes the PDVs for all project alternatives assessed in this CBA. An additional summary table is available in the appendix.

Table 5 - Cost Analysis Summary (C)

CBA Project Alternative	Total Cost PDV
Proper Construction; With O&M	$17,455
Inferior Construction; With O&M	$12,583
Proper Construction; No O&M	$14,876
Inferior Construction; No O&M	$11,914
Inferior Construction; With O&M; Local GW Quality Compromised, Treatment Provided	$765,845
Inferior Construction; With O&M; Local GW Quality Compromised, No Treatment	$12,583
Inferior Construction; No O&M; Local GW Quality Compromised, Treatment Provided	$171,601
Inferior Construction; No O&M; Local GW Quality Compromised, No Treatment	$11,914

Benefits Analysis

Moving on to assess the benefits for the project alternatives, recall that potential benefits include the value to users of water, net benefits from return flows, net benefits from indirect uses, adjustment for societal objectives, and intrinsic value. For this analysis, benefits from return flows, indirect use, and intrinsic value are assumed to be negligible and therefore set to values of zero. These benefits are more commonly associated with irrigation or restoration projects. It is possible that agriculture and/or livestock could benefit in some way from a new well, but not including these possible benefits makes the analysis more conservative.

For estimating the value to users of water, this analysis uses a revealed preference for the value to users of water, which is the preferred method for assessing the value of a policy or project to its beneficiaries. There are three common methods for this type of assessment as follows: (1) market-based (i.e., monetary value of time saved), (2) contingent valuation (e.g., survey regarding willingness to pay), and (3) revealed preference (i.e., how much people are already paying for a comparable good or service). Out of these three options, revealed preference should be used if the data is available because it requires fewer inferences. In this case, data is available that estimates households in developing countries spend about 10 percent of their annual income on water (Cameron et al., 2011, p. 42). Income is again based on GNI per capita, PPP, as it was in the Cost Analysis, and this benefit needs to be discounted for annual benefits in the future. The resulting PDV[5] is $658,923 for a properly constructed well with O&M, $202,835 for an inferiorly constructed well with O&M, $164,630 for a properly constructed well with no O&M, and $43,000 for an inferiorly constructed well with no O&M.

Another meaningful aspect of this benefits analysis is the adjustment for societal objectives. The reason many organizations take on well drilling projects in the first place is for this reason, to improve the livelihoods of people currently lacking access to clean water. Poverty alleviation and public health improvements are both key societal objectives. Safe access to water has direct implications for improved

[5] A table of PDV computations is available in the appendix.

health; it can also be a catalyst for other benefits such as increased productivity and happiness (Hutton et al., 2007). However, these are largely secondary benefits afforded by improved health. Therefore, indirect impacts will not be included to avoid potential double counting. This paper focuses on the direct health impacts of clean water that can be provided by a new well, in terms of associated reductions in diarrhea and related deaths. While there are other illnesses connected to lack of safe access to clean water, diarrhea is the most significant and there is a wealth of data to support related analysis. Other conceivable direct benefits such as money saved on medical expenses and time saved collecting water are not included in this section of the Benefits Analysis to avoid double counting with the Value to Users of Water. Overall, these deliberate constraints only make this analysis more conservative.

Estimating societal benefits involves several steps. First is the most controversial part of CBA, the value of a statistical life (VSL) must be set. This value allows the assignment of an economic value to life and productivity, to enable accounting for lives lost or saved and reductions or gains in productivity. As standard practice for CBA, the VSL has been rigorously estimated at $8.9 million[6] in the United States (Viscusi & Aldy, 2002, p. 67). Emulating the methodology used by Hatfield Consultants (2009), the VSL in Kenya can be calculated by adjusting for the difference in GNI per capita, PPP between the US and Kenya. This results in a VSL of $313,623 in Kenya.

The next step is to determining the value of a disability-adjusted life year (DALY). The DALY is a common metric used in the field of public health for quantifying disease burden. It incorporates all associated health costs, including morbidity (disability) and mortality (death). The World Health Organization (2012) commonly uses an average equivalency of 36 DALYs per premature death. Again replicating the approach taken by Hatfield Consultants, the value per DALY can be determined by dividing the VSL by the number of DALYs assigned for a premature death. This results in the value of $8,712 per DALY in Kenya; see Table 6.

[6] Adjusted from Viscusi & Aldy's 2002 value of $7 million using the United States Bureau of Labor Statistics Consumer Price Index Inflation Calculator.

Table 6 - Summary of Value per DALY Calculations

Metric	US	Kenya
GNI/capita, PPP adjusted	$48,890	$1,720
Value of a Statistical Life (VSL)	$8,914,553	$313,623
DALY equivalent for a premature death, on average	36	36
Value per DALY	**$247,626**	**$8,712**

Now, the number of DALYs averted due to the well project must be determined. According to the World Health Organization's "Rapid Needs Assessment for Water, Sanitation, and Hygiene" (2004), the average number of diarrhea cases per person per year is 1.3 in East Africa. On average, a case of diarrhea lasts three days per with a disability weight of 10 percent (Cameron et al., 2011, p. 22; Pruss, Fewtrell, & Bartram, 2002, p. 542). The disability weight accounts for the fact that diarrhea is not completely debilitating in most cases. Stand-alone water supply improvements (not including treatment, sanitation, or hygiene aspects) have been shown to reduce the incidence of diarrhea by 19 percent on average (Fewtrell, Kaufmann, Kay, Enanoria, Haller, & Colford, 2005, p. 49). Considering the number of beneficiaries is assumed to be 250 for one well, the number of morbidity-based DALYs averted by this program is estimated to be 0.051 per year as follows:

$DALY_{Morbidity}$ = *(250 beneficiaries)(1.3 cases diarrhea per year)(3 days per case)(1 year/365 days)(10% disability)(19% reduction)*

In addition, according to the World Health Organization's "Department of Measurement and Health Information" spreadsheet (2004), in Kenya an average of 78.1 lives per 100,000 people are lost each year due to diarrhea. Assuming this project reduces deaths caused by diarrhea at the same rate as the incidence reduction (19 percent), 0.037 mortality-based DALYs are averted each year, calculated as follows:

$DALY_{Mortality}$ *= (250 beneficiaries)(78.1/100,000 lives lost)(19% reduction)*

This adds up to 0.088 DALYs averted annually that can be attributed to the project. Discounting for future benefits over the expected life of the well, again using the 3 percent discount rate used in the Cost Analysis, the PDV[7] of the adjustment for societal objectives is $11,728 for a properly constructed well with O&M, $3,610 for an inferiorly constructed well with O&M, $2,930 for a properly constructed well without O&M, and $765 for an inferiorly constructed well without O&M. For the scenarios with localized groundwater contamination, the benefits for societal objectives are zero unless water treatment is provided to restore this beneficial aspect of the project. The results of the Benefits Analysis are displayed in Tables 7, 8, and 9.

Table 7 - Benefits Analysis Summary (A)

CBA Project Alternatives:		**Proper Construction; With O&M**	**Inferior Construction; With O&M**	**Proper Construction; No O&M**	**Inferior Construction; No O&M**
Benefits	**Descriptions**	**Well Value Estimates**			
Value to Users of Water	PDV of Value to Users of Water	$658,923	$202,835	$164,630	$43,000
Net Benefits from Return Flows	n/a	$0	$0	$0	$0
Net Benefits from Indirect Uses	n/a	$0	$0	$0	$0
Adjustment for Societal Objectives	PDV of DALYs Averted	$11,728	$3,610	$2,930	$765
Intrinsic Value	n/a	$0	$0	$0	$0
Total PDV Benefits		**$670,651**	**$206,445**	**$167,560**	**$43,765**

[7] A table of PDV computations is available in the appendix.

Table 8 - Benefits Analysis Summary (B)

CBA Project Alternatives:		**Inferior Construction; With O&M; Local GW Quality Compromised, Treatment Provided**	**Inferior Construction; With O&M; Local GW Quality Compromised, No Treatment**	**Inferior Construction; No O&M; Local GW Quality Compromised, Treatment Provided**	**Inferior Construction; No O&M; Local GW Quality Compromised, No Treatment**
Benefits	**Descriptions**	**Well Value Estimates**			
Value to Users of Water	PDV of Value to Users of Water	$202,835	$0	$43,000	$0
Net Benefits from Return Flows	n/a	$0	$0	$0	$0
Net Benefits from Indirect Uses	n/a	$0	$0	$0	$0
Adjustment for Societal Objectives	PDV of DALYs Averted	$3,610	$0	$765	$0
Intrinsic Value	n/a	$0	$0	$0	$0
Total PDV Benefits		**$206,445**	**$0**	**$43,765**	**$0**

Table 9 - Benefits Analysis Summary (C)

CBA Project Alternative	Total Benefits PDV
Proper Construction; With O&M	$670,651
Inferior Construction; With O&M	$206,445
Proper Construction; No O&M	$167,560
Inferior Construction; No O&M	$43,765
Inferior Construction; With O&M; Local GW Quality Compromised, Treatment Provided	$206,445
Inferior Construction; With O&M; Local GW Quality Compromised, No Treatment	$0
Inferior Construction; No O&M; Local GW Quality Compromised, Treatment Provided	$43,765
Inferior Construction; No O&M; Local GW Quality Compromised, No Treatment	$0

Conclusion

Finally, the Cost Analysis and Benefits Analysis can be integrated to produce a net present value (NPV) for each project alternative. This is done as follows: $NPV = PDV_{Benefits} - PDV_{Costs}$.

A benefit-cost ratio is also calculated, by dividing the Total Benefits PDV by the Total Cost PDV. A final summary of the results of this CBA are displayed in Table 10, in order of declining NPV.

Table 10 - Summary of Cost-benefit Analysis

CBA Project Alternative	Total Benefits PDV	Total Cost PDV	Total NPV	Benefit/Cost Ratio
Proper Construction; With O&M	$670,651	$17,455	$653,196	38.42
Inferior Construction; With O&M	$206,445	$12,583	$193,862	16.41
Proper Construction; No O&M	$167,560	$14,876	$152,684	11.26
Inferior Construction; No O&M	$43,765	$11,914	$31,851	3.67
Inferior Construction; No O&M; Local GW Quality Compromised, No Treatment	$0	$11,914	-$11,914	0
Inferior Construction; With O&M; Local GW Quality Compromised, No Treatment	$0	$12,583	-$12,583	0
Inferior Construction; No O&M; Local GW Quality Compromised, Treatment Provided	$43,765	$171,601	-$127,836	0.26
Inferior Construction; With O&M; Local GW Quality Compromised, Treatment Provided	$206,445	$765,845	-$559,399	0.27

These results illustrate the importance of both proper construction and O&M. The differences in the total NPV between scenarios with proper construction, inferior construction, and the presence or absence of O&M are related to the compounding of annual costs and benefits over time. Simply stated, inferior construction and the absence of O&M are both likely to result in a well with a shorter lifespan, which substantially reduces the overall benefit of implementing the well in the first place. In this CBA, even in the best case scenario inferior construction with O&M provides only 30 percent of the potential benefits – a decrease of nearly $500,000 in benefits in order to save a comparatively small amount of money, $5,000.

Even worse, inferior construction methods have an increased probability of causing bigger problems such as groundwater contamination and aquifer damage. Even in the limited case of localized groundwater contamination, this CBA suggests that cutting a few thousand dollars from the budget up front can mean the benefits are reduced to nothing. Furthermore, if a treatment scheme is provided to deal with the contamination, the costs are estimated to outweigh the benefits by a ratio of nearly four to one. This does not mean that a contaminated source should be left for use without treatment, but it might be more cost effective to start from scratch with a different source if available. Instead, this should be taken as a compelling reason for proper well construction practices, even if saving a few dollars at the beginning of the project seems tempting at first glance.

The role of O&M in the costs and benefits of a well project is also highlighted in this CBA. A properly constructed well still requires an appropriate O&M plan; otherwise the lifespan will be shortened significantly. In this way, project sustainability is directly related to the total value of the benefits provided. The absence of O&M has a comparable impact on the estimated value of a well, whether properly or inferiorly constructed, with a reduction of around 80 percent. As an example, proper construction without O&M saves about $2,500 over the lifespan of the well but reduces the benefits by over $500,000.

Given all of the considerations presented in this analysis, hopefully it is evident that shortcuts are not a wise strategy when it comes to drilling wells. This is not to say that there is no such thing as a properly constructed, low-cost well. However, keep in mind that the greatest benefit will not necessarily come from minimizing the upfront costs and maximizing the number of wells constructed, with disregard for the quality of construction, operation, and maintenance. But rather, the most benefits will be realized through the greatest number of properly constructed and maintained wells. Well construction approaches that provide cost savings should be carefully assessed to avoid (1) increasing associated environmental and health risks and (2) reducing the anticipated lifespan of the project.

A detailed spreadsheet including all calculations can be found online at

www.seidc.com/pdf/Hydrophilanthropy_Well_Guidlelines.pdf

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Appendix

Table 11 - Present Discounted Value (PDV) Computation Details $\left[PDV = \sum_{t=0}^{n} \frac{D_t}{1+r^{\;t}} \right]$

Year	PDV O&M	PDV GW Contamination	PDV Value to Users of Water	PDV DALYs Averted
0	n/a	$638.75	$43,000.00	$765.34
1	$174.76	$620.15	$41,747.57	$743.04
2	$169.67	$602.08	$40,531.62	$721.40
3	$164.73	$584.55	$39,351.09	$700.39
4	$159.93	$567.52	$38,204.94	$679.99
5	$155.27	$550.99	$37,092.18	$660.19
6	$150.75	$534.94	$36,011.82	$640.96
7	$146.36	$519.36	$34,962.93	$622.29
8	$142.09	$504.24	$33,944.60	$604.16
9	$137.96	$489.55	$32,955.92	$586.57
10	$133.94	$475.29	$31,996.04	$569.48
11	$130.04	$461.45	$31,064.11	$552.89
12	$126.25	$448.01	$30,159.33	$536.79
13	$122.57	$434.96	$29,280.91	$521.16
14	$119.00	$422.29	$28,428.07	$505.98
15	$115.54	$409.99	$27,600.06	$491.24
16	$112.17	$398.05	$26,796.18	$476.93
17	$108.90	$386.45	$26,015.71	$463.04
18	$105.73	$375.20	$25,257.97	$449.55
19	$102.65	$364.27	$24,522.30	$436.46
20	$99.66	$353.66	$23,808.06	$423.75

Table 12 - Summary of Cost Analysis (A and B)

CBA Project Alternatives:		Proper Construction; With O&M	Inferior Construction; With O&M	Proper Construction; No O&M	Inferior Construction; No O&M	Inferior Construction; With O&M; Local GW Quality Compromised, Treatment Provided	Inferior Construction; With O&M; Local GW Quality Compromised, No Treatment	Inferior Construction; No O&M; Local GW Quality Compromised, Treatment Provided	Inferior Construction; No O&M; Local GW Quality Compromised, No Treatment
Costs	**Descriptions**	**Well Value Estimates**							
Capital Charges	well construction & development	$11,850	$8,888	$11,850	$8,888	$8,888	$8,888	$8,888	$8,888
	pump components & installation	$1,800	$1,800	$1,800	$1,800	$1,800	$1,800	$1,800	$1,800
O&M Cost	PDV, assumes 10% pump cost as proxy for annual O&M cost	$2,678	$824	$0	$0	$824	$824	$0	$0
Opportunity Cost	time spent for training (1 day per beneficiary)	$1,178	$1,178	$1,178	$1,178	$1,178	$1,178	$1,178	$1,178
Economic Externalities	negative economic impacts	$0	$0	$0	$0	$0	$0	$0	$0
Environmental Externalities	negative environmental impacts	$48	$48	$48	$48	$891,058	$48	$611,430	$48
Total PDV Costs		**$17,554**	**$12,738**	**$14,876**	**$11,914**	**$903,748**	**$12,738**	**$623,295**	**$11,914**

Table 13 - Summary of Benefits Analysis (A and B)

CBA Project Alternatives:		Proper Construction; With O&M	Inferior Construction; With O&M	Proper Construction; No O&M	Inferior Construction; No O&M	Inferior Construction; With O&M; Local GW Quality Compromised, Treatment Provided	Inferior Construction; With O&M; Local GW Quality Compromised, No Treatment	Inferior Construction; No O&M; Local GW Quality Compromised, Treatment Provided	Inferior Construction; No O&M; Local GW Quality Compromised, No Treatment
Benefits	**Descriptions**	**Well Value Estimates**							
Value to Users of Water	PDV of Value to Users of Water	$682,731	$239,927	$164,630	$164,630	$239,927	$0	$164,630	$0
Net Benefits from Return Flows	n/a	$0	$0	$0	$0	$0	$0	$0	$0
Net Benefits from Indirect Uses	n/a	$0	$0	$0	$0	$0	$0	$0	$0
Adjustment for Societal Objectives	PDV of DALYs Averted	$12,152	$4,270	$2,930	$2,930	$4,270	$0	$2,930	$0
Intrinsic Value	n/a	$0	$0	$0	$0	$0	$0	$0	$0
Total PDV Benefits		**$694,883**	**$244,198**	**$167,560**	**$167,560**	**$244,198**	**$0**	**$167,560**	**$0**

Table 14 - Acronym Definitions

Acronyms and page first identified.		
CBA	1	Cost-Benefit Analysis
O&M	2	Operation and Maintenance
PDV	5	Present Discounted Value
NPV	5	Net Present Value
GNI	7	Gross National Income
PPP	7	Purchasing Power Parity
VSL	13	Value of a Statistical Life
DALY	13	Disability-Adjusted Life Year