VALUATION OF A MULTI-STAGE RAINWATER HARVESTING TANK CONSTRUCTION USING A REAL OPTION APPROACH

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ABSTRACT: Under climate change and urbanization, rainwater harvesting (RWH) systems are emerging as an alternative source of water supply because of growing concern about water sustainability. RWH systems can satisfy the various watering needs and provide the environmental benefits of lessening the damages from flood, drought, and runoff. The economic success of a RWH system is vitally concerned with the determination of the design capacity of storage tank to be built in the system. The design capacity is determined by the factors of average annual rainfall, period of water scarcity, and water price during the whole life-cycles. Despite the high uncertainties inherent in these factors, the current engineering design of RWH system construction often assumes that storage tanks should be built all at once. This assumption implicitly ignores the managerial flexibility in responds to the future as new information comes out–the right to build storage tanks stage by stage depending on the evolution of demand. This study evaluates the value of a multi-stage storage tank construction using a real option approach. A case study involving a typical RWH system construction in Jeonju, the Republic of Korea is conducted. The managerial flexibility obtained from the real option perspective allows engineers to develop investment strategies to better cope with the issue of water sustainability.

Keywords: Rainwater harvesting system; Real option; Life cycle cost; Planning

1. INTRODUCTION

Rainwater harvesting (RWH) systems involve collecting water directly from rainfall and storing it to satisfy various watering needs. A typical RWH system is relatively small-scale in terms of system size and capital investment at the local level [1]. The historical evidence of RWH technique dates back to ancient times, and this technique was widely used for agricultural purposes all over the world, but RWH systems almost disappeared with modernization [2]. Recently, however, RWH systems have drawn renewed attention due to climate change and urbanization.

Climate change has the potential to increase the frequency and severity of weather events, such as floods and droughts [3]. Floods degrade the quality of water resources through runoff while droughts cause fresh water shortages. Increasing impermeable surfaces as a result of urbanization are likely to intensify such flood damages. Water shortages become more severe with higher population growth in urban areas. Ironically, these circumstances have heightened public demand for RWH systems because they provide the environmental benefits of lessening the damages from flood, drought, and runoff [2]. Additionally, climate change leads to a change in paradigm in water supply and management. Current water supply systems (large-scale and centralized) are often affected by floods because of their close location to rivers [4]. Demand of small-scale and decentralized systems, like RWH systems, have gained a momentum. Overall, RWH systems offer a variety of public benefits for adaptation to climate change and urbanization. Hence, investment in RWH systems is being encouraged in various regions of the world [5].

From the perspective of private entities, their benefits are straightforwardly calculated by the total amount of water replacement during the life-cycle of RWH systems rather than the public benefits. The total saving by the replacement is dictated by the factors of average annual rainfall, period of water scarcity, and water price during the whole life-cycle [6]. Given these factors, vital concern is the determination of the design capacity of a storage tank to be constructed in a RWH system.

Results of most previous studies on this topic were predicated on the assumption that the optimal design capacity of a storage tank provides the highest ratio of the total saving to its construction cost under a fixed annual rainfall scenario [7]. This assumption may underestimate the potential change of the rainfall scenario under climate change. Furthermore, the premise of these studies was that a storage tank(s) is constructed all at once in a RWH system. This premise implicitly ignores the managerial flexibility in responds to the future as new information comes out–the right to build storage tanks stage by stage depending on the evolution of demand. This idea is strengthened when considering the current understanding of climate change as follows.

It is clear that rainfall patterns have been changing due to climate change. There is now no doubt that climate change is occurring [8]; human-induced greenhouse gas emissions are causing global warming, which in turn is encouraging climate change. As a result, rainfall events are more concentrated in particular seasons and years [9]. Additionally, extreme rainfall events become more frequent and intense [9]. These observations lead to substantial uncertainty about what design capacity of storage tank is required because it is unclear exactly how the changes in rainfall will come about.

In this study, we evaluate the value of a multi-stage storage tank construction using a real option approach. It should be noted that the public benefits of RWH systems are not incorporated in the real option valuation. Although RWH systems provide significant adaptability benefits to climate change and urbanization, it is difficult to evaluate these benefits in monetary terms. If accurate benefits can be estimated, they also revert to the public sector rather than private entities.

In the remainder of this paper, we investigate RWH systems and their components to derive managerial options inherent in RWH system investment. Then, we conduct a case study involving a typical RWH system in Jeollabuk-do, the Republic of Korea to calculate the net present values of the RWH system with the options. Finally, we conclude this paper with a discussion of the results obtained.

2. SEARCH FOR A STRATEGY

2.1 Investigation of RWH systems

RWH systems intercept and store incoming rainwater for a number of later uses, including toilet flushing, gardening, cleaning, and firefighting. Regardless of the scale, rainwater harvesting systems essentially comprises the following three components (Figure 1) [10]:

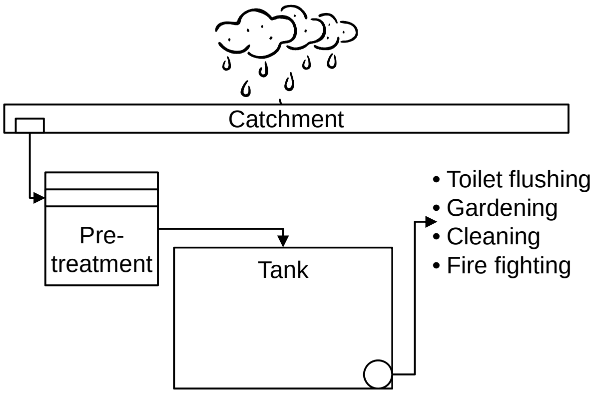


Figure 1. Typical rainwater harvesting system components

·Catchment: the catchment of a RWH system is a building's roof surface which directly intercepts for providing rainwater to pre-treatment. This component can sometimes be an area of open ground of a building, such as terrace, courtyard, and lawn. RWH is not tightly constrained by roofing materials.

·Pre-treatment: the pre-treatment contains all of devices to ensure high quality water to storage tank. This component generally includes mesh screen, first-flushing diverter, and filter. Some devices such as filter socks may be installed at the inside of the storage tank.

·Storage Tank: the storage tank is generally made of fiberglass, plastic, wood, metal, or concrete. The siting position of this component varies in space availability: aboveground, underground, and partially aboveground (or partially underground). Additionally, depending on space constraints, it can be formed in various shapes, such as cylindrical, rectangular, and square geometry.

To link between the components of a RWH system, pipelines are constructed out of a variety of materials such as polyvinyl chloride and galvanized iron.

Generally, the storage tank is the primary and costly component in a RWH system. Although selecting and sizing each component is somewhat influenced by those of the other components, the storage tank is relatively insensitive to the others. That is, a storage tank in a RWH system can be additionally constructed without major changes of the others.

2.2 Creation of an Option (Multi-Stage Construction)

When private entities decide to invest, they are eager to maximize their future benefits. These desires can result in finding or creating options inherent in their investment.

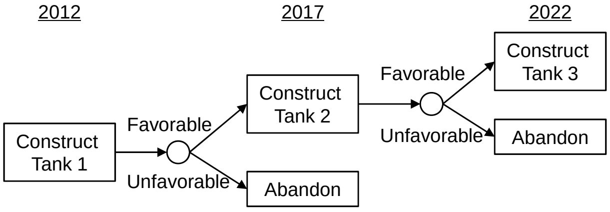


Figure 2. Private entity's options in a RWH project

Figure 2 provides a graphical representation of the options inherent in a RWH system construction project. Note that all values (years and tank numbers) in Figure 2 are just an example. Although a private entity decides to construction Tank 1 in 2012, he/she is not obligated to construct Tank 2 in 2017 and subsequently Tank 3 in 2022. Rather, he/she has the right but not obligation to construct Tank 2 in 2017. If he/she learns by 2017 that the demand of additional storage tank is favorable, it will exercise his/her right by spending the construction cost for Tank 2. On the contrary to this, if he/she learns by 2017 that the estimate of additional water saving by Tank 2 is worth less than the construction cost for Tank 2, he can abandon the construction of Tank 2.

In brief, the private entity buys five years prior to making the second decision (construct Tank 2 or abandon), which in turn give him adequate information to decide the construction of additional storage tank. This strategy is particularly promising when it is difficult to forecast the changes in annual rainfall scenario due to climate change.

3. VALUING THE OPTION

3.1 Case Study Area

Jeollabuk-do (a province in the Republic of Korea) was considered as a case study area. The Korean Peninsula is located in a monsoon climate region with more than half of the rainfall during the summer [11]. For the present study, daily rainfall records from Jeonju station (Latitude 35°49´´N/Longitude 127°09´´E) were obtained from the Korea Meteorological Administration. Figure 3 shows annual rainfalls calculated from the daily rainfall records during the year 1960 through 2011.

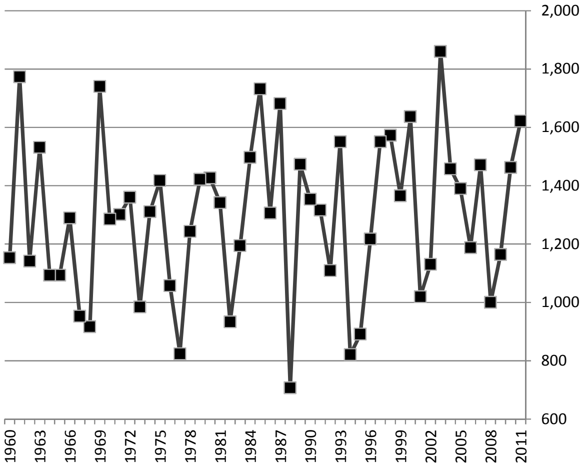


Figure 3. Annual rainfall records during years 1960-2011 at Jeonju

The maximum and minimum rainfall occurred in this period were 1860.3 mm during the year 2003 and 707.1 mm during the year 1988, respectively. The difference between the two years was up to 2.5 times. This trend is expected to be further strengthened under climate change [9]. Thus, private entities in the Republic of Korea are forced to spend a significant amount of time and effort in finding the design capacity of a storage tank. Rather, the private entities are encouraged to defer their decisions; the final design capacity of a storage tank of a RWH system is not determined at the time of the decision to invest in the system.

3.2 Valuing a RWH System without the Option

The Republic of Korea (ROK) is on the verge of experiencing floods and droughts. In response to this concern, the ROK government initiated one of the largest engineering projects in the country’s history, called “the Four Major Rivers Restoration Project.” Approximately $18 billion was directed toward improving river functions, including irrigation and flood control (assuming 1 USD = 1,100 KRW). Meanwhile, Jeollabuk-do provincial government also, but to a lesser extent, has promoted investment in RHW systems by the same token. In 2011, Jeollabuk-do provincial government decided to invest in a small-scale RWH system on 2012 as a pilot project to attract private sector participation. This system would have a 1,200 m^2 roof catchment area, only with 90% of rainwater to be stored (i.e., a 10% of deduction rate) in its storage tank. The capacity of the storage tank would be designed to be a 60t.

Three years selected from 1st decile (wet year), 5th decile (average year), and 9th decile (dry year) of annual total rainfall amount based on the historical rainfall records at Jeonju station. Wet and dry years would be expected during the system life-cycles with probability approximately 10%, respectively, whereas average years would be expected at the period with probability approximately 80%.

The followings were determined by a cost estimator to conduct the expected discounted cash flow (DCF) analysis of the RWH system:

·Daily total water replacement amount: 7 t
·Water Price: $2 per ton
·Rate of water price increase: 6.5% per year
·Interest rate: 3.0% per year
·Total construction cost: $145,455
·Construction cost of a 20t of storage tank: $40,909
·Lifespan of the system: 35 years

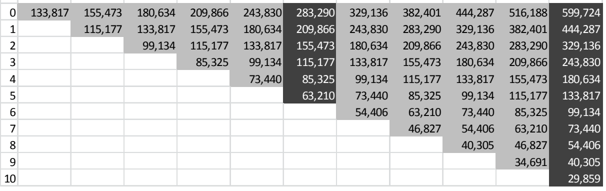
Note that all of the dollar values were US$ and converted to those in 2012. Given these values and the three separate rainfall scenarios, the expected 2012 DCF value of the RWH system was calculated based on the information available as of 2011:

$$
\begin{aligned}
&E\{\,2012\ DCF\ value\ of\ the\ project\} = [\\
&E\{\,2012\ DCF\ value\ of\ water\ saving\ in\ a\ wet\ year\} +\\
&E\{\,2012\ DCF\ value\ of\ water\ saving\ in\ an\ average\ year\} +\\
&E\{\,2012\ DCF\ value\ of\ water\ saving\ in\ a\ dry\ year\}] \times Lifespan\\
&= [\$4{,}413 \times 10\% + \$3{,}949 \times 80\% + \$2{,}230 \times 10\%] \times 35\\
&= \$133{,}817
\end{aligned}
$$

The result of the expected DCF analysis suggests that the Jeollabuk-do provincial government should make the no-go decision because the investment would incur a negative value of $11,638(=$133,817-$145,455).

3.3 Valuing the RWH System with the Option

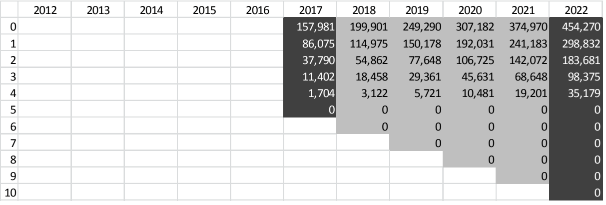
As previously estimated, the underlying asset of the RWH project is worth $133,817. The final and intermediate exercise years, respectively, are 2022($145,455) and 2017($40,909). The present study assumed that annual standard deviation of the expected DCF value would be 15%. To this end, the binomial tree of the RWH project was developed as shown in Figure 4.



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
0	133,817	155,473	180,634	209,866	243,830	283,290	329,136	382,401	444,287	516,188	599,724
1		115,177	133,817	155,473	180,634	209,866	243,830	283,290	329,136	382,401	444,287
2			99,134	115,177	133,817	155,473	180,634	209,866	243,830	283,290	329,136
3				85,325	99,134	115,177	133,817	155,473	180,634	209,866	243,830
4					73,440	85,325	99,134	115,177	133,817	155,473	180,634
5						63,210	73,440	85,325	99,134	115,177	133,817
6							54,406	63,210	73,440	85,325	99,134
7								46,827	54,406	63,210	73,440
8									40,305	46,827	54,406
9										34,691	40,305
10											29,859

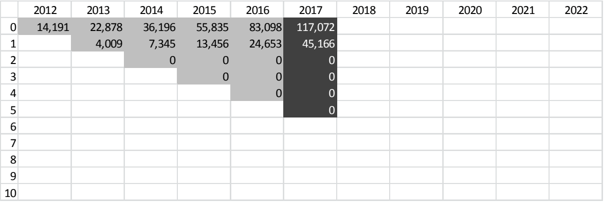
Figure 4. Binomial tree of the RWH project (in $)

Using the backward calculation, the option value was estimated as depicted in Figures 5 and 6.



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
0						157,981	199,901	249,290	307,182	374,970	454,270
1						86,075	114,975	150,178	192,031	241,183	298,832
2						37,790	54,862	77,648	106,725	142,072	183,681
3						11,402	18,458	29,361	45,631	68,648	98,375
4						1,704	3,122	5,721	10,481	19,201	35,179
5						0	0	0	0	0	0
6							0	0	0	0	0
7								0	0	0	0
8									0	0	0
9										0	0
10											0

Figure 5. Option values given an exercise price of $145,455 (in $)



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
0	14,191	22,878	36,196	55,835	83,098	117,072					
1		4,009	7,345	13,456	24,653	45,166					
2			0	0	0	0					
3				0	0	0					
4					0	0					
5						0					
6											
7											
8											
9											
10											

Figure 6. Option value given an exercise price of $40,909 (in $)

Figure 6 shows the option value of the two times of multi-stage storage tank construction. By considering the managerial flexibility inherent in the RWH investment, the expected DCF was slightly higher than the total construction cost; the option value ($14,191) is over the project value without the options (-$11,638). It leads to the validity of such investment in terms of the cost-benefit analysis even without public benefits provided by the RWH system.

4. CONCLUSIONS

Climate change has become a significant environmental issue and has been placed on the national agendas because it causes serious global environmental hazards, such as floods, droughts, and runoff. Urbanization tends to exacerbate these hazards. This study described the value of RWH systems as a response to this problem. Despite their public benefits, especially in terms of the environment, typical RWH systems are not economically viable by themselves. This is an economical limitation on encouraging private entities to install RWH systems.

This paper provided a way of improving the private benefit of RWH systems using a real option approach. A case study of the construction of a typical RWH system in Jeonju, the Republic of Korea was conducted to verify the idea of this study. To the best of our knowledge, this study is the first attempt to incorporate the concept of the real option into the construction of RWH system. The managerial flexibility obtained from the real option perspective encourages private entities' participation to install RWH systems.

Future studies are required to investigate the long-term trend of water price and the impact that water price have on private entities' attitudes toward water replacement amount. These future studies will ensure more accurate estimations of input variables which will lead to better valuations of multi-stage rainwater harvesting tank construction.

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