

# Tail Irrigation Water Problem with Value Engineering

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**ABSTRACT:** Shortage of irrigation water is a challenge frequently occurs at Canal Tail-end (CT). This paper uses Value Engineering (VE) methodology to find solutions of this problem. VE methodology includes collecting information about the water shortage at CT, analyse functions of canals, develop creative ideas, assess creative ideas based on evaluation criteria, obtain a short list of value alternatives, and develop value alternatives using Life Cycle Cost (LCC) and Net Present Value (NPV). Study results indicate that VE methodology is a problem solving tool that helps in finding solutions with focus on achieving the basic function of the system.

**KEYWORDS:** Canal tail-end, Irrigation, Value engineering, Life cycle cost

## I. INTRODUCTION

Surface irrigation system is commonly used in Egypt and consists of four grades of open canals; main, branch, distribution, and field canals. Surface irrigation system suffers from water shortage at Canal Tail-end (CT) which means that the actual canal discharge is less than the designed discharge at the end of the canal. Water shortage at CT is caused mainly by;

- Widening of the Canal Cross Section (CCS) due to routine maintenance which decreases the velocity of water.
- Water losses due to conveyance and seepage along canal path.
- Obtaining insufficient water at the canal intake.
- Growing crop patterns requiring extra amount of irrigation water than the designed canal discharge.

Water shortage at CT has a negative impact on the crop yield of the cultivated lands on both sides of the canal end. The percentage of cultivated land affected by water shortage at the canal end is approximately equal to 20% of total cultivated land served by this canal [14]. Other than Egypt, this problem exists in Palestine, Tajikistan, Canada, Nepal, India, and Pakistan [(Al-Jayyousi [2], Wegerichet al. [20], Ring et al. [18], Adhikari et al. [1], Development Support Center (dsc) [7] and Hussain [11]). Many researches addressed water shortage at CT. Al-Jayyousi [2] presented the methodology to improve efficiency and rehabilitate the irrigation distribution system of Jericho City Palestine by converting the existing irrigation canal system to a pipe network under pressure. Ring et al. [18] presented the rehabilitation of the irrigation water delivery infrastructure in Alberta - Canada. Soliman and Manadely [19] analyzed the shortage of irrigation water at the canal end in Southern Egypt using two approaches; (1) the resources infrastructure demand and access, (2) the Bayesian Networks. Adhikari et al. [1] studied canal tail water shortage in southern Nepal. The study suggested that the conventional irrigation design principles should be applied very cautiously with full knowledge of the existing socio-institutional setting, hydroecological regime, and indigenous technology for upgrading any traditional irrigation system successfully. Mateos et al. [13] presented an evaluation of the rehabilitation of a small, representative irrigation scheme governed by a farmers' cooperative. Hussain [11] presented the rehabilitation design approaches adopted on rehabilitation of canal system in Pakistan. Morgado et al. [15] studied lining technology using; concrete cast on site, precast concrete slabs, and prefabricated membranes to rehabilitate canals to minimize water leakage from canals. Allam and Negm [3] studied the suitability of drainage water reuse in irrigation by backflow from drains at the end of the irrigation canals in Northern Egypt as a solution to canal-end shortage of irrigation water. Moreover, the study assessed the drainage water quality and its suitability for direct reuse in irrigation in this area.

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## II. RPROBLEM IDENTIFICATION AND OBJECTIVES

From the previous literature, these researches studied the shortage of water at CT. While some of researches didn't offer a solution for this problem [Ring et al. [18], Soliman and Manadely [19], Mateos et al. [13]], the rest offered one solution [Al- Jayyousi [2], Adhikari et al. [1], Hussain [11], Morgado et al. [15], Allam and Negm [3]]. The main objective of this paper is utilizing Value Engineering (VE) methodology to find alternatives for water shortage at CT which maintain and/or enhance the function of water conveying system with the minimum cost. The objective of VE isn't to cut the cost, rather it enhances the performance and mains the main function of the water conveying system. The adopted methodology focuses on finding solutions for this problem assuming,

1. The soil type other than heavy clay and pure sand.
2. Climate condition is semi-arid.

The methodology adopted to achieve the research objectives:

1. Collect information about this problem and its effect on the crop yield.
2. Function analysis of canal and interrelationships between functions.
3. Develop creative ideas to solve this problem.
4. Asses creative ideas generated from the previous step based on evaluation criteria weighted by panel of experts.
5. Design the short list of value alternative and calculate the benefits from saving water and increasing crop yield.
6. Evaluate the short list of value alternative by Life Cycle Cost (LCC)
7. Select the best value alternative to solve the water shortage atCT

## III. DATE COLLECTION

There are two types of data are collected, data for value analysis and field data for the case study. The data used in value analysis is collected in three stages, the first and second stages are brain storming sessions but the third stage is a questionnaire.

Stage 1:

The first brain storming session is employed using a panel of experts in irrigation engineering to identify other ways to irrigate land at CT.

Stage 2:

The second brain storming session is conducted in five steps to identify the problem. These steps depend on idea screening, the first and second steps are "(GO or NO GO) and Champion" to select the best ideas. In the third step (Go for It) the advantages and dis-advantages are discussed for the accepted ideas and take the average voting. The fourth step is "Trade-off Study" which is done depending on performance characteristics (as land use, water saving, continuity of supply and easy maintenance) to select the final alternatives to solve end tail-end canal problem. The last step in this stage is "Customer Acceptance" to determine the acceptance criteria and develop proposal scenarios. The conclusion of these two stages is developing some value alternatives (VA) from the final ideas to put an integrated solution for canal end problem.

Stage 3:

A questionnaire is done to evaluate the selected VA are consideredby using main evaluation criteria. Comparisonmatrix is utilized to calculate the weights of evaluation criteriaby using a scale of 0 to 5 to express the importanceof each evaluation criteria relative to the others. Weightsof evaluation criteria are calculated by dividing evaluationcriteria score by total evaluation criteria scores. Each VA isassigned a score between 0 and 10 against each evaluationcriteria. These scores were assigned by a panel some of 10experts having great experience. For each expert response,the score of each VA is multiplied by the relevant weightof evaluation criteria and the total score is calculated foreach VA.The data for the case study area is collected from Ministry ofWater Resources and Irrigation.

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## IV. VALUE ENGINEERING

Value Engineering (VE) was introduced into the construction industry in the early 1960s by Dell'Isola and became a trend thereafter. It is a systematic and organized process that maximizes the different values of multi-disciplinary stakeholders in a construction project. Traditionally, VE is a value enhancing tool rather than just a method of cost cutting [6]. VE is an intensive, interdisciplinary problem solving activity that focuses on improving the value of the functions that are required to accomplish the goal, or objective of any product, process, service, or organization. VE is an organized approach directed at analysing the function of systems, equipment, facilities, services and supplies for the purpose of achieving their essential functions at the lowest life cycle cost consistent with required performance, quality and safety. The highest performance in VE is achieved especially when the purpose is mainly increasing the value rather than reducing the costs. Therefore, VE is used to determine the best design alternatives for projects. Rezania et al. [17] used value engineering to ensure the success of irrigation and drainage projects. Annappa and Panditrao [4] presented the basic fundamental of value engineering that can be implemented in any product to optimize its value. Annappa and Panditrao [5] introduced how to apply Value Engineering in the industry by using tools such as Function analysis, Functional Evaluation and Decision Matrix to find the best possible alternative from the choices.

1) Value Engineering methodology: VE uses rational logic (a unique “how” - “why” questioning technique) and the analysis of function to identify relationships that increase value. It is considered a quantitative method similar to the scientific method, which focuses on hypothesis- conclusion approaches to test relationships, and operations research, which uses model building to identify predictive relationships. All VE methodology should contain the following minimal essential features:

- a. Description of the objectives and scope of the project in enough details to assure direction of the study.
- b. Goals for the study.
- c. Schedule for completion of each phase of VE including the anticipated VE study timing.
- d. Establishment of a target data for formal presentation of project results.

2) Application of VE on irrigation water shortage at canal tail-end

There are six phases to apply VE on irrigation water shortage at canal tail-end, these phases are:

### 1. Information Phase

In this phase, the current conditions of the project and the goals of the study are reviewed and defined. The problem is shortage of irrigation water at CT due to one or more of the following reasons:

- a. Consumption of irrigation water at the beginning of canal;
- b. Obstacles in the CCS prevents water from reaching its tail end;
- c. Discharging insufficient irrigation water into the canal intake;
- d. Widening of CCS due to the routine maintenance;
- e. Irrigation water losses due to conveyance and seepage.

### 2. Function Analysis Phase

This phase focuses on understanding the system element from a functional perspective; what must it do, rather than how it is currently doing. Functions are defined using two-words, active verb/measurable noun. The studied system is the irrigation system which includes branch, distribution, and field canals. System elements under consideration are canal cross section (CCS's) for branch, distribution, and field canals.

- a. Identify CCS Functions: CCS functions are identified as; convey water, provide water, prevent scouring, prevent silting, cause seepage, and cause evaporation
- b. Classify CCS Functions: Irrigation system has many functions that could be classified into basic and secondary.
  - a) Basic function is the most important action performed by a system. Basic functions of CCS are convey water, form sloop, and provide water to farm land along its whole length.
  - b) Secondary function is support functions and categorized as required function and unwanted function.

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Required function is a secondary function that is essential to support the performance of the basic function under the current design. Required functions of CCS are to prevent scouring, prevent silting, maintain cross section, and prevent widening.

Unwanted function is a negative function caused by the method used to achieve the basic function. Unwanted functions of CCS are cause seepage and cause evaporation

ITEM	FUNCTION	BASIC FUNCTION	SECONDARY FUNCTION
Longitudinal section	Convey water, form slope	√	√
Cross section Area	Prevent Scouring, Prevent Silting		√
Wetted Perimeter	Maintain cross section, Prevent widening		√
Intake	Provide water		√
Climate	Cause Evaporation		√
Soil	Cause Seepage		√

Table 1 presents the classification of irrigation system items into basic and secondary functions.

c) Develop Function Model of CCS:

The functions of solving water shortage at CT are defined using a Functional Analysis System Technique (FAST) diagram. This diagram represents a function displaying the inter-relationship of functions to each other in a ‘‘how-why’’ logic as shown in Fig. 1. The logical question ‘how’ is applied to each function starting from left to right. Then the logical question ‘why’ is applied to validate FAST diagram starting from right and left. Functions satisfying ‘how-why’ logic form ‘Major Critical Path’ functions to be put in line. The higher order function of the irrigation system is ‘‘irrigate land’’, where the causative function is ‘‘Hardening Cross section’’.

### 3. Creative Phase

Creative techniques are employed to identify other ways to perform the system functions by first session of brain storming from the point of view of 38 experts in engineering and have known the nature of the area and its problems. We can irrigate land at CT using methods shown in Table 2.

### 4. Evaluation Phase

Second stage of brain storming is conducted to identify the problem from the same experts. The questionnaire depends on idea screening steps:

(a) GO - NO GO

Scratch ideas that hold no interest.

(b) Champion

Someone support the idea.

(c) GFI (Go For It)

Discuss pros/cons and vote. GFI is team average. Combine ideas; add new ideas. Record all assumptions when voting.

(d) Trade-Off Study

Quantify performance characteristics. Select top candidates using Pair-wise Comparison, etc. Could use software such as Expert Choice. Record all assumptions when voting.

(e) Customer Acceptance

Determine & quantify customer acceptance criteria. Rate surviving ideas against norm & risk. Develop proposal scenarios.

The above eighteen ideas are displayed on the experts and they voted as shown in Table 3. After voting there are nine ideas accepted. These ideas are discussed depends on their advantages and disadvantages as shown in Table 4. Then the ‘‘Trade-off Study’’ is done to select the final alternatives to solve end tail-end canal Problem as shown in Table 5

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### 5. Development Phase

The purposes of this phase are analysis, the questionnaire is done to develop a short list of ideas and develop those with merit into value alternatives. The remaining ideas -after voting- are five ideas (I-03, I-07, I-09, I-10 and I-11). Three value alternatives are developed from these ideas to put an integrated solution for canal end problem. These value alternatives are:

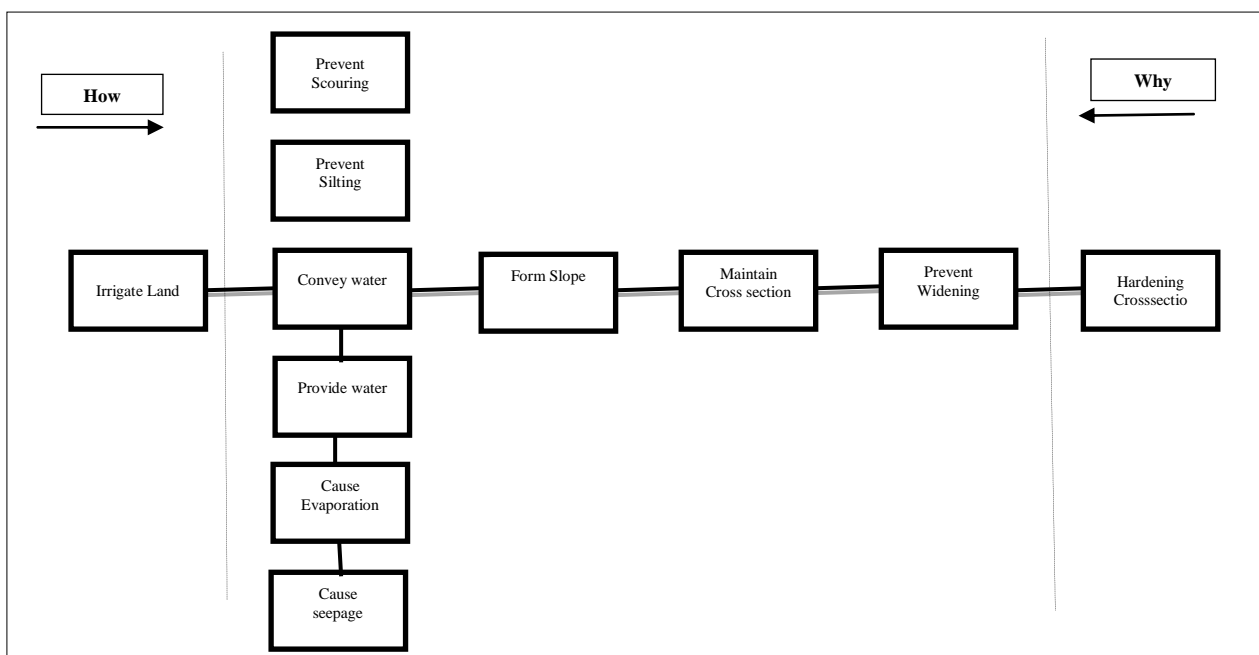


Figure 1 Fast diagram for solving the irrigation water storage.

Code	Idea
1-01	Rain
1-02	Dig another canal
1-03	Use plastic pipes for field canals to provide water
1-04	Dig wells
1-05	Use tank trucks to convey water
1-06	Use drainage water to irrigate land
1-07	Replace high consumptive use crops with low consumptive use types
1-08	Use alternatives to water to irrigate land
1-09	Lining of the surface cross section of canals
1-10	Use separate pipes to irrigate canal tail-end land
1-11	Build ground tanks at canal tail-end to store water
1-12	Build elevated tank at canal tail-end to store water
1-13	Use water pump at the canal intake into increase water pressure
1-14	Increase water discharge at the canal intake
1-15	Use valves for each farm to control water use
1-16	Use modern irrigation systems
1-17	Set aside canal tail-end farmland
1-18	Chemical production of water on farm

Table 2 Methods to irrigate land at the end.

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Code	Idea	GO or NO GO	Champion
1-01	Rain	NO GO	-
1-02	Dig a new canal from another route	NO GO	-
1-03	Use plastic pipes for field canals to provide water	GO	Yes
1-04	Dig wells	GO	Yes
1-05	Use tank trucks to convey water	NO GO	-
1-06	Use drainage water to irrigate land	GO	No
1-07	Replace high consumptive use crops with low consumptive use types	GO	Yes
1-08	Use alternatives to water to irrigate land	NO GO	-
1-09	Lining of the surface cross section of canals	GO	Yes
1-10	Use separate pipes to irrigate canal tail-end land	GO	Yes
1-11	Build ground tanks at canal tail-end to store water	GO	Yes
1-12	Build elevated tank at canal tail-end to store water	GO	Yes
1-13	Use water pump at the canal intake into increase water pressure	GO	Yes
1-14	Increase water discharge at the canal intake	GO	No
1-15	Use valves for each farm to control water use	GO	No
1-16	Use modern irrigation systems	GO	Yes
1-17	Set aside canal tail-end farmland	GO	No
1-18	Chemical production of water on farm	NO GO	-

Table 3 Voting on methods to irrigate land at the end.

(1) Value alternative 1 (VA-1) : This alternative includes lining of the surface cross sections of canals (I-09) and replacing high consumptive use crops with low consumptive use types (I-07).

(2) Value alternative 2 (VA-2) :This alternative includes using modern irrigation system (I-16) and replacing high consumptive use crops with low consumptive use types (I-07).

(3) Value alternative 3 (VA-3) :This alternative includes using separate pipes to irrigate canal tail-end land (I-10) and using plastic pipes for field canals to provide water (I-03)

Code	Idea	Advantages	Disadvantages	Average Note
1-03	Use plastic pipes for field canals to provide water	1.Minimum losses, Evaporation and friction losses 2. Save Land	High construction cost	
1-04	Dig water wells	1.Easy Construction 2. Good quality water	1.Not durable 2.Limited quantity	
1-07	Replace high consumptive use crops with low consumptive use types	Save water	Not available for all crops	
1-09	Lining of the surface cross section of canals	1.Decrease seepage 2.Increase velocity		
1-10	Use separate pipes to irrigate canal tail-end land	Deliver water		
1-11	Store water in ground tanks at canal tail-end	Store water	High construction cost	
1-12	Store water in elevated tank at canal tail-end	Store water	1.High construction cost 2.Need land space	Reject
1-13	Use water pump at the canal intake	Increase water velocity	Operation cost	

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1-16	Use modern irrigation systems	1. Save water 2. Suitable for more crops.	1. Not for all crops 2. Not for all soil types	
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Table 4 Advantages and Disadvantages for nine ideas.

Code	Idea	Performance Characteristics				Voting
		Land use	Water saving	Continuity of supply	Easy Maintenance	
1-03	Use plastic pipes for field canals to provide water	√	√	√	√	
1-04	Dig water wells			√	√	Reject
1-07	Replace high consumptive use crops with low consumptive use types		√	√	√	
1-09	Lining of the surface cross section of canals		√	√	√	
1-10	Use separate pipes to irrigate canal tail-end land	√		√	√	
1-13	Use water pump at the canal intake			√	√	Reject
1-16	Use modern irrigation systems		√	√	√	

Table 5 Trade off only.

### 6. Evaluation Criteria Phase

There are eight main evaluation criteria to evaluate previously stated VA as shown in Table 6. A questionnaire is done to evaluate the value alternatives by using the evaluation criteria don't have equal importance. A comparison matrix is utilized to calculate the weights of evaluation criteria. A scale of 0 to 5 is used to express the importance of each evaluation criteria relative to the others. A score of 0 is assigned to the comparison matrix when both criteria are equally important, while a score of 5 is assigned to the comparison matrix when a criteria is extremely important than the other. A score of 1, 2, 3, and 4 is assigned to the comparison matrix for in-between values. The comparison matrix shown in Table 6 indicates the evaluation criteria which are more important and the degree of its importance relative to the other evaluation criteria. In order to calculate weights of evaluation criteria, relative importance score for each evaluation criterion in Table 6 is added together and divided by the overall relative importance score of all evaluation criteria. Final weights of evaluation criteria are shown in Table 7.

### V. VALUE ALTERNATIVE SCORING

Table 6 shows that each VA is assigned a score between 0 and 10 against each evaluation criteria. These scores were assigned by a panel of 10 experts having experience ranges between 5 and 15 years of experience in consultation of irrigation works. For each expert response, the score of each VA is multiplied by the relevant weight of evaluation criteria and the total score is calculated for each VA. Table 8 presents the average score of each evaluation criteria and the total score for VA's as provided by the panel of experts. The results shows that VA-1 has the highest total score based on the evaluation criteria. The next step should calculate the Life Cycle Cost (LCC) of VA's to calculate Value Index.

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### VI. CALCULATING LIFE CYCLE COST

Life Cycle Cost (LCC) is a methodology to calculate the total cost of a system from inception to disposal. LCC is the sum of all recurring and non-recurring costs over the life span of a given system. It includes purchase price, installation, operation, maintenance and upgrading costs. On the other hand, Net Present Value (NPV) is defined as the difference between the present value of cash inflows and cash outflows. Therefore, NPV method is used to evaluate VA's using LCC. Eq. (1) is used in calculating NPV for VA's [16]:

$$NPV = C_i + R_e - S_r + A_a + M + E$$

where  $C_i$ : investment costs;  $R_e$ : replacement costs;  $S_r$ : resale value at the end of life span;  $A_a$ : annually recurring operating, maintenance and repair costs (except energy costs);  $M$ : non-annually recurring operating, maintenance and repair cost (except energy costs);  $E$ : energy costs.

	A	B	C	D	E	F	G	H
Water saving	A	2	3	5	4	3	2	2
Easy to construct	B		2	4	4	2	4	3
Ease of maintenance	C			2	5	3	2	3
Durability	D				1	5	2	3
Constructability	E					5	3	4
Continuity of supply	F						2	2
Health & safety	G							3
Environment friendly	H							

Table 6 Evaluation Criteria.

	Evaluation Criteria	Weight	VA – 1	VA – 2	VA – 3
A	Water saving	0.06	5	9	7
B	Easy to construct	0.08	9	4	7
C	Ease of maintenance	0.08	9	6	8
D	Durability	0.26	7	9	8
E	Constructability	0.30	8	7	8
F	Continuity of supply	0.08	7	9	9
G	Health & safety	0.08	6	9	8
H	Environment friendly	0.06	7	9	8
	Total	1.00	58	62	63



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Table 7 Weight of evaluation criteria and value alternatives score.

	<b>Evaluation Criteria</b>	<b>Weight</b>	<b>VA – 1</b>	<b>VA – 2</b>	<b>VA – 3</b>
<b>A</b>	Water saving	0.06	0.3	0.54	0.42
<b>B</b>	Easy to construct	0.08	0.72	0.32	0.56
<b>C</b>	Ease of maintenance	0.08	0.72	0.48	0.64
<b>D</b>	Durability	0.26	1.82	2.34	2.08
<b>E</b>	Constructability	0.30	2.4	2.10	2.40
<b>F</b>	Continuity of supply	0.08	0.56	0.72	0.72
<b>G</b>	Health & safety	0.08	0.48	0.72	0.64
<b>H</b>	Environment friendly	0.06	0.42	0.54	0.48
	Total Value	1.00	7.42	7.76	7.94

Table 8 Scores of value alternative.

### VII. NET PRESENT VALUE OF VA'S

To study the benefits of using VE and LCC in evaluating the pervious alternatives, an area of  $4.2 \times 10^8 \text{m}^2$  is used as the study area. The soil composition of this area is silty-clay and the crop pattern is low consumptive use of water as vegetables, citrus and fruits.

#### 1) Alternatives design

##### (a) VA-1

This alternative includes lining surface irrigation system of canals and using low consumptive use crops. This alternative is accompanied with surface drainage system. The surface cross section of canals and drains is designed by Manning formula according to the crop consumptive use as a trapezoidal cross section [12]. The crop consumptive use is calculated using Blanny- Criddle method [8].

##### (b) VA-2

This alternative includes using modern irrigation system as trickle (drip) system and using low consumptive use crops. The component of this system (emitters, sub-main and main lines, control head and pumps) are designed [9], the five pumps are used in series.

##### (c) VA-3

This alternative includes using separate pipes (which convey the flow from the main or branch canals) to irrigate branch and distribution canals tail-end land as well as using plastic pipes (usually made from PVC) for field canals to convey water to the field. The crop pattern is the same as that used in VA-1 and VA-2. Hazen- William formula is used to design VA-3 taking into consideration that irrigation water is pressurized in pipes using two pumps in series at the canal intake [10].

Parameters	<b>VA – 1</b>	<b>VA – 2</b>	<b>VA – 3</b>
AS (m <sup>2</sup> )	$4.2 \times 10^8$	$4.2 \times 10^8$	$8.4 \times 10^7$
V (m/s)	0.7	0.536	1.8
C	-	-	155
D <sub>p</sub> (m)	-	-	0.82
D <sub>lateral</sub> (m)	-	0.1	-
D <sub>submain</sub> (m)	-	0.2	-
D <sub>main</sub> (m)	-	0.46	-
n	0.011	-	-
b (m)	3	-	-
y (m)	1.5	-	-
Z	1.5	-	-

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A (m <sup>2</sup> )	7.9	-	0.53
P (m)	8.4	-	-
R (m)	0.93	-	-
L (m)	4300	-	4300
L <sub>lateral</sub> (m)	-	190	-
L <sub>submain</sub> (m)	-	610	-
L <sub>main</sub> (m)	-	1800	-
S	4.2 × 10 <sup>-6</sup>	-	6.5 × 10 <sup>-6</sup>
Q (m <sup>3</sup> /s)	5.53	5.53	1.0
H <sub>E</sub> (m)	0.0003454	-	0.013
H <sub>F</sub> (m)	0.0141594	-	0.9
H <sub>T</sub> (m)	-	-	0.003
H <sub>ex</sub> (m)	-	-	0.04
HL <sub>total</sub> (m)	0.015	-	1.32
HP (horse)	-	600	442
PW (kilowatt/h)	-	500	390

Table 9 Details for three alternatives design.

AS: area served (m<sup>2</sup>).V: flow velocity (m/s).C: Hazen-William coefficient.D<sub>p</sub>: separate pipe diameter (m).D<sub>lateral</sub>: lateral pipe diameter (m).D<sub>submain</sub>: sub-main pipe line diameter (m).D<sub>main</sub>: main pipe line diameter (m).n: Manning coefficient for lining canal.b: bed width of surface canal cross-section(m).y: water depth of surface canal cross section (m).z: side slope of surface canal cross section.A: cross-sec area (m<sup>2</sup>).P: wetted perimeter (m).R: hydraulic radius (m).L: canal length (m).L<sub>lateral</sub>: lateral pipe line length (m).L<sub>submain</sub>: sub-main pipe line length (m).L<sub>main</sub>: main pipe line length (m).S: slope of water in the cross section.Q: system flow (m<sup>3</sup>/s).H<sub>E</sub>: Head losses due to entrance (m).H<sub>F</sub>: Head losses due to friction (m).H<sub>T</sub>: head losses due to network grasses (m).H<sub>ex</sub>: head losses due to exit (m).HL<sub>total</sub>: Total head losses (m).HP: pump capability (horse).PW: electric energy (kilowatt/h).

	VA – 1	VA – 2	VA – 3
Excavation volume (m <sup>3</sup> )	30.6 × 10 <sup>7</sup>	-	19.2 × 10 <sup>7</sup>
Total initial cost (Billion L.E.)	2.1	2.9	2.38
Annual operating and maintenance cost (Billion L.E.)	0.006	0.08	0.009
Total cost as a present value (Billion LE.)	2.157	3.65	2.46

Table 10 the cost of alternatives.

Details for the design of three alternatives are shown in Table 9. First, each VA is designed to obtain the dimension and parameters of its element. Next, the initial and annul operating and maintenance cost is calculated for each VA as shown in Table 10. Calculating the net annual crop benefit (NACB) requires calculating the Basic Net Annual Crop Benefit (BNACB) and the Extra Net Annual Crop Benefit (ENACB). BNACB is benefits from the crop yield cultivated in the basic area, whilst ENACB is benefits from crop yield cultivated in extra land using the saved water.

### 2) Basic net annual crop benefit

BNACB is the yield of crops cultivated in the basic area within one year rotation. The percentage area cultivated with vegetables, citrus and fruits is 33% each. Eq. (2) is used to convert the future value to the present value while Eq. (3) is used to convert the present value to annual value [10].

$$P_v = F / (1 + i)^N$$

where P<sub>v</sub>: the present value; F: the future value; i: interest rate, and  
N: number of years.

$$(A_n = P_v \times (i \times (1 + i)^N / (1 + i)^N - 1))$$

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where  $A_n$ : annual value,  $P_v$ : present value,  $i$ : interest rate, and  $N$ : number of years. Interest rate used is equal to 10% whereas the crop yield is obtained at the end of the first year. Table 11 shows present value of crop cost, present value of crop revenue, equivalent annual crop cost, equivalent annual crop revenue, and basic net annual crop benefit.

### 3) Extra net annual crop benefit

ENACB is benefits from crop yield cultivated in extra land using water saved from using each VA. Water saved for each VA is used to cultivate extra area with the same crops used in the basic area. The ENCB is calculated for each VA as shown in Table 12.

### 4) Value index

Total Net annual crop benefit per m<sup>2</sup> is calculated for each alternative by adding benefits from the crop yield cultivated in the basic area (BNACB) plus benefits from crop yield cultivated in extra land using the saved water (ENACB). Total benefits for each alternative is calculated as a present value the NPV is calculated as subtraction of total cost as a present

Value from total benefits as a present value. To take the last decision for the best alternative to solve tail-end canal shortage, the two methods (VE and LCC) are connected by division the value of NPV over VE value to find the value index. The best alternative obtains the largest value index. These calculations are shown in Table 12.

## VIII. DISCUSSION OF RESULTS

Referring to Table 8, the total value of VA-3 is greater than VA-1 and VA-2 by 6.5% and 6.7%, respectively. Therefore, VA-3 is the best alternative fulfilling the evaluation criteria and achieving the basic function of canal. Table 12 shows that there is water saving from all VA's, however VA-2 saves more water allowing the largest extra area to be cultivated using saved water. Total net annual crop benefit of VA-2 is greater than VA-1 and VA-3 by 6.4% and 0.7%, respectively.

The NPV of VA-3 is greater than VA-1 and VA-2 by 13.2% and 2.5%, respectively. The value index of VA-3 is greater than VA-1 and VA-2 by 7.2% and 0.26%, respectively. As a result of previous discussion, VA-3 become the best alternative to avoid water shortage at CT. VA-3 is achieved using separate pipes to irrigate branch and distribution canals tail-end land as well as using PVC pipes for field canals. The irrigation water is pressurized in pipes using two pumps in series at the canal intake.

Crop	Crop cost per m <sup>2</sup>	Present value of crop cost (L.E.)	Crop yield per m <sup>2</sup> (kg)	Crop revenue per m <sup>2</sup>	Present value of crop revenue (L.E.)
Citrus	4.4	1.32	2.1	5	3.15
Vegetables	5.3	1.59	2.14	5.9	3.8
Fruits	6	1.8	2.23	7.2	4.8
Total Present value of crop cost per m <sup>2</sup> (L.E.)					4.71
Total Present value of crop revenue per m <sup>2</sup> (L.E.)					11.75
Equivalent annual crop cost per m <sup>2</sup> (L.E)					5.181
Equivalent annual crop revenue per m <sup>2</sup> (L.E)					12.93
Basic net annual crop benefit (BNACB) per m <sup>2</sup> (L.E)					7.749

Table 11 Crop cost and benefit per m<sup>2</sup>

Design alternatives	VA – 1	VA – 2	VA – 3
Saves water (m <sup>3</sup> /sec)	2.0	2.82	2.73
Extra area cultivated by saved water (m <sup>2</sup> )	1.3 × 10 <sup>7</sup>	1.86 × 10 <sup>7</sup>	1.8 × 10 <sup>7</sup>
Extra net annual crop benefit result by Extra area cultivated with saved water	1.52	2.17	2.1
Basic net annual crop benefit per m <sup>2</sup>	7.749	7.749	7.749

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(L.E)			
Total net annual crop benefit (LE/m <sup>2</sup> )	9.27	9.92	9.849
Total area (m <sup>2</sup> )	4.2 × 10 <sup>8</sup>	4.2 × 10 <sup>8</sup>	4.2 × 10 <sup>8</sup>
Net annual crop benefit for the area (Billion L.E.)	3.9	4.166	4.137
Total cost as a present value (Billion L.E.)	2.157	3.65	2.46
Total benefits as a present value (Billion L.E.)	33.9	39.27	39
NPV (Billion L.E)	31.7	35.62	36.54
Value Index = NPV/Total Value	4.27	4.59	4.602

Table 12 Calculation of value Index

### IX. CONCLUSIONS

Water saving alternatives include saving irrigation water by enhancing the non-efficient surface irrigation system including water shortage at CT. Causes of this water shortage include: widening of CCS; water losses due to conveyance and seepage along canal path; obtaining insufficient water at the canal intake, and growing crop patterns requiring extra amount of irrigation water than the designed canal discharge. Water shortage at CT has a negative impact on the crop yield of the cultivated lands on both sides of the canal end.

In this study, VE methodology was utilized to find alternatives for water shortage at CT which maintain and/or enhance the function of water conveying system with minimum cost. VE steps are:

- Collecting information about this problem and its effect on the crop yield.
- Function analysis of canal and interrelationships between functions;
- Develop creative ideas to solve this problem.
- Assess creative ideas generated from the previous step based on evaluation criteria weighted by panel of experts.
- A short list of value alternative is generated using evaluation criteria weights multiplied by alternative score to find the total value. The largest total value is for the third alternative.
- Value alternatives are designed and the benefits from saving water and increasing crop yield are calculated.
- LCC methodology is applied to evaluate the three value alternatives by calculating NPV for each alternative.
- The value index is obtained by dividing NPV over total value for each value alternative.

The best value alternative to prevent water shortage at CT is VA-3; using separate pipes to irrigate branch and distribution canal tail-end land as well as using PVC pipes for field canals. The irrigation water is pressurized in pipes using one pump at the canal intake.

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