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APPLICATION OF DYNAMIC PROGRAMMING IN WATER RESOURCES MANAGEMENT: A CASE STUDY OF UNIVERSITY OF BENIN WATER SUPPLY SYSTEM, UGBOWO, EDO STATE NIGERIA

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ABSTRACT

The paper evaluates the potentials for conjunctive use of surface water and groundwater resources to meet the present and future water demand of the University of Benin, Benin City, Edo state, Nigeria. A discrete dynamic model was developed and applied to predict the demand, consumption and net benefit of the conjunctive use of the two sources.

In the model, allocations each user was assumed to represent a stage in the sequence of decisions. Three decision variables (x_1, x_2 and x_3), were used to maximize the Net Benefits achieved from assumed discrete quantities S_1, S_2 and S_3. Results from the study show that about 52,000m^3 of water could be supplied per day by conjunctive use of surface and groundwater sources. This quantity is 32,500m^3/day higher than the present daily demand and can satisfy the demand up to the year 2023. The Net Benefit for using the multi-stage approach was found to be approximately 1.7 times greater than using both sources as a single unit.

KEYWORDS: Discrete Dynamic Programming, Surface Water Resources, Groundwater Resources, Net Benefit

1. INTRODUCTION

The role of water in both plant and animal life cannot be overemphasized. It is well reported that about 65% of the human bodyweight consist of water. Surface water may be defined as rainfall/water on the ground surface. Some texts refer to it as surface runoff. Groundwater on the other hand, is referred to as rainfall/water that infiltrates the soil and penetrates to the underlying soil strata [1].

Surface water and groundwater resources sustain all human and ecological water uses. Globally, surface water resources provide less than 1% of total water supply [2], while the rest is provided by groundwater. Surface water resources are regulated by storage facilities (reservoirs) that support various water uses including water supply to urban, agricultural, and industrial areas, recreation, environmental and ecological sustainability, energy generation, flood protection and navigation. Groundwater resources are associated with groundwater aquifers (i.e. water bearing soil layers) that are exploited by pumping to supply water for use.

Groundwater and surface water are not isolated phenomena occurring apart and distinct from each other. In nature, groundwater and surface water can intermix or interconnect. A water management strategy that recognizes the interconnection between groundwater and surface water is called coordinated or conjunctive water management.

The management of surface water and/or groundwater is aimed at developing and implementing strategies for water resources utilization with due consideration of spatial and temporal interdependencies among natural processes and water uses. Management may include supply decisions and demand decision. Supply decision may include reservoir and aquifer regulation whereas the demand decisions include water conservation and recycling.

Surface and groundwater management is a challenging undertaking. Complicating factors such as uncertain river flows and water demands, nonlinear dynamics, multiple water uses and management objectives, and complex interdependences of natural processes and water uses be-devil surface water systems. Groundwater systems likewise, are characterized by nonlinear response, large dimensionality due to their spatial extent and various uncertainty sources (such as recharge rates, boundary conditions, and parameter heterogeneity).

Conjunctive surface water and groundwater management becomes imperatives when there is strong affinity between the two subsystems. The relationship may be due to interaction of management objectives, interaction of natural processes, or both. An example of the latter occurs when aquifers and streams are hydraulically connected. In such cases, water is transferred to the streams from the aquifers when aquifer levels are high and streamflows are low. Water transfer is reversed when aquifer levels experience drawdowns and streams experience normal or high flows. The coupling of management objectives occurs when either surface water or groundwater may meet certain water uses. In such cases, substantial transfers of water can occur between the two subsystems by preferentially using one or the other to meet the water uses. Conjunctive management compounds the challenges of managing either surface water or groundwater separately. The difficulty increases as one must represent the response of both systems and their interactions, and develop management strategies that simultaneously address reservoir and aquifer control [3].

The University of Benin as at 2004 was being supplied with water from ground water only from the University of Benin water board (an arm of the Institution responsible for the management of the water supply system within the school environment). Water is pumped from this facility to all the communities within the school premises. It also supplied water to a neighbouring community (Ekosodin), to assist, especially, the students living within it. The water is pumped through a network of pipes (with necessary appurtenances located at strategic points) into elevated and underground reservoirs. Anyata B. U., et al [4] in their study found out that only one out of the four pumps was fully functional. It was proposed that, in order to meet future demand, surface water should be channelled from the Ikpoba River into three tanks which would serve as the water source.

2. METHODOLOGY

A mathematical model of a discrete dynamic programming problem would be used.

Formulation of Problem

Considering the University of Benin, Ugbowo Campus as a single community divided into three users: User 1 (comprising UDSS, SSQ, Staff School, Faculty of Engineering, Faculty of Social Sciences and Block of flats), User 2 (comprising the Administrative Office, Main Auditorium, Sports Complex, Faculty of Science, Faculty of Pharmacy, Main Café, Medical Hostel and the Library), User 3 (comprising the Hostels – Halls 1 – 5, Intercontinental Hostel, Faculty of Education, Faculty of Law, Faculty of Agricultural Science, the Health Centre, Medical Complex and Dentistry).

From Anyata B. U., et al [4], estimated water requirement in 2023 would be 32,500m^3/day. The estimated a pumping output of 2,000m^3/hr/pump for the pumps (of which only one was functional) with an estimated 12hrs/day pumping hours, giving the pump output of 24,000m^3/day. For the proposed surface channel, a proposed flow rate of 0.376m^3/s and pumping hours of 22hrs were given. This would amount to a volume of about 29,000m^3/day from the surface water supply. Therefore the total volume of water to be supplied from both schemes would be about 53,000m^3/day.

Problem

Taking the quantity of water for supply to be Q_i, that could be allocated to the three water users denoted by index i = 1, 2 and 3. The problem is to determine the allocation x_i to each user i, that maximizes the total Net Benefit.

Therefore,

i = 1 = User 1

i = 2 = User 2

i = 3 = User 3

x_1 = allocation to User 1

x_2 = allocation to commercial users

x_3 = allocation to industrial users

Assuming the Gross Benefits is defined by the function: $a_i[1 - \exp(-b_i x_i)]$ for each user i and the cost of supplying the water is defined by the concave function $c_i x_i^{d_i}$ where c_i & d_i are known positive constants and $d_i < 1$. Also, a_i and b_i are known positive constant.

Assume also, that the cost function for each user exhibits economics of scale i.e. has decreasing marginal or average cost as the quantity allocated x_i increases and the objective be to maximise the total net benefits; the planning model would be:

$$\textbf{Max} \sum_{i=1}^{3} \{a_i[1 - \exp(-b_i x_i)] - c_i x_i^{d_i}\} \tag{2. 1}$$

$$\textbf{Subject to} \sum_{i=1}^{3} x_i \le Q \tag{2. 2}$$

$$x_i \ge 0 \textbf{ for each use i} \tag{2. 3}$$

where,

a_i = Revenue generated for use i(₦)

b_i = Maintenance cost for use i(₦)

c_i = Pumping cost for use i (₦)

$d_i = (1 - \mu_i)$; μ_i = Frictional force in pipes for use i ($d_i < 1$)

Q = Quantity of water to be allocated to all users

x_i = Quantity of water allocated to user i

Restructuring the problem as a sequential allocation process or a multistage decision-making procedure, the problem could be seen as shown in the figure below.

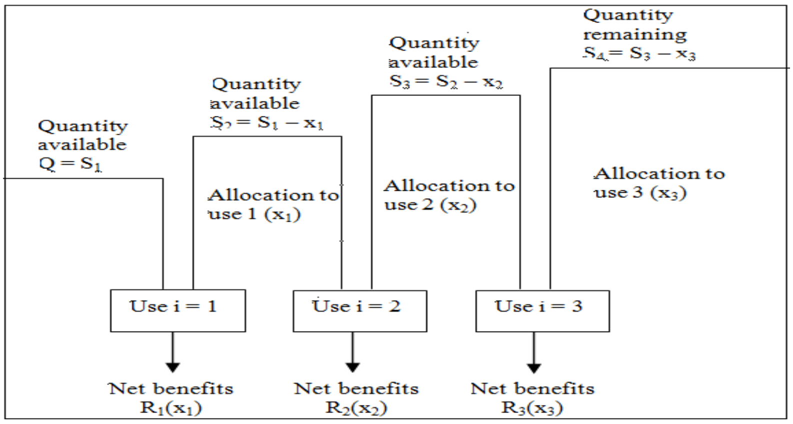


Figure 1: Sequential Allocation Process

Let the allocation to each user be considered as a decision stage in the sequence of decisions.

When a part, x_i, of the total water supply Q is allocated to stage i, the Net benefit resulting is given as:

$$\mathbf{R_i(x_i) = a_i\,[1 - \exp(-b_i x_i)] - c_i x_i^{d_i}}$$

Let S_i be a state variable which may be defined as the amount of water available to the remaining (4 – i) users or stages.

Let the state transformation $S_{i+1} = S_i - x_i$ define the state in the next stage as a function of the current state and the current allocation or decision.

Generating the recursive equation for the three users, we can re-write equations (2. 1) – (2. 3) thus:

$$f_1(Q) = \text{Maximum}\,[R_1(x_1) + R_2(x_2) + R_3(x_3)] \qquad (2.\ 4)$$
$$x_1 + x_2 + x_3 \le Q$$
$$x_1,\ x_2,\ x_3 \ge 0$$

where $f_1(Q)$ = Maximum Net Benefit obtained from the allocation of a quantity of water Q to the three users.

Each allocation cannot be negative and their sum cannot exceed the quantity of water available, Q.

Equation 2. 4 represents a problem having three decision variables. We shall now try to transform equation 3. 4 into three problems having only are decision variable each. Thus:

$$\mathbf{f_1(Q) = \underset{\substack{x_1 \\ 0 \le x_1 \le Q}}{maximum} \{R_1(x_1) + \underset{\substack{x_2 \\ 0 \le x_2 \le Q - x_1 = S_2}}{maximum} [R_2(x_2) + \underset{\substack{x_3 \\ 0 \le x_3 \le S_2 - x_2 = S_3}}{maximum} R_3(x_3)]\}} \qquad (2.\ 5)$$

Let the function $f_3(S_3)$ be equal to the maximum net benefit achieved from use 3 given a quantity of water S_3 available for allocation that use. Therefore, with various discrete values of S_3 from 0 to Q, the value of $f_3(S_3)$ can be determined thus:

$$f_3(S_3) = \underset{\substack{x_3 \\ 0 \le x_3 \le S_3}}{\text{maximum}} [R_3(x_3)] \qquad (2.\ 6)$$

Similarly, if $f_2(S_2)$ equals the maximum net benefit obtained from users 2 and 3 with a quantity S_2 to allocate to them, with various discrete values of S_2 between 0 and Q, the value of $f_2(S_2)$ can be determined thus:

$$f_2(S_2) = \underset{\substack{x_2 \\ 0 \le x_2 \le S_2}}{\text{maximum}} [R_2(x_2) + f_3(S_3)] \tag{2. 7}$$

Since the water available for use 3 (S_3), is equal to the water available for user 2 and 3 (S_2) minus the quantity used at stage 2 (x_3), mathematically, we have:

$$S_3 = S_2 - x_2 \tag{3. 8}$$

This equation 5 can be re-written as:

$$f_1(Q) = \underset{\substack{x_1 \\ 0 \le x_1 \le Q}}{\text{maximum}} \{R_1(x_1) + \underset{\substack{x_2 \\ 0 \le x_2 \le S_2}}{\text{maximum}} [R_2(x_2) + f_3(S_3)] \} \tag{3. 9}$$

$$f_1(Q) = \underset{\substack{x_1 \\ 0 \le x_1 \le Q}}{\text{maximum}} \{R_1(x_1) + \underset{\substack{x_2 \\ 0 \le x_2 \le S_2}}{\text{maximum}} [R_2(x_3) + f_3(S_2 - x_2)]\} \tag{3. 10}$$

with equation 3. 7, equation 3. 10 can be written thus:

$$f_1(Q) = \underset{\substack{x_1 \\ 0 \le x_1 \le Q}}{\text{Maximum}} [R_1(x_1) + f_2(S_2)] \tag{3. 11}$$

Also, water available to user 2 and 3 (i.e. S_2) is equal to the total water available to use1 minus the quantity of water x_1 used in that stage.

Thus, mathematically,

$$S_2 = Q - x_1 \tag{3. 12}$$

Substituting equation 3. 12 into 3. 11, we have an equation that is written in terms of x_1 and Q only. Thus:

$$f_1(Q) = \underset{\substack{x_1 \\ 0 \le x_1 \le Q}}{\text{maximum}} \{R_1(x_1) + f_2(Q - x_1)\} \tag{3. 13}$$

Where $f_1(Q)$ = maximum net benefits achievable with a quantity of water Q to allocate to users 1, 2, and 3.

Now, equation 3. 13 cannot be solved without a knowledge of $f_2(S_2)$. Equation 3. 7, which gives $f_2(S_2)$ cannot also be solved without a knowledge of $f_3(S_3)$. However equation 3. 6 can be used to obtain the value of $f_3(S_3)$ without further reference to any other equation or net benefit function $f_i(S_i)$. Therefore, with a knowledge of the value of $f_3(S_3)$, we can find the value of $f_2(S_2)$ and subsequently the value of $f_1(Q)$.

Equations 3. 6, 3. 7 and 3. 13 are called **recursive equations** since they must be sequentially solved.

3. RESULTS AND DISCUSSIONS

Assuming:

a_i = 2000; 1000; 3000 (in millions of Naira)

b_i = 0.3; 0.2; 0.4 (in millions of Naira)

c_i = 160; 180; 240 (in millions of Naira)

d_i = 0.9; 0.4; 0.6

Quantity of Groundwater (Q_g) ~ 24,000m^3 = 24 units and

Quantity of Surface water (Q_s) ~ 28,000m^3 = 28 units

The following tables show the Maximum Net Benefit of supplying Q_g and Q_s as individual or separate units and as a single unit, Q_{gs}.

Table 1: Values of $R_iX_i = \{a_i[1 - \exp(-b_ix_i)] - c_ix_i^{di}\}$ for x_i = 0, 4, 8, ..., 24

x_i	$R_1(x_1)$	$R_2(x_2)$	$R_3(x_3)$
0	0	0	0
4	1341.9	519.33	2339.17
8	1714.6	756.75	2794.14
12	1795.6	860.65	2686.72
16	1789.53	904.67	2868.34
20	1757.88	922.02	2854.17
24	1719.05	927.6	2838.24

Table 2: Values of $f_3(S_3) = \underset{x_3}{\text{Maximum}}[R_3(x_3)]$ for values of x = 0, 4, 8, ..., 24

$0 \le x_3 \le S_3$

State	$R_3(x_3)$							$F_3(S_3)$	x_3*
S_3	x_3:0	4	8	12	16	20	24		
0	0							0	0
4	0	2339.17						2339.17	4
8	0	2339.17	2794.14					2794.14	8
12	0	2339.17	2794.14	2868.72				2868.72	12
16	0	2339.17	2794.14	2868.72	2868.34			2868.72	12
20	0	2339.17	2794.14	2868.72	2868.34	2854.17		2854.72	12
24	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2838.72	12

Table 3: Values of $f_2(S_2) = \underset{x_2}{\text{Maximum}}[R_2(x_2) + f_3(S_3)]$ for values of x = 0, 4, 8, ..., 24

$0 \le x_2 \le S_2$

State	$R_2x_2+f_3(S_2-x_2)$							$F_2(S_2)$	x_2*
S_2	x_2:0	4	8	12	16	20	24		
0	0							0	0
4	2339.17	519.33						2339.17	0
8	2794.14	2858.5	756.75					2858.5	4
12	2868.72	3313.47	3095.92	860.65				3313.47	4
16	2868.72	3388.05	3550.89	3199.82	904.67			3550.89	8
20	2868.72	3388.05	3625.47	3654.79	3243.84	922.02		3654.79	12
24	2868.72	3388.05	3625.47	3729.37	3698.81	3261.19	927.6	3729.37	12

Table 4: Values of f_1 (Q) = Maximum [R_1 (x_1) + f_2 (S_2)] for values of x = 0, 4, 8, ..., 24
x_1
$0 \le x_1 \le Q$

State	$R_1x_1+f_2$ (S_1-x_1)							F_1 (S_1)	x_1*
S_1	x_1:0	4	8	12	16	20	24		
0	3729.37	4996.69	5265.07	5109.07	4646.03	4097.05	1719.05	5265.49	8

Table 5: Values of $R_iX_i = \{a_i[1 - \exp(-b_ix_i)] - c_ix_i^{di}\}$ for x_i = 0, 4, 8, ..., 28

x_i	R_1 (x_1)	R_2 (x_2)	R_3 (x_3)
0	0	0	0
4	1341.9	519.33	2339.17
8	1714.6	756.75	2794.14
12	1795.6	860.65	2686.72
16	1789.53	904.67	2868.34
20	1757.88	922.02	2854.17
24	1719.05	927.6	2838.24
28	1678.51	928.05	2822.74

Table 6: Values of f_3 (S_3) = Maximum [R_3 (x_3)] for values of x = 0, 4, 8, ..., 28
x_3
$0 \le x_3 \le S_3$

State	R_3 (X_3)								F_3 (S_3)	x_3*
S_3	x_3:0	4	8	12	16	20	24	28		
0	0								0	0
4	0	2339.17							2339.17	4
8	0	2339.17	2794.14						2794.14	8
12	0	2339.17	2794.14	2868.72					2868.72	12
16	0	2339.17	2794.14	2868.72	2868.34				2868.72	12
20	0	2339.17	2794.14	2868.72	2868.34	2854.17			2868.72	12
24	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24		2868.72	12
28	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2822.74	2868.72	12

Table 7: Values of f_2 (S_2) = Maximum [R_2 (x_2) + f_3 (S_3)] for values of x = 0, 4, 8, ..., 28
x_2
$0 \le x_2 \le S_2$

State	$R_2x_2+f_3$ (S_2-x_2)								F_2 (S_2)	x_2*
S_2	x_2: 0	4	8	12	16	20	24	28		
0	0								0	0
4	2339.17	519.33							2339.17	0
8	2794.14	2858.5	756.75						2858.5	4
12	2868.72	3313.47	3095.92	860.65					3313.47	4
16	2868.72	3388.05	3550.89	3199.82	904.67				3550.89	8
20	2868.72	3388.05	3625.47	3654.79	3243.84	922.02			3654.79	12
24	2868.72	3388.05	3625.47	3729.37	3698.81	3261.19	927.6		3729.37	12
28	2868.72	3388.05	3625.47	3729.37	3772.81	3716.16	3266.77	928.05	3772.81	16

Table 8: Values of f_1 (Q) = Maximum [R_1 (x_1) + f_2 (S_2)] for values of x = 0, 4, 8, ..., 28
x_1
$0 \le x_1 \le Q$

State	$R_1x_1+f_3$ (S_1-x_1)								F_1 (S_1)	x_1*
S_1	x_1: 0	4	8	12	16	20	24	28		
0	3790.74	5114.71	5443.97	5450.39	5340.42	5071.55	4577.55	4009.68	5450.39	12

Table 9: Values of $R_iX_i = \{a_i[1 - \exp(-b_ix_i)] - c_ix_i^{d_i}\}$ for x_i = 0, 4, 8, ..., 52

x_i	$R_1(x_1)$	$R_2(x_2)$	$R_3(x_3)$
0	0	0	0
4	1341.9	519.33	2339.17
8	1714.6	756.75	2794.14
12	1795.6	860.65	2686.72
16	1789.53	904.67	2868.34
20	1757.88	922.02	2854.17
24	1719.05	927.6	2838.24
28	1678.51	928.05	2822.74
32	1637.83	926.34	2807.99
36	1597.43	923.78	2793.94
40	1557.43	920.94	2780.49
44	1517.80	918.07	2767.57
48	1478.52	915.25	2755.12
52	1439.57	912.54	2743.07

Table 10: Values of $f_3(S_3) = \underset{x_3}{\text{Maximum}}[R_3(x_3)]$ for values of x = 0, 4, 8, ..., 52

$$0 \leq x_3 \leq S_3$$

State	$R_3(x_3)$														$F_3(S_3)$	x_3^*
S_3	x_3:0	4	8	12	16	20	24	28	32	36	40	44	48	52		
0	0														0	0
4	0	2339.17													2339.17	4
8	0	2339.17	2794.14												2794.14	8
12	0	2339.17	2794.14	2868.72											2868.72	12
16	0	2339.17	2794.14	2868.72	2868.34										2868.72	12
20	0	2339.17	2794.14	2868.72	2868.34	2854.17									2868.72	12
24	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24								2868.72	12
28	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2822.74							2868.72	12
32	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2822.74	2807.99						2868.72	12
36	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2822.74	2807.99	2793.94					2868.72	12
40	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2822.74	2807.99	2793.94	2780.49				2868.72	12
44	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2822.74	2807.99	2793.94	2780.49	2767.57			2868.72	12
48	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2822.74	2807.99	2793.94	2780.49	2767.57	2755.12		2868.72	12
52	0	2339.17	2794.14	2868.72	2868.34	2854.17	2838.24	2822.74	2807.99	2793.94	2780.49	2767.57	2755.12	2743.07	2868.72	12

Table 11: Values of $f_2(S_2) = \underset{x_2}{\text{Maximum}}[R_2(x_2) + f_3(S_3)]$ for values of x = 0, 4, 8, ..., 52

$$0 \leq x_2 \leq S_2$$

State	$R_2x_2+f_3(S_2-x_2)$														$F_2(S_2)$	x_2^*
S_2	x_2: 0	4	8	12	16	20	24	28	32	36	40	44	48	52		
0	0														0	0
4	2339.17	519.33													2339.17	0
8	2794.14	2858.50	756.75												2858.50	4
12	2868.72	3313.47	3095.92	860.65											3313.47	4
16	2868.72	3377.83	3550.89	3199.82	904.67										3550.89	8
20	2868.72	3377.83	3615.25	3654.79	3243.84	922.02									3654.79	12
24	2868.72	3377.83	3615.25	3719.15	3698.81	3261.19	927.60								3719.15	12
28	2868.72	3377.83	3615.25	3719.15	3763.17	3716.16	3266.77	928.05							3763.17	16
32	2868.72	3377.83	3615.25	3719.15	3763.17	3780.52	3721.74	3265.51	926.34						3780.52	20
36	2868.72	3377.83	3615.25	3719.15	3763.17	3780.52	3786.10	3720.48	3265.51	923.78					3786.10	24
40	2868.72	3377.83	3615.25	3719.15	3763.17	3780.52	3786.10	3784.84	3720.48	3262.95	920.94				3786.55	28
44	2868.72	3377.83	3615.25	3719.15	3763.17	3780.52	3786.10	3784.84	3784.84	3717.92	3260.11	918.07			3786.55	28
48	2868.72	3377.83	3615.25	3719.15	3763.17	3780.52	3786.10	3784.84	3784.84	3782.28	3715.08	3257.24	915.25		3786.55	28
52	2868.72	3377.83	3615.25	3719.15	3763.17	3780.52	3786.10	3784.84	3784.84	3782.28	3779.44	3712.21	3254.42	912.54	3786.55	28

Table 12: Values of $f_1(Q) = \underset{x_1}{\text{Maximum}}[R_1(x_1) + f_2(S_2)]$ for values of x = 0, 4, 8, ..., 52

$$0 \leq x_1 \leq Q$$

State	$R_1x_1+f_3(S_1-x_1)$														$F_1(S_1)$	x_1^*
S_1	x_3: 0	4	8	12	16	20	24	28	32	36	40	44	48	52		
0	3786.55	5128.45	5501.15	5582.15	5575.63	5538.40	5482.22	5397.66	5292.62	5148.32	4870.90	4376.30	3817.69	1439.59	5582.15	12

Table 1 shows the values of the Net Benefit of each of the uses $R_1(x_1)$, $R_2(x_2)$, $R_3(x_3)$ varying the quantity of groundwater available from 0 – 24 units.

Table 2 shows the values of $R_3(x_3)$ and max $R_3(x_3)$ represented by the function $F_3(S_3)$ for values of x = 0 – 24 units. x_3^* represents the quantity of groundwater used where the $F_3(x_3)$ occurs for each state S_3.

Table 3 shows the values of $R_2(x_2) + f_3(S_2 - x_2)$ and max $R_2(x_2) + f_3(S_2 - x_2)$ represented by the function $F_2(S_2)$ for values of x = 0 – 24 units. x_2^* represents the quantity of groundwater used where the $F_2(x_2)$ occurs for each state S_2.

Table 4 shows the values of $f_1(Q)$ = Maximum $[R_1(x_1) + f_2(S_2)]$ and max $f_1(Q)$ represented by the function $F_1(S_1)$ for values of x = 0 – 24 units. x_1^* represents the quantity of groundwater used where the $F_1(x_1)$ occurs for each state S_1.

Table 5 shows the values of the Net Benefit of each of the uses $R_1(x_1)$, $R_2(x_2)$, $R_3(x_3)$ varying the quantity of surface water available from 0 – 28 units.

Table 6 shows the values of $R_3(x_3)$ and max $R_3(x_3)$ represented by the function $F_3(S_3)$ for values of x = 0 – 28 units. x_3^* represents the quantity of surface water used where the $F_3(x_3)$ occurs for each state S_3.

Table 7 shows the values of $R_2(x_2) + f_3(S_2 - x_2)$ and max $R_2(x_2) + f_3(S_2 - x_2)$ represented by the function $F_2(S_2)$ for values of x = 0 – 28 units. x_2^* represents the quantity of surface water used where the $F_2(x_2)$ occurs for each state S_2.

Table 8 shows the values of $f_1(Q)$ = Maximum $[R_1(x_1) + f_2(S_2)]$ and max $f_1(Q)$ represented by the function $F_1(S_1)$ for values of x = 0 – 28 units. x_1^* represents the quantity of surface water used where the $F_1(x_1)$ occurs for each state S_1.

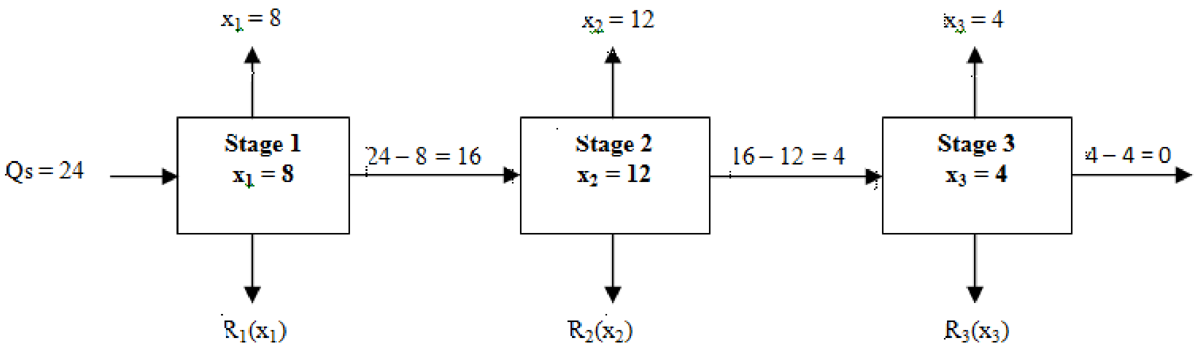
Table 9 shows the values of the Net Benefit of each of the uses $R_1(x_1)$, $R_2(x_2)$, $R_3(x_3)$ varying the quantity of water available from 0 – 52 units.

Table 10 shows the values of $R_3(x_3)$ and max $R_3(x_3)$ represented by the function $F_3(S_3)$ for values of x = 0 – 52 units. x_3^* represents the quantity of water used where the $F_3(x_3)$ occurs for each state S_3.

Table 11 shows the values of $R_2(x_2) + f_3(S_2 - x_2)$ and max $R_2(x_2) + f_3(S_2 - x_2)$ represented by the function $F_2(S_2)$ for values of x = 0 – 52 units. x_2^* represents the quantity of water used where the $F_2(x_2)$ occurs for each state S_2.

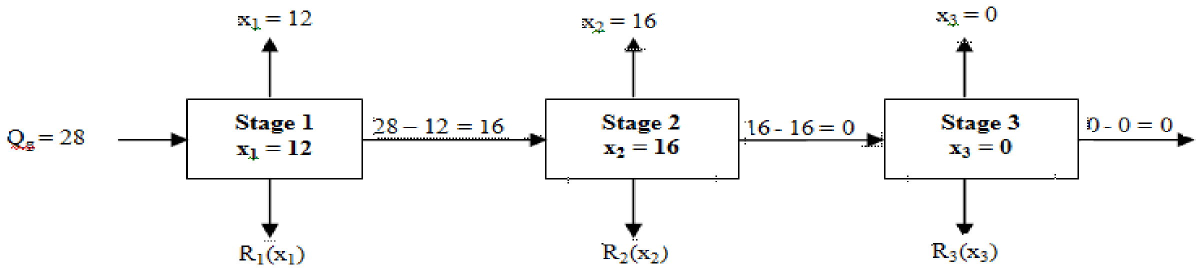
Table 12 shows the values of $f_1(Q)$ = Maximum $[R_1(x_1) + f_2(S_2)]$ and max $f_1(Q)$ represented by the function $F_1(S_1)$ for values of x = 0 – 52 units. x_1^* represents the quantity of water used where the $F_1(x_1)$ occurs for each state S_1.

A comparison of the maximum Net Benefits is represented in the figures below.



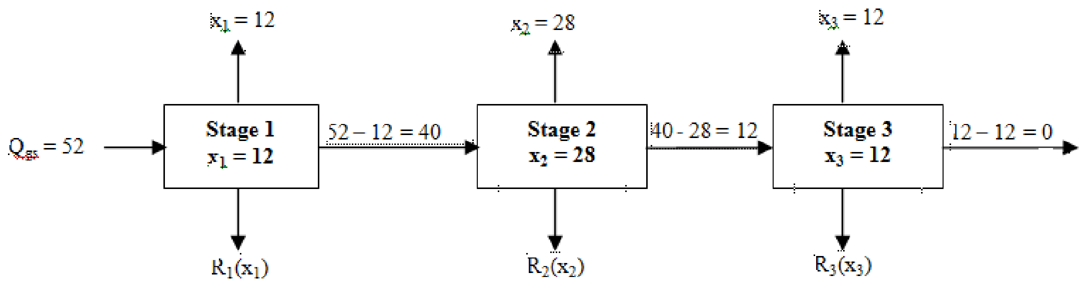
Net Benefit => 5265.49 + 3729.37 + 2339.17 = 11,334.03

Figure 2: Surface water Distribution as a Single Unit



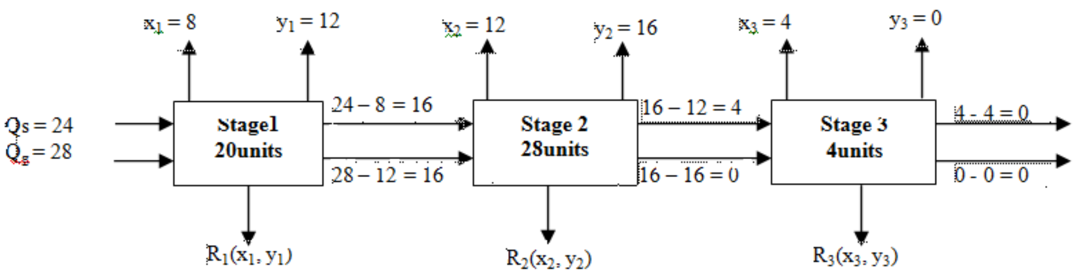
Net Benefit => 5450.39 + 3772.81 + 0 = 9223.20

Figure 3: Groundwater Distribution as a Single Unit



Net Benefit => 5582.15 + 3786.55 + 2868.72 = 12.237.42

Figure 4: Groundwater and Surface Water Distribution Conjunctively as a Single Unit



Net Benefit => 5450.39 + 3772.81 + 0 + 5265.49 + 3729.37 + 2339.17 = 20,557.23

Figure 5: Groundwater and Surface Water Distribution Conjunctively Managed Using the Multi-Stage Approach

4. CONCLUSIONS

It can therefore be concluded that the conjunctive management of surface water and groundwater resources is better than the separate management of these resources.

5. RECOMMENDATIONS

From the above findings, it is recommended that:

- The University Management should adopt the method of conjunctive management in addressing the problem of water supply affecting the Ugbowo Campus presently.
- There is the need for proper planning of communities, towns, cities etc to serve as a proactive approach in handling the problem of effective and efficient water supply in the future.
- The Federal and State Water Boards should adopt this method in order to enhance the effective and efficient use, supply and distribution of water.

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