IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 06, Issue 12 (Dec. 2016), ||V2|| PP 29-35

Impact of Outflow in Salinity Control – An Assessment of Kochi Water Supply Scheme

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Abstract: - Salinity intrusion into the estuary of the river Periyar in the western region of the Kerala State was concentrated in view of Mass Balance Equation and utilizing the Harlman's Empirical relationship. The upstream stretch of the salinity front under negative conditions achieves a river section situated at around 20 km upstream the river mouth, where the intake for Kochi Water supply scheme situates. The applied mathematical relationship made to this river conditions constitutes a powerful tool for assessment of the salinity intrusion design in the river Periyar estuary, and an auxiliary instrument for decision making in river basin water management. Accordingly this paper is a re-assessment work based on the conclusions already made.

Key words: *Empirical, Estuary, Hydrodynamics, Mathematical Relationship, Saline intrusion, Scheme*

I. INTRODUCTION

A river is a natural water course, usually fresh water, flowing towards an ocean, a lake, a sea, or another river. In a few cases, a river simply flows into the ground or dries up completely before reaching another body of water. Small rivers may also be called by several other names, including stream, creek, brook, rivulet, tributary and rill. There is no general rule that defines what can be called a river, although in some countries or communities a stream may be defined by its size [1]. Rivers are part of the hydrological cycle. Water within a river is generally collected from precipitation through a drainage basin from surface runoff and other sources such as ground water recharge, springs, and the release of stored water in natural glaciers. A river is fresh water flowing across the surface of the land, usually to the sea, it flows in a channel. Recently (in 2012), the water treatment plant for Kochi water Supply scheme, suspended its operations in several hours in several days. Similar situations occurred in some years back after finding a considerable rise in salinity levels. It is noticed that the upsurge in salinity took place following the high tide from the sea reaching the upstream.

One important component to derive from the subject of stream flow is water resource management, which includes initiatives to control or to protect streams, rivers, lakes, wetlands, or entire watersheds. If we look at water availability and its supporting sources, such as precipitation contributions to lakes, streams are interrelated to drinking water, manufacturing, power generation, irrigation, or other beneficial usages. One objective of water resource management is to preserve and enhance these usages, where any added understanding of stream flow rates and total volume contributions are important learning and research considerations [5]. The main source of Kochi Drinking Water Supply is River Periyar, which is also affected several times due to poor flow and Salinity intrusion, giving importance of this study. It is observed that the discharge rate of water from Bhoothathankettu decreased over the years. The storage capacity at Bhoothathankettu also came down considerably. It is also observed that the salinity started entering the upstream as the flow of water receded with the onset of summer and the incursion could be prevented through water release from the Boothathankettu dam.

Periyar River is the main source of drinking water to Kochi area. A huge quantity of water discharged to sea during monsoon and facing acute scarcity during summer. The lean flow during summer opens the door for salinity intrusion to the intake point. Earlier studies revealed that the proper conservation and efficient management of water resources are required and have conducted detailed studies. This paper is an attempt to ascertain the results based on earlier works.

Periyar River is seriously affected by the strong salinity intrusion and as a result of this drinking water to the Kochi Water Supply Scheme is continuously threatened in recent years. In this background, a study was conducted on the outflow through the two estuaries of Periyar River. In the earlier paper [4] the study was based on the year 2004 flow. This paper considered the 2008 flow and a comparison with the earlier results were carried out. In this regard the following were conceded.

1. To study the monthly variation in final fresh water out flow during 2008 to the two estuaries using the Mass balance study.
2. To assess the rate of salinity intrusion towards the area of intake of Kochi water supply scheme by applying the Harleman's Empirical relationship [5].
3. To study the Salinity intrusion rate with respect to the computed values with the actual measured value

4. Assessing the quantity of fresh water could have been saved in the system after prper attention given to maintain the quality of drinking water.

II. METHODOLOGY

Mass balance Study was carried out and by applying the equation of continuity, the out flow of each section was computed vide Table-2.

1. Based on the geometrical values and the velocity of the river, the salinity intrusion at the intake point can be predicted by applying Harleman's empirical relationship.
2. Compare the computed concentration of salinity at the intake with the measured values and ascertain its validity using statistical methods
3. Compute the quantity of discharge, which can be adjusted for maintaining the quality of drinking water and to get an idea for developing an automatic control system.
4. A comparison was carried out in the results obtained during the year 2004 with year 2008

III. RESULTS AND DISCUSSIONS

3.1 Details of Study Area

Considering the convenience of the study the river was divided into 8 sections from the Barrage, Bhuthathankettu to the estuaries. Details of the sections and the related code of the study area is given in Table - 1. The Periyar River has been divided into 7 sections from the Bhoothathankettu Barrage towards the two estuaries (Purapillikavu and Eloor).

Table -1 PERIYAR RIVER - STATION DETAILS

Sl. No	Name of Station	Section Code	Location	Average Width M	Average Depth M	Distance from Bhoothathankettu in Km
1	BHOOTHATHANKETTU	BH	10^0 2' 6"N 76^0 39' 50.4"E	230.00	2.00	0.00
2	VENGOOR(NEAR)	VG	$10^0$10'19.2"N 76^0 34' 4.8"E	113.30	2.00	15.10
3	KALADY	KA	10^0 09' 54"N 76^0 26' 8"E	114.11	4.00	30.20
4	VALLOM	VL	$10^0$10'19.2"N 76^0 34' 4.8"E	115.00	3.50	42.30
5	CHOWARA	CW	$10^0$6'21.6"N 76^0 23' 26.65"E	200.00	2.50	50.00
6	ALUVA	AV	$10^0$6' 21.6"N 76^0 23' 26.65"E	340.00	3.50	64.10
7	PURAPPALLIKKAVU	PU	$10^0$08'34.48"N 76^0 17' 03.17"E	450.00	4.00	82.50
8	ELOOR	EL	$10^0$04'52.84"N 76^0 18' 30.27"E	111.00	2.00	75.40

3.2 Total Discharge

Total discharge to the first section is the sum of the discharges from the barrage, runoff from the section and industrial discharge of the section. This will be known as the inflow (Qi) of first section. Likewise, the sum of the discharges of all sections will provide the total discharge of the system under consideration.

3.3 Outflow

Out flow of the section is the net available quantity after all withdrawals and losses from the inflow of the section. This concept is represented through the figure given below and is continued up to the nth section of the river for the Mass Balance study of the river.

The outflows from each section will be the net result of the inflows and losses. When considering the first section, the outflow from the first section can be calculated as per equation (Fig - 1). The outflow from the

first section is taken as the inflow to the next section. The entire stretch of the river is analysed in the same manner. The process can be expressed as follows.

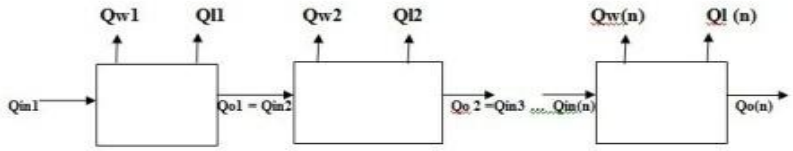


Fig - 1 The river entire stretch

The outflow from the final section (n^{th} section) will be the final fresh water outflow to the sea.

3.4 Mass Balance Calculations

Let us consider the river as a whole and the water released from the barrage is the main inflow to the river downstream.

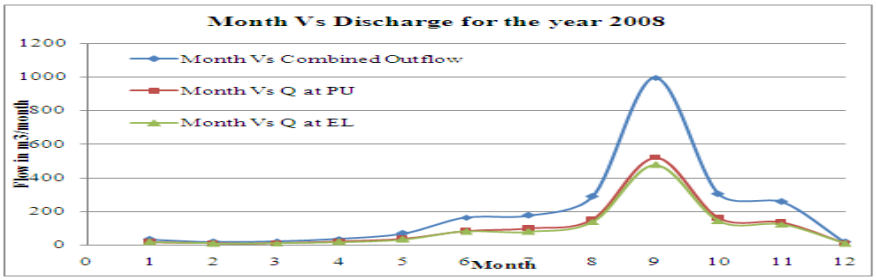


Fig- 2 Month wise Discharge

As the water flow downwards, various tributaries will be joining along the course of river till it finally meets with the Arabian sea. Along the banks of the river various organisation like Kerala water authority, Irrigation department, are withdrawing water for water supply and for irrigation purposes. Flats, Apartments, and private firms located nearby are also using the river water for domestic and other purposes. So certain amount of water will be lost. The industries located at the downstream discharges effluents to the river thereby reducing the fresh water amount. The fresh water amount reaching the estuary should be sufficient to overcome the salinity intrusion towards upstream [4]. The maximum permissible limit of chloride in Drinking water is 250 ppm. (IS 10500:1991). So the Chloride rate should be controlled to the minimum at the intakes of Water supply schemes.

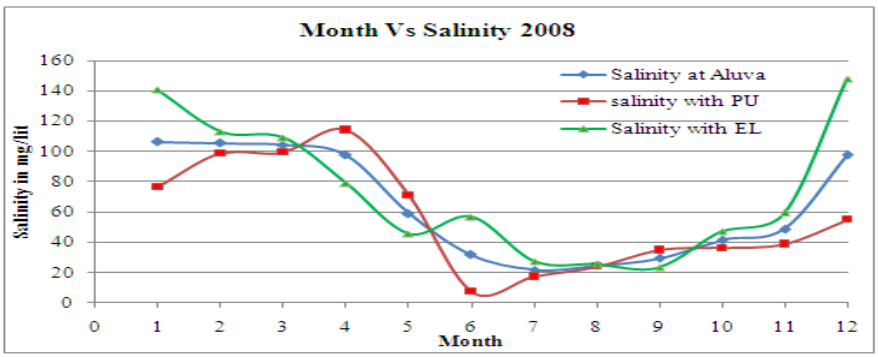


Fig- 3 Monthwise Salinity

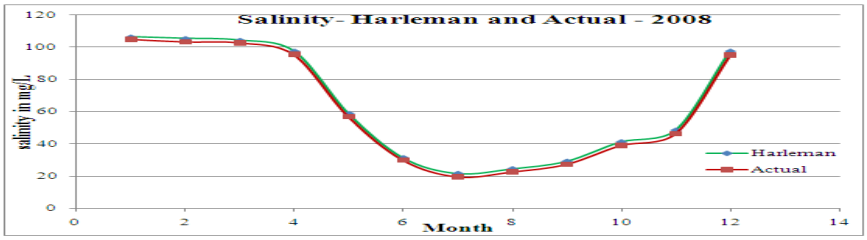


Fig- 4 Comparison of Salinity Computed with Actual

3.5 Salinity Intrusion Study

The discharges through the estuaries and the concentration of salinity at the estuaries were used to predict the salinity level at the headwork's area situated about 20kms upstream with a time lag to take an early precautionary action. Harleman's Mathematical model (1961) is found to be most suitable for the conditions prevailing to Periyar estuaries. The Harleman Model, determine the chloride concentration to assess the salinity level in mg/lit by finding the Coefficient of Eddy diffusion (Metcalf & Eddy1990),

$E = CnvR^{5/6}$

Where, E= Coefficient of eddy diffusion (m2/sec), C= 63.2 (SI units), n = Manning's roughness coefficient, v= velocity (m/sec) and R=hydraulic radius , Chloride concentration $C = C0\ e^{jx}$, Where, C_0 is the Chloride concentration at the estuary in mg/lit and J= v/E

The validity of the model has been tested with the past results (Fig. 4) and the coefficient of correlation is obtained as 0.999. This work is for the reassessment based on the 2004 results [4].

Fig- 5 Assessment of Salinity Computed with Harleman

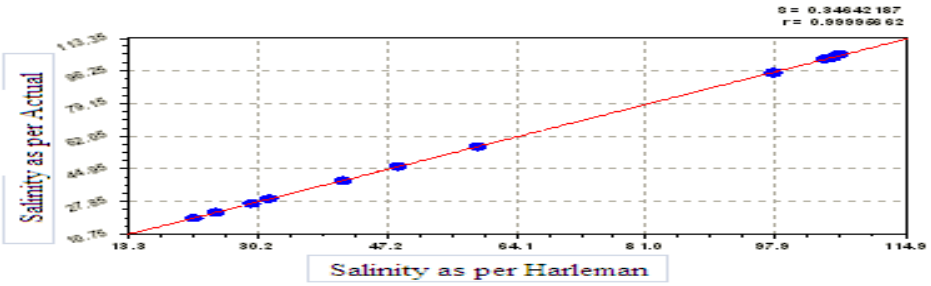
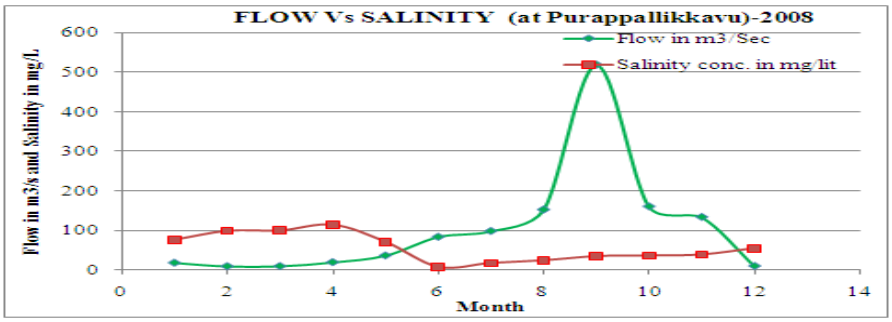


Fig- 6 Relation between Flow and Salinity (PU)



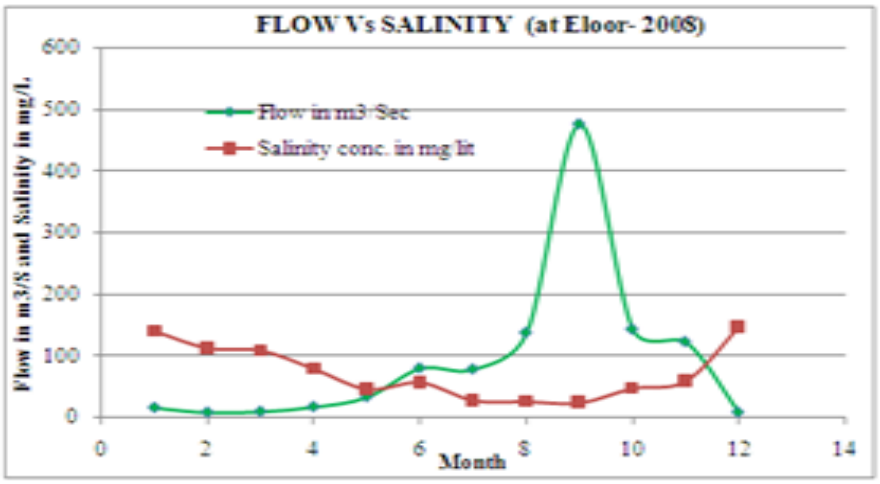
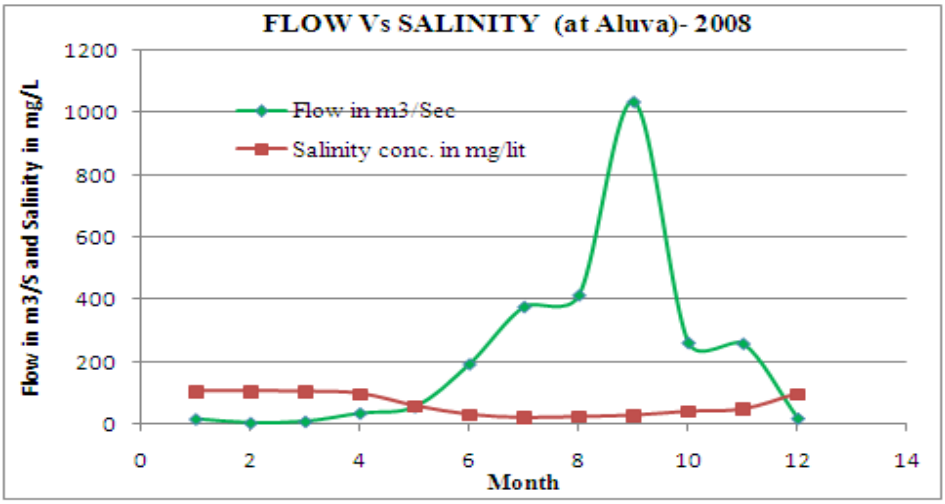


Fig- 7 Relation between Flow and Salinity (EL)

Fig- 8 Relation between Flow and Salinity(AV)



IV. CONCLUSIONS

1. The output of Mass Balance study incorporates the prevailing regime of Periyar River
2. The Study results will assist for early actions for uninterrupted water supply to Kochi.
3. The study reiterates the Harleman's empirical model is a strong tool to predict the salinity values of Kochi water supply scheme too.
4. The mass balance study details can be utilized for the proper River Management actions.
5. The study gives inspiration to control the river flow to avoid unfruitful discharges into the river.
6. By developing a proper control method the salinity intrusion can be controlled.
7. By noticing the salinity at an earlier stage, the drinking water source can be protected.
8. By implementing a proper control method, the flow can be optimised for, in terms of usage and salinity level.
9. The results obtained through the empirical relationship are validated with the actual values using statistical methods
10. The study results for 2008 reassess the results obtained for the year 2004

V. TABLES AND FIGURES

Table-2 MONTH WISE FLOW DETAILS IN m3/ sec DURING 2008

Station	Distance in kM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BH	0.0	22.9	10.9	14.4	41.5	60.5	194.2	366.0	410.4	1035.3	260.7	264.8	24.5
VG	13.3	22.6	10.7	14.2	41.2	60.6	194.5	370.1	412.8	1036.3	262.2	264.5	24.2
KA	29.7	20.9	9.0	12.8	39.4	59.5	195.0	375.2	415.0	1036.8	263.3	263.0	22.7
VL	36.5	19.5	7.5	11.4	38.0	58.2	195.0	376.8	415.1	1036.3	263.0	261.6	21.4
CW	44.4	18.6	6.6	10.6	37.1	57.6	194.9	377.8	415.4	1036.1	262.9	260.8	20.6
AV	49.0	16.3	4.0	8.3	34.7	55.3	192.7	376.4	413.6	1034.0	261.0	258.4	18.3
PU	69.8	7.3	3.6	6.6	16.9	36.0	109.3	253.8	256.1	557.3	160.1	133.4	8.5
KM	56.0	7.8	2.5	4.8	16.7	28.0	94.5	187.9	204.8	499.5	128.6	124.1	8.8
EL-1	65.6	1.9	1.3	2.2	4.1	8.6	25.5	54.8	57.7	125.6	35.4	30.4	2.1
MU	56.0	4.6	1.2	3.5	11.3	21.9	74.5	153.0	163.4	381.4	101.4	92.7	5.5
PA	59.7	4.2	1.4	4.0	11.0	23.0	76.2	160.3	169.6	384.2	104.5	92.4	5.1
EL-2	65.4	4.0	1.8	4.6	10.9	24.3	78.2	167.3	175.6	387.0	107.6	92.4	5.0
ELT	65.7	5.9	3.1	6.8	15.0	32.8	103.7	222.1	233.2	512.6	143.0	122.8	7.1

Based on the above mentioned method, by applying the continuity equation, the flow at every point can be calculated. Flow details for the year 2008 for the stations are given above vide Table-2.

5.1 Quality Assessment at Source of Kochi WSS through Salinity Intrusion

Table-3 Flow at Purappallikavu During 2008

Month	Out Flow at PU in m3/Sec	Salinity in mg/litre at mouth	Area in m2	velocity m/sec V	Radius, R	R^(5/6)	Coefficient of diffusion E m2/Sec	J= V/E per m	salinity Concentration (P)at aluva, C
Jan	7.3	12000	440.0	0.02	2.0	1.7	0.1	0.2	76.4
Feb	3.6	12000	496.8	0.01	2.1	1.9	0.0	0.2	98.6
Mar	6.6	12000	423.2	0.02	1.8	1.6	0.1	0.2	99.5
Apr	16.9	12000	387.0	0.04	1.8	1.6	0.2	0.2	114.2
May	36.0	10000	348.3	0.10	1.6	1.5	0.4	0.2	71.0
Jun	109.3	7000	105.0	1.04	1.0	1.0	3.0	0.3	7.4
Jul	253.8	4000	120.0	2.11	1.2	1.1	6.9	0.3	17.4
Aug	256.1	4000	140.0	1.83	1.4	1.3	6.7	0.3	24.0
Sep	557.3	4000	170.0	3.28	1.6	1.5	14.1	0.2	34.7
Oct	160.1	7000	322.5	0.50	1.5	1.4	2.0	0.3	36.3
Nov	133.4	9000	309.6	0.43	1.4	1.3	1.6	0.3	38.7
Dec	8.5	11000	329.0	0.03	1.5	1.4	0.1	0.2	54.9

Table -4 Flow at Eloor During 2008

Month	Out Flow at EL in m3/Sec	Salinity in mg/litre at mouth	Area in m2	velocity m/sec V	Radius, R	R^(5/6)	Coefficient of diffusion E	J= V/E per m	Salinity Concentration (E)at
Jan	5.9	12000	345.6	0.02	1.9	1.7	0.1	0.2	140.5
Feb	3.1	12000	352.0	0.01	1.7	1.6	0.0	0.2	113.1
Mar	6.8	12000	288.0	0.02	1.4	1.3	0.1	0.3	109.1
Apr	15.0	12000	239.4	0.06	1.2	1.2	0.2	0.3	79.0
May	32.8	10000	196.9	0.17	1.1	1.1	0.5	0.3	45.8
Jun	103.7	8000	72.0	1.44	1.2	1.1	4.6	0.3	56.7
Jul	222.1	4000	60.0	3.70	1.0	1.0	10.2	0.4	27.2
Aug	233.2	4000	66.0	3.53	1.1	1.1	10.6	0.3	25.4
Sep	512.6	4000	72.0	7.12	1.2	1.1	22.8	0.3	23.5
Oct	143.0	6000	104.0	1.38	1.3	1.2	4.7	0.3	47.1
Nov	122.8	8000	239.4	0.51	1.2	1.2	1.7	0.3	59.4
Dec	7.1	11000	290.7	0.02	1.5	1.4	0.1	0.3	148.1

Table -5 Combined Out Flow and Salinity for the Year 2008

Month	Flow From Barrage in m3/s	Flow at Purapalikav in m3/Sec	Flow at Eloor in m3/Sec	Salinity Thru' Purap in mg/lit	Salinity thru' Eloor in mg/lit	Combined Out Flow in m3/sec	Salinity at Aluva in mg/lit
Jan	42.89	17.70	15.54	76.44	140.50	33.24	106.39
Feb	20.94	8.83	7.92	98.56	113.07	16.76	105.42
Mar	19.41	9.21	9.21	99.49	109.10	18.42	104.29
Apr	45.49	18.96	16.95	114.21	79.02	35.91	97.60
May	60.47	36.00	32.85	71.02	45.79	68.84	58.98
Jun	144.18	83.26	79.70	7.39	56.75	162.96	31.53
Jul	66.01	97.81	78.07	17.40	27.25	175.88	21.77
Aug	210.40	152.15	137.19	23.95	25.43	289.34	24.65
Sep	960.34	518.35	476.56	34.70	23.45	994.91	29.31
Oct	260.70	160.09	143.03	36.26	47.14	303.12	41.39
Nov	264.80	133.41	122.76	38.69	59.41	256.17	48.62
Dec	26.51	9.53	8.08	54.89	148.10	17.61	97.65

5.2 Flow adjustment and Comparison

Table -6 POLLUTION (SALINITY INTRUSION) CONTROL BY FLOW CONTROL- 2004									
Month	From Barrage in m^3/sec	Corrected Q from the Barrage in m^3/sec	Flow at Purapalikav in m^3/Sec	Salinity at Pura palikav in mg/lit	Salinity conc. through Pura to Aluva in mg/lit	Flow at Eloor in m^3/Sec	Salinity at Eloor in mg/lit	Salinity conc. through EL to AV in mg/lit	Salinity Conc. at aluva, C in mg/lit
Jan	19.88	32.88	12.5	4200	29.77	10.73	4300	131.79	76.91
Feb	13.12	20.12	5.37	4300	27.7	4.07	4500	107.63	62.14
Mar	9.29	14.29	6.02	4300	28.21	6.43	4500	55.35	42.23
Apr	42.46	69.46	36.68	4500	29.7	32.95	4700	34.9	32.16
May	35.65	21.65	24.58	3200	29.46	26.45	3100	14.19	21.55
Jun	140.33	0.33	65.67	2300	3.9	49.74	2200	11.99	7.39
Jul	234.72	0.72	27.67	1900	17.19	23.05	2000	4.79	11.56
Aug	570.28	10.28	87.33	1900	29.29	48.96	2000	7.48	21.45
Sep	307.15	177.15	90.09	2100	29.66	83.62	2200	11.99	21.15
Oct	593.83	163.83	123.22	2000	29.15	106.97	2100	16.5	23.27
Nov	158.17	58.17	26.52	2300	29.28	25.07	2300	17.08	23.35
Dec	9.72	9.72	0.8	3400	19.04	-0.03	3200	48.9	17.89
Quantity additionally used in the year in Mm^3									139.28
Quantity saved in the year in Mm^3									4306.87
Net Savings/ year in Mm^3									4168.59

Table -7 SALINITY INTRUSION CONTROL BY FLOW CONTROL - 2008

Month	From Barrage in m3/sec	Corrected Q from the Barrage in m3/sec	Flow at Purapalikav in m3/Sec	Salinity at Pura palikav in mg/lit	Salinity conc. through Pura to Aluva in mg/lit	Flow at Eloor in m3/Sec	Salinity at Eloor in mg/lit	Salinity conc. through EL to AV in mg/lit	Salinity Conc. at aluva, C in mg/lit
Jan	22.89	42.89	17.70	4951.51	76.44	15.54	4584.44	140.50	106.39
Feb	10.94	20.94	8.83	4938.98	98.56	7.92	4727.37	113.07	105.42
Mar	14.41	19.41	9.21	8614.47	99.49	9.21	8870.31	109.10	104.29
Apr	41.49	45.49	18.96	10683.99	114.21	16.95	10640.29	79.02	97.60
May	60.47	60.47	36.00	10000.00	71.02	32.85	10000.00	45.79	58.98
Jun	194.18	144.18	83.26	9185.18	7.39	79.70	10409.79	56.75	31.53
Jul	366.01	66.01	97.81	10378.14	17.40	78.07	11380.02	27.25	21.77
Aug	410.40	210.40	152.15	6733.38	23.95	137.19	6799.84	25.43	24.65
Sep	1035.34	960.34	518.35	4300.87	34.70	476.56	4302.26	23.45	29.31
Oct	260.70	260.70	160.09	7000.00	36.26	143.03	6000.00	47.14	41.39
Nov	264.80	264.80	133.41	9000.00	38.69	122.76	8000.00	59.41	48.62
Dec	24.51	26.51	9.53	9799.90	54.89	8.08	9692.14	148.10	97.65
Quantity additionally used in the Year in Mm3									109.81
Quantity Saved in the Year in Mm3									1674.00
Net Savings/ year in Mm3									1564.19

The flow of water was adjusted manually as part of the automation work/ modeling, in the Mass balance Work by keeping the salinity intrusion level with in the permissible level. By the adjustment it is now understand that a quantity of 4168 Mm3 was seen saved during 2004 and that for 2008 was seen as 1564.19 Mm3 was simply discharged in to the sea without its utilization. From 2004 to 2008 a quantity of 2603.81Mm3 was seen reduced in the savings due to poor rain as rain is an influencing factor in the outflow [4].

VI. ACKNOWLEDGEMENTS

This paper is prepared in this form with the whole hearted cooperation and assistance of Central Water Commission, Government of India, Water Resources Department, Kerala, Kerala Water Authority and Kerala State Pollution Control Board by providing required data. The author expresses his sincere thanks to the concerned organizations in this regard.

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