Determination of the Volume of Flow Equalization Basin in Wastewater Treatment System

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Abstract
The function of a wastewater treatment plant is to improve the quality of wastewater by removing suspended organic and inorganic solids and other materials before discharging it into a waterway. In treating wastewater, the rate at which the wastewater arrives at the treatment process might vary dramatically during the day, so it is convenient to equalize the flow before feeding it to the various treatment steps. Flow equalization is a process of controlling flow velocity and flow composition. It is necessary in many municipal an industrial treatment processes to dampen severe variation inflow and water quality. Providing consistent flow and loading to a biological process is important to maintain optimal treatment. Equalization basins are designed to provide consistent influent flow to downstream processes by retaining high flow fluctuations. Due to the additional retention time, aeration and mixing is required to prevent the raw wastewater from becoming septic and to maintain solids in suspension. Generally flow equalization is provided for dampening of flow rate variations so that a constant or nearly constant flow rate is achieved.
Keywords: Equalization, Dampen, BOD, Inline Flow, aeration

1. INTRODUCTION
The influent to a wastewater treatment plant usually exhibits a wide diurnal cyclic variation, both in flow rate and concentration (BOD, COD, TKN, TS), and consequently in load rate (defined as the product of flow rate and concentration). The forms of the input patterns to a particular plant are determined by a number of factors such as population structure; sewer layout, lengths and gradients; climatic and seasonal effects; etc. However, despite the many influencing factors, generally it is found that the combined effect gives rise to influent flow and load rate patterns that are similar for most plants. Typically the flow rate reaches a maximum, at some time during the day, of about two times the average daily rate, and a minimum sometime during the night of about half the average rate. The influent BOD, COD, TS and TKN concentrations show a similar pattern of behavior, virtually in phase with the flow variations. As a result the diurnal cyclic load rate variation can range from four to six times to less than a quarter of the average daily value. Daily cyclic variations in flow and load rates affect the design, performance, and operation of wastewater treatment plants.

2. FLOW EQUALIZATION
Flow equalization is used to minimize the variability of water and wastewater flow rates and composition. Each unit operation in a treatment train is designed for specific wastewater characteristics. Improved efficiency and control are possible when all unit operations are carried out at uniform flow conditions. If there exists a wide variation in flow composition over time, the treatment efficiency of the overall process performance may degrade severely. These variations in flow composition could be due to many reasons, including the cyclic nature of industrial processes, the sudden occurrence of storm water events, and seasonal variations. To dampen these variations, equalization basins are provided at the beginning of the treatment train. The influent water with varying flow composition enters this basin first before it is allowed to go through the rest of the treatment process. Equalization tanks serve many purposes. Different WWTP processes use equalization basins to accumulate and consolidate smaller volumes of wastewater such that full scale batch reactors can be operated. Other processes incorporate equalization basins in continuous treatment systems to equalize the waste flow so that the effluent at the downstream end can be discharged at a uniform rate. Various benefits are ascribed by different investigators to the use of flow equalization in wastewater treatment systems. Some of the most important benefits are listed as follows:

a) Equalization improves sedimentation efficiency by improving hydraulic detention time.
b) The efficiency of a biological process can be increased because of uniform flow characteristics and minimization of the impact of shock loads and toxins during operation.
c) Manual and automated control of flow-rate-dependent operations, such as chemical feeding, disinfection, and sludge pumping, are simplified.
d) Treatability of the wastewater is improved and some BOD reduction and odor removal is provided if aeration is used for mixing in the equalization basin.
e) A point of return for recycling concentrated waste streams is provided, thereby mitigating shock loads

to primary settlers or aeration basin.

f) The design of an equalization facility involves not only the sizing of the equalization tank, but also the provision of an operating strategy to ensure that the desired objectives are met

3. OBJECTIVES OF EQUALIZATION

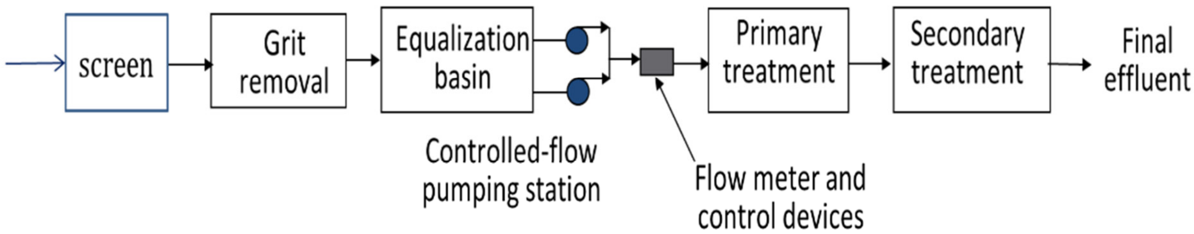
The primary objective of the flow equalization basins has been to dampen the variations in the flow to achieve nearly constant flow rates through the downstream treatment processes. Moreover, equalizing the organic load to the process could significantly benefit the performance of the biological treatment process (Dold et al., 1984; Armiger et al., 1993). The U.S. EPA (1974) considers equalization of flow rate as one of the alternatives available for upgrading existing wastewater treatment plants for one or more of three major reasons:

1. To meet more stringent treatment requirements
2. To increase hydraulic and organic loading capacity
3. To correct or compensate for performance problems resulting from improper plant design and operation

4. TYPES OF FLOW EQUALIZATION

a) In- line equalization

In this case, all the flow passes through the equalization basin and helps in achieving educing fluctuations in pollutant concentration and flow rate.



a) Off- line equalization

In this case, only over-flow above a predetermined value is diverted into the basin. It helps in reducing the pumping requirements. In this method of equalization, variations in loading rate can be reduced considerable. Off-line equalization is commonly used for the capture of the “first flush” from combined collections systems.

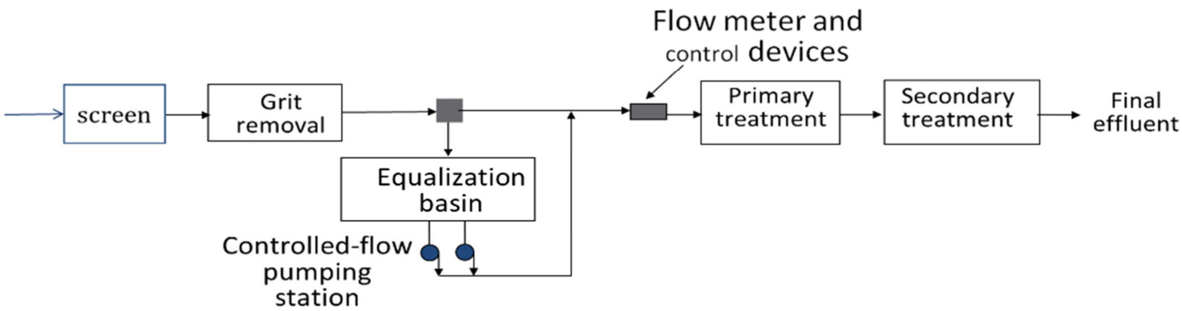


Figure 1: Typical wastewater-treatment plant flow diagram incorporating flow equalization: *a*) in-line equalization and *b*) off-line equalization.

5. DESIGN CONSIDERATIONS OF FLOW EQUALIZATION BASIN

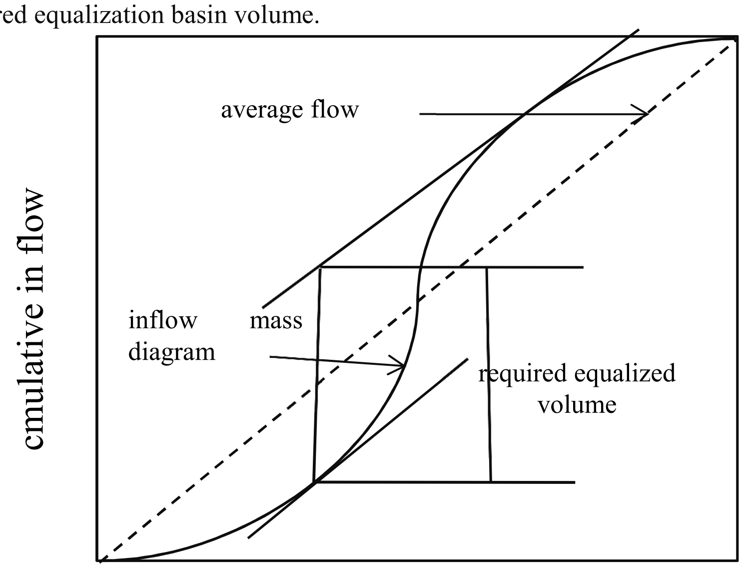
The principal factors that must be considered in the design of equalization basins are: (1) location and configuration, (2) volume, (3) basin geometry, (4) mixing and air requirements, (5) appurtenances, and (6) pumping facilities.

Location and configuration:

The basins are normally located near the head end of the treatment works, preferably downstream of preliminary treatment facilities such as bar screens and grit chambers and before primary treatment and biological treatment is appropriate. In some cases flow equalization can be applied after grit removal, after primary sedimentation, and after secondary treatment where advanced treatment is used. (Source*:* Metcalf & Eddy, 2003.). This arrangement considerably reduces problem of sludge and scum in the equalization basin.

Two basic configurations are recommended for an equalization basin: variable volume and constant volume. In a variable volume configuration, the basin is designed to provide a constant effluent flow to the downstream treatment units. However, in the case of a constant volume basin, the outflow to other treatment units changes with changes in the influent. Both configurations have their uses in different applications.

Volume requirement: The volume required for the equalization tank can be worked out using an inflow mass diagram in which cumulative inflow volume is plotted versus the time of day. Figure Inflow mass diagrams for determination of required equalization basin volume.



In practice, the volume of tank is kept 10 to 20% greater than the theoretical volume. This additional volume is provided for the following:

- Not to allow complete drawdown to operate continuous mixing or aeration (e.g. floating aerators)
- Some volume must be provided to accommodate concentrated stream to get diluted wastewater.
- Safety for unforeseen changes in flow.

Basin Geometry: If the basin configuration is for in-line equalization, the geometry should allow the basin to function as a continuous flow stirred tank reactor. This implies that long rectangular basins should be avoided, and inlet and outlet locations should be chosen to minimize short circuiting. In particular, the inlet should discharge near the mixing equipment.

Mixing and Air Requirements: Both in-line and off-line equalization basins require mixing. Adequate aeration and mixing must be provided to prevent odors and solids deposition. Mechanical aerators and diffused aeration have been used to supply mixing and aeration.

The following steps should be applied to the system design:

Step 1: Determine the frequency and duration of the variance to be diverted (this will allow design of the equalization basin).

Step 2: Calculate the diverted flow's controlled release rate that will maintain normal operations.

Step 3: Use the diverted volume to calculate the surge basin's volume so continuous flow to the treatment facility can be maintained.

Step 4: Verify that the equalized flow meets desired discharge limits.

6. DETERMINATION OF THE VOLUME OF FLOW EQUALIZATION BASIN

Determination of flow rate - equalization volume requirements and effects on BOD_5 mass loading

For the flow rate and BOD concentration data given in the table determine;

(1) The in-line storage volume required to equalize the flow rate

(2) Time period when the equalization tank is empty

(3) The effect of the flow equalization on BOD mass - loading rate

Table 1: Wastewater Flow Variation with Time

Time	Given data		derived data		
	average flow m^3/s	average BOD5 mg/l	average flow m^3/h	cumulative volume m^3/h	BOD Mass loading kg/h
(1)	(2)	(3)	(4)	(5)	(6)
M-1	0.375	160	1350	990	216
1-2	0.320	125	1152	1782	144
2-3	0.265	85	954	2376	81
3-4	0.230	60	828	2844	50
4-5	0.205	55	738	3222	41
5-6	0.200	70	720	3582	50
6-7	0.220	100	792	4014	79
7-8	0.305	140	1098	4752	154
8-9	**0.455**	**185**	**1638**	**6030**	303
9-10	0.510	210	1836	7506	386
10-11	0.525	225	1890	9036	425
11-N	0.530	230	1908	10584	439
n-1	0.525	230	1890	12114	435
1-2	0.505	220	1818	13572	400
2-3	0.485	210	1746	14958	367
3-4	0.450	200	1620	16218	324
4-5	0.425	190	1530	17388	291
5-6	0.425	180	1530	18558	275
6-7	0.430	185	1548	19746	286
7-8	0.465	220	1674	21060	368
8-9	0.500	290	1800	22500	522
9-10	0.500	315	1800	23940	567
10-11	0.480	255	1728	25308	441
11-M	0.445	190	1602	26550	224

Solution: Design of the equalization basin volume.

1. The in-line storage volume required to equalize the flow rate

Because of the repetitive and tabular nature of the calculations, a spreadsheet is ideal for this problem. The spreadsheet solution is easy to verify if the calculations are set up with judicious selection of the initial value. If the initial value of the first flow rate is greater than the average after the sequence of night time low flows, then the last row of the computation should result in a storage value of zero for a perfect sinusoidal flow pattern.

A. The first step is to develop a cumulative curve of the wastewater flow rate expressed in cubic meters. The cumulative volume curve is obtained by converting the average flow rate during each hourly period to cubic meters, using the following expression and then cumulative by summing the hourly volume to obtain to cumulative flow volume.

$$\text{Volume } (m^3/h) = (q_h, m^3/s)(3600s/h)(1.0h)$$

For the first three periods shown in the data table-1 above at the fourth column, the corresponding hourly volumes are as follow:

For the time period M-1

$$VM-1 = (0.275\, m3/s)(\,(3600s/h)(1.0h) \;=\; 990\, m3$$

For the time period 1-2

$$V1-2 = (0.220\, m3/s)(\,(3600s/h)(1.0h) \;=\; 792\, m3$$

For the time period 2-3

$$VM-1 = (0.165\, m3/s)(\,(3600s/h)(1.0h) \;=\; 594\, m3$$

The cumulative flow expressed in m^3 above at the fifth column at the end of each time period is determined as follows:

At the end of first time period M-1, V_1=990m^3
At the end of first time period 1-2, V_2 =990+792 = 1782m^3
At the end of first time period 2-3, V_3 = 1782+594 = 2376m^3

B. The second step is to prepare a plot of the cumulative flow volume, as shown in the following diagram. As will be noted, the slope of the line drawn from the origin to the endpoint of the inflow mass diagram represents the average flow rate for the day, which in this case is equal to 0.307m^3/s.

C. The third step is to determine the required storage volume. The required storage volume is determined by drawing a line parallel to the average flow rate tangent to the low point of the inflow mass curve diagram. The required volume is represented by the vertical distance from the point of tangency to the straight line representing the average flow rate. Thus, the required volume is equal to volume of equalization basin,

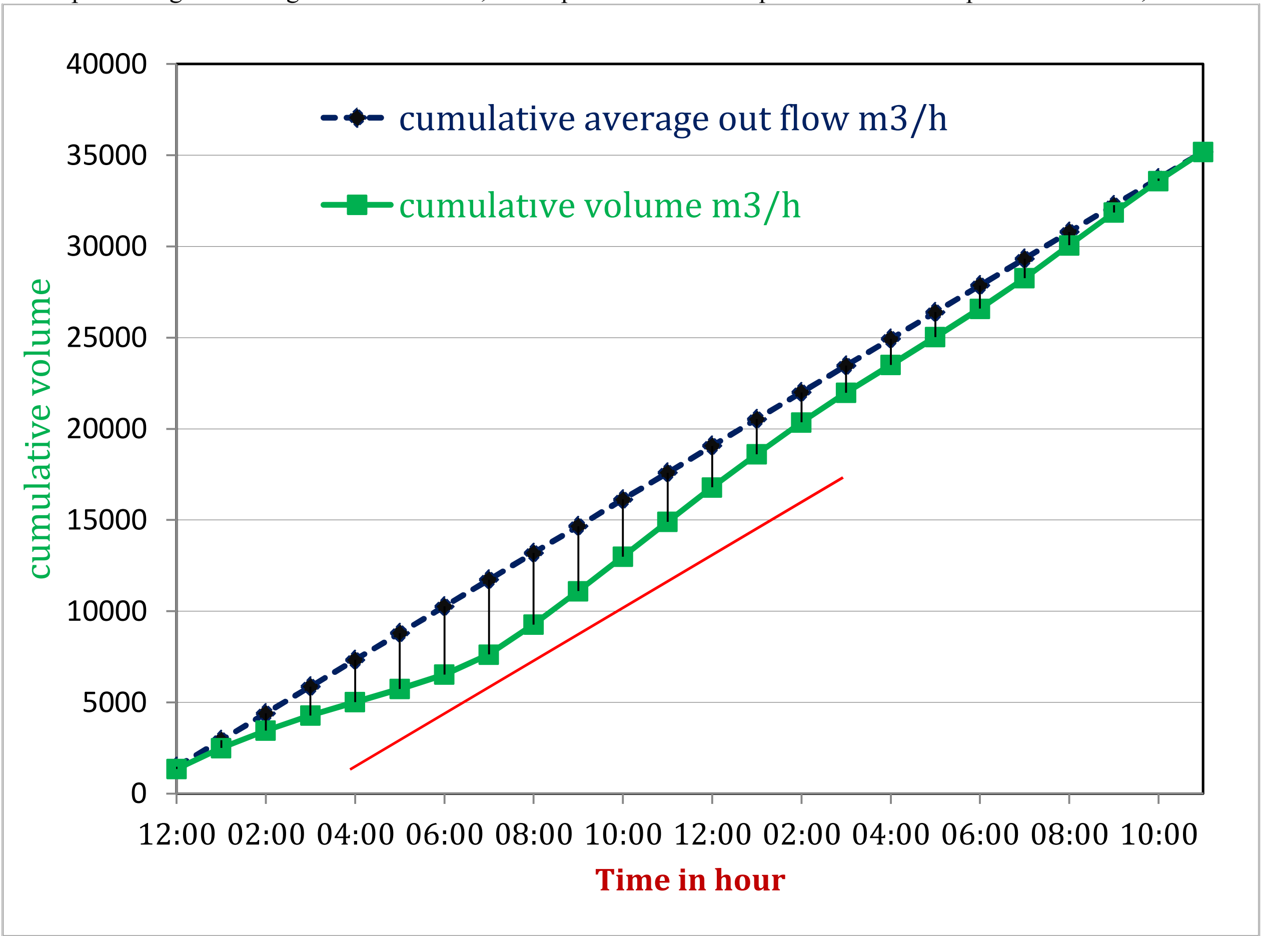


Figure 2: Mass Curve Analysis (Ripple Diagram Method)

Required volume, V =A-B=11730-7632=4098m^3 ≈≈4100m^3

2. Determine the effect of the equalization basin on the BOD mass loading rate. Although there are alternative computation methods, perhaps the simplest way is to perform the necessary computations starting with the time period when the equalization basin is empty. Because the equalization basin is empty at about 8:30 A.M., the necessary computations will be performed starting with the time 8-9 time periods.

A. The depending on the average flow, i.e.; In this case it is 0.407 m3 /s. Next, the flows are arranged in order beginning with the time and flow that first exceeds the average. In this case it is at 8-9 h with a flow of 0.455 m3 /s. The tabular arrangement is shown in Table blow. An explanation of the calculations for each column is given in the following steps. In the fourth column, the flows are converted to volumes using the time interval between flow measurements:

V=0.455 m3/s) (1 h) (3,600 s/h) =1638 m^3/h

B. The second step is to compute the liquid volume in the equalization basin at the end of each time period. The volume required is obtained by subtracting the equalized hourly flow rate expressed as a volume. The average volume that leaves the equalization basin is calculated in the fifth column. It is the average flow rate computed on an hourly basis in column sixth. V = (0.407 m3/s)(1 h)(3,600 s/h)=1466m^3/h. using this value, the volume in storage is computed using the following expression: $D_S = V_{in} - V_{out}$

Where: D_s - difference between the inflow volume and the outflow volume at the current time period

V_{in} – inflow volume in the equalization basin at the each time

V_{out} – *out flow* volume in the equalization basin at each time i.e. average volume

The seventh column is the difference between the inflow volume and the outflow volume.

$D_S = V_{in} - V_{out}$ =1638 m^3 -1466 m^3=172 m^3/h

C. The required storage is computed in the eighth column. It is the cumulative sum of the difference between the inflow and outflow (*ds*). For the second time interval, it is

Storage=∑Ds=370m^3+172m^3=542m^3/h

The volume in storage at the end of each time period has been computed in a similar way.
Note that the last value for the cumulative storage is 0.0 m^3. At this point the equalization basin is empty and ready to begin the next day's cycle. Time period when the equalization tank is empty is between

D. The required volume for the equalization basin is the maximum cumulative storage. It is the shaded value.

$$\text{Storage} = 4098 m^3 \approx\approx 4100\ m^3$$

E. The second step is to compute the average concentration entering and leaving the storage basin.
The mass of BOD_5 entering the equalization basin is the product of the inflow (Q), the concentration of BOD_5 (S_o), and the integration time (Δt):

$$M_{BOD\text{-}in} = (Q)\ (S_o)\ (\Delta t)$$

The mass of BOD_5 leaving the equalization basin is the product of the average outflow (Q_{avg}), the average concentration (S_{avg}) in the basin, and the integration time (Δt):

$$M_{BOD\text{-}out} = (Q_{avg})\ (S_{avg})\ (\Delta t)$$

The average concentration is determined as:

$$Savg = \frac{(Vin * \mathrm{So}) + (Vs * Sprevious)}{(Vi + Vs)}$$

Where

V_{in}-volume of inflow during time interval Δt, m^3
S_o- average BOD_5 concentration during time interval Δt, g/m^3
V_s-volume of wastewater (D_s) in the basin at the end of the previous time interval Δt, m^3
S_{prev} - concentration of BOD_5 in the basin at the end of the previous time interval Δt, g/m^3

Noting that 1 mg/L = 1 g/m^3, find that the first row (8-9 h time) computations in columns 9, 10, and 11 are

$$M_{BOD\text{-}in} = (0.455\ m3/s)(185\ g/m3)(1\ h)(3600\ s/h)(10^{-3}\ kg/g)$$
$$= (1638 m^3/h)(185 mg/l)(10^{-3} kg/g) = 303 kg/h$$
$$Savg = \frac{(1638 * 185) + (0 * 0)}{(1638 + 0)} = 185 mg/l$$
$$M_{BOD\ out} = (0.407\ m3\ /s)(185 mg/l)(1\ h)(3600\ s/h)(10-3\ kg/g) = 271\ kg \quad \text{Or}$$
$$= (1466 m3\ /h)(185 mg/l)(10-3\ kg/g) = 271\ kg)$$

Note that the zero values in the computation of S_{avg} are valid only at start-up of an empty basin. Also note that in this case $M_{BOD\text{-}in}$ and $M_{BOD\text{-}out}$ differ only because of the difference in flow rates.
For the second row (9 h), the computations are,

$$M_{BOD\text{-}in} = (0.51 m3/s)(210\ g/m3)(1\ h)(3600\ s/h)(10^{-3}\ kg/g)$$
$$= (1836 m^3/h)(210 mg/l)(10^{-3} kg/g) = 386 kg$$
$$Savg = \frac{(1836*210)+(172*185)}{(1836+172)} = 208 mg/l$$
$$M_{BOD\ out} = (0.407\ m3\ /s)(210 mg/l)(1\ h)(3600\ s/h)(10-3\ kg/g) = 305\ kg) \quad or$$
$$= (1466 m3\ /h)(208 mg/l)(10-3\ kg/g) = 305\ kg)$$

Note that V_s is the volume of wastewater in the basin at the end of the previous time interval. Therefore, it is equal to the accumulated D_S. The concentration of BOD_5 (S_{prev}) is the average Concentration at the end of previous interval (S_{avg}) and *not* the influent concentration for the previous interval (S_o).

Table 2: volume computation

Time (1)	Flow (m3/s) (2)	BOD5, mg/l (3)	Vol_{in} ,m^3 (4)	Vol_{out} ,m3/s (5)	Vol_{out} ,m^3 (6)	ds. m^3 (7)	$\Sigma ds\ m^3$ (8)	$M_{BOD-in,}$ kg (9)	*S*,mg/l (10)	$M_{BOD-out}$,kg (11)
8_9	0.455	**185**	1638	0.407	1466	172	172	303	185	271
9_10	0.51	210	1836	0.407	1466	370	542	386	208	305
10_11	0.525	225	1890	0.407	1466	424	965	425	221	324
11_N	0.53	230	1908	0.407	1466	442	1407	439	227	333
n_1	0.525	230	1890	0.407	1466	424	1831	435	229	335
1_2	0.505	220	1818	0.407	1466	352	2183	400	224	329
2_3	0.485	210	1746	0.407	1466	280	2462	367	218	320
3_4	0.45	200	1620	0.407	1466	154	2616	324	211	309
4_5	0.425	190	1530	0.407	1466	64	2680	291	203	298
5_6	0.425	180	1530	0.407	1466	64	2744	275	195	286
6_7	0.43	185	1548	0.407	1466	82	2825	286	191	280
7_8	0.465	220	1674	0.407	1466	208	3033	368	202	296
8_9	0.5	290	1800	0.407	1466	334	3367	522	235	344
9_10	0.5	315	1800	0.407	1466	334	3701	**567**	263	**385**
10_11	0.48	255	1728	0.407	1466	262	3962	441	260	382
11_M	0.445	190	1602	0.407	1466	136	4098	304	240	352
M-1	0.375	160	1350	0.407	1466	-116	3982	216	220	323
1_2	0.320	125	1152	0.407	1466	-314	3668	144	199	292
2_3	0.265	85	954	0.407	1466	-512	3155	81	175	257
3_4	0.230	60	828	0.407	1466	-638	2517	50	151	222
4_5	0.205	55	738	0.407	1466	-728	1789	**41**	130	190
5_6	0.200	70	720	0.407	1466	-746	1043	50	112	165
6_7	0.220	100	792	0.407	1466	-674	368	79	107	**157**
7_8	0.305	140	1098	0.407	1466	-368	0	154	132	193
Average = **0.407**								**289**		**289**

Summary

A fundamental prerequisite to begin the design of wastewater treatment plant is a determination of the design storage capacity. This, in turn, is a function of wastewater flow. Flow equalization basin is one part of the treatment plant so the determination of storage capacity is a crucial importance and the major aspect of in wastewater treatment plant design and management. In the present paper, storage capacity for the different hourly variation flow has been computed by using Ripple Diagram (mass curve diagram) and Analytical method. The mass curve was developed by W. Ripple (1883). A mass curve is a plot of the cumulative flow volumes as a function of time. Mass curve analysis is done using a graphical method called Ripple's method. It involves finding the maximum positive cumulative difference between a sequence of pre-specified average out flow releases and known inflows (as shown in figure 2). From the mass curve diagram above (figure 2) for the 24 hour, it is observed that in the 8 hour shows maximum basin storage capacity of 4098m^3.

In the analytical method determination of the storage capacity of the basin can be determine by rearranging the hourly flow starting from the immediate accidence (the value greater than the average flow) and calculating the cumulative flow. From the table-2 above the maximum cumulative value is 4098m^3. Depending up on the two methods the storage capacity of basin is the maximum value but in this paper the output of both cases are nearly the same. Therefore the basin storage capacity for the proposed flow equalization basin is 4100m^3.

The effect of the flow equalization on BOD mass - loading rate

The effect of flow equalization can be shown best graphically by plotting the hourly unequalized and equalized BOD mass loading. The following ratios, derived from the data presented in the table given in the problem statement and the computation table prepared in step 2, are also helpful in assessing the benefits derived from flow equalization:

Flow	Unequalized BOD	Equalized BOD
Minimum	41	157
Average	289	289
Maximum(Peak)	567	385

Table 3: Effect BOD5 in the Wastewater

Ratio	BOD mass loading	
	unequalized	equalized
peak/average	567/289=1.962	385/289=1.332
minimum/average	41/289=0.142	157/289=0.543
peak/minimum	567/41=13.829	385/157=2.45

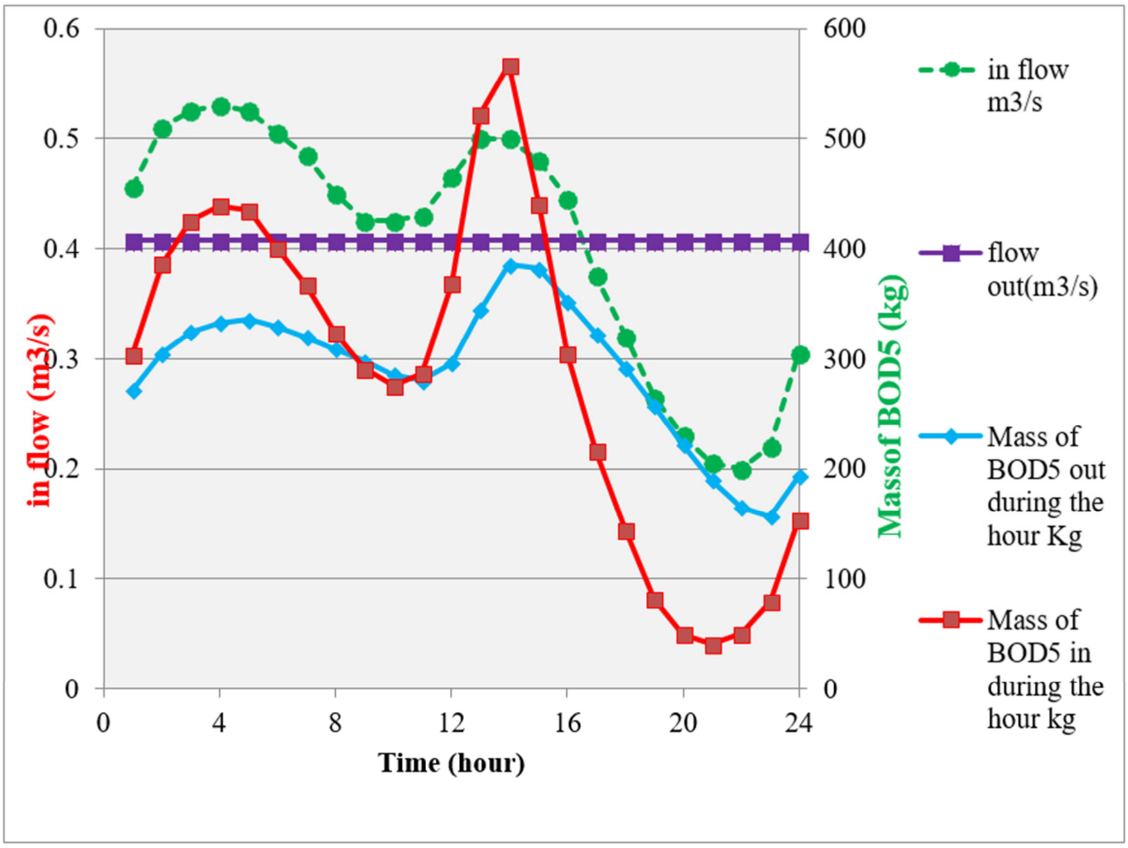


Figure 3: Unequalized and equalized BOD mass loading

7. CONCLUSION

The function of a wastewater treatment plant is to improve the quality of wastewater by removing suspended organic and inorganic solids and other materials before discharging it into a waterway. From a theoretical viewpoint, complete or near complete equalization of both flow and load would either eliminate the need for in-plant control or reduce the required in-plant control to the simplest level, within the competence of the plant operator. However, for sewage treatment plant of small community, where wastewater flow rate considerably vary with time, and for industrial wastewater treatment plants, where wastewater flow and characteristic varies with time, equalization becomes essential to obtain proper performance of the treatment plant by avoiding shock loading (hydraulic and organic) to the systems. Due to possibility of variation in flow rate received at treatment plant, there may be deterioration in performance of the treatment plant than the optimum value. To facilitate maintenance of uniform flow rate in the treatment units, flow equalization is used. This helps in overcoming the operational problems caused by flow variation and improves performance of the treatment plant. Generally flow equalization is provided for dampening of flow rate variations so that a constant or nearly constant flow rate is achieved.

REFFERENCE

[1] Anna Mikola, The effect of flow equalization and Flowrate prefermentation on the activated sludge process and biological nutrient removal, 2013; P 32-34.
[2] Handbook of environmental engineering, volume 3: Physicochemical Treatment Processes edited by Lawrence K. Wang, Yung-Tse Hung, Nazih K. Shammas; p 21-28.
[3] Industrial Wastewater Management, Treatment, and Disposal, Water Environment Federation manual of Practice No. FD-3. Third Edition, P 236-253.
[4] Mackenzie L. Davis, Water and Wastewater Engineering Design Principles and Practice, (2010); McGraw-Hill Companies, Inc. publish. Chapter-20; p 36-43.
[5] Metcalf & Eddy Inc., Wastewater Engineering: Treatment Disposal Reuse, 4th ed., McGraw-Hill, New York, 2003. P 333-345.
[6] Tjan Kwang Wei, Industrial Wastewater Treatment (2006): Published by Imperial College Press.
[7] Japan Sewage Works Association, Design Standard for Municipal Wastewater Treatment Plants Second Edition- 2013; P 10-11.