A Study on the Hydrologic Design of Detention Storage Ponds in Urbanized Area

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ABSTRACT : This study is to develop the suitable hydrologic models for determination of the size and location of detention storage facilities to restrain stormwater runoff in urban areas. Hypothetical areas of two levels are considered to seize the hydrologic response characteristics. A one-square-kilometer area is selected for the catchment level, and a 10-square-kilometer area consisting of 10 catchments is adapted at the watershed level as representative of urban drainage area. In this analysis, different rainfall frequencies, land uses, drainage patterns, basin shapes and detention storage policies are considered. Flow reduction effect of detention storage facilities is deduced from storage ratio and detention basin factor. A substantial saving in detention storage volumes is achieved when the detention storage is planned at the watershed level rather than the catchment level. For the application of real watersheds, two watersheds in Seoul metropolitan area-Jamshil 2 and Seongnae 1-are selected on the basis of hydrologic response characteristics. Through the regression analysis between dimensionless detention storage volume, dimensionless upstream area ratio and reduction rate of storage ratio, the regression equations to determine the size and location of detention storage facilities are presented.

1. Introduction

Population is concentrated on cities as the economy grows rapidly, and for this rapid changes, the urban stream has damaged even by small rainfall event. As the result of increase in impervious area, infiltration capacity is decreased and runoff volumes and flow rates are increased. Therefore flood damage in urban area is increased. Such flood damage is mainly from the change of the watershed and rapid economic development, and this has to be controlled.

Especially for metropolitan cities like Seoul, flood damage of interior water is increased due to

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rapid increasement in population,and enlargement of urban area. But existing drainage facilities can not manage this change of hydrologic characteristics in urban area. The enlargement of impervious surfaces and the rearrangement of drainage line have resulted in increasement of the flow rates through the change of rainfall-runoff system. When the drainage system is overstressed by increasing flow, it is necessary to consider the runoff restraint as the measures for inundation. Recently, the detention storage basin, which detains stormwater temporarily and releases it at the rate before development, is considered as a viable management alternative for flood control.

In this study, the change of the hydrologic characteristics due to the location of the detention basin is examined to prevent the inteior flood and mitigate the flood damages, and the analytical model is developed to determine the size and location of detention storage basin for reasonable internal drainage system.

Hypothetical unit catchment and watershed and real urban area are adopted to determine the size and location of the detention basin and the hydrologic response characteristics in urban area according to the development level. One-square-kilometer area is selected for the catchment level and a 10-square-kilometers area consisting of 10 catchments is adopted at the watershed level as the representative of typical urban drainage areas.

2. Hydrologic Characteristics in Urban Area

Hydrologic response is affected by natural factors, some of which are substantially changed by urbanizing progress altering the natural water balance of a watershed. Urbanization generally increases the runoff volumes and peak flow rates and decrease time-to-peak. Therefore hydrologic response characteristics according to the shape, development level and the detention basin placement are analyzed in this study.

2.1 Effect of Watershed Shape

Because hydrologic response is affected by watershed shapes, a shape analysis is performed to choose representative shapes at catchment and watershed level.

Eagleson (1970) defined a geometrical shape similarity factor as $SF=A/L^2$, where A is the watershed area in square kilometers and L is the length of the main channel in kilometers. From real data, Eagleson showed that the shape factor decreases as the area increases, which indicates a tendency toward elongation of the larger catchments.

For the Seoul metropolitan area, a shape analysis is performed on 63 watersheds to determine the shape factors of watershed and average catchment shape factor ($SF=0.51$) of hypothetical catchment is used to analyze the hydrologic response characteristics in urban areas.

2.2 Effect of Development Level in Urban Area

Five levels of development are considered using the runoff coefficient($C=0.3$, 0.4, 0.6, 0.7, 0.8), and the hydrologic model is used to examine the hydrologic characteristics under rainfall frequencies and land use stages.

2.3 Effect of Detention Storage Facilities

Detention storage simulation is based on reservoir and channel hydrograph routing. In this study, routing procedures used hydrologic routing for reservoirs and steady-flow routing with hydrograph time shifting for channels.

A one-square-kilometer is considered as the unit catchment level to be simulated for several rainfall frequencies, land use stages, drainage patterns, detention storage policies, the model developed in this study is used to determine detention storage volumes with variable depth and diameter of outflow pipes. A combination of 6 flood frequencies (5, 10, 20, 30, 50, 100-year) and 6 detention storage policies totaling 36 possible occurrences is performed for the catchment detention storage simulation under fully developed conditions.

From the unit catchment level, ten unit catchments are combined to form three 10-square-kilometers watersheds of 3 shapes (elongated, medium, concentrated). Flood frequencies, developed land use, and drainage types are considered in the watershed simulation for three watershed shapes.

3. Single Detention Basin Design

The simplest case of detention storage design is a single detention basin where there is not any dynamic runoff hydrograph interaction with adjacent sub-basins and outflow rate is independently determined. The purpose of this detention storage design is to provide hydrologic concepts and procedures to design the size and land requirements of a single detention basin for a given outflow criterion. Detention storage volumes are generally constant for a specific outflow criteria, however, land requirements are variable according to the available outflow depth.

3.1 Allowable Outflow of Single Detention Basin

A popular management control strategy is to restrict peak flows to the existing channel capacity with the aid of detention storage in the upper watershed areas. This policy implies that all new upstream developments should temporarily detain stormwater to delay peak flows and release it at the rate prior to development, in order to avoid increasing downstream peak flows.

In this study the allowable outflow is analyzed as peak flow rates before development. As the single detention basin depth and land requirements varies according to the allowable outflow, several probable floods before development are analyzed as the allowable outflow.

Probable floods are determined using rainfall-runoff model in which design rainfalls of Seoul area with the 5, 10, 20, 30, 50, 100-year are inputted, and these probable floods are to be used as the allowable outflow.

3.2 Size of Single Detention Basin (Depth and Area)

The model developed in this study is used to determine the detention storage volumes and required area of unit catchment for rainfall frequencies.

The depth of a detention basin is dictated by that of the receiving stream where the discharge is made. Areas draining to major watercourses of which the channel depths are high require substantially less watershed area for detention storage than the case of small receiving streams. Several detention basin depths are analyzed to determine the watershed land requirements for different flood frequencies in this study.

3.3 Location of Single Detention Basin

Detention storage is an effective stormwater control, however, random or unplanned placement can significantly reduce its effectiveness and, in some cases, aggravate potential flood hazards. In many real situations land is not available anywhere in a watershed. Thus detention storage placement is restricted to available locations that sometimes are not the most effective in the attenuation of peak flows. A location analysis of placing only one detention basin in the watershed is performed for all drainage lines in order to test several locations until arriving at the one that requires less detention storage or minimum cost. Watershed shapes E and M are used in the location analysis. The basic criterion is that the peak flow at the outlet is the same for any detention basin location.

4. Analysis Result in Hypothetical Unit Catchment and Watershed

4.1 Analysis Result in Hypothetical Unit Catchment

More than ten probable rainfall intensity formulas in Seoul have been suggested by several researchers. The formula suggested at Report on investigative study for the safety diagnosis and management measures of the river shore hydraulic structures (1991) is used in this study.

The change of hydrologic response according to urbanization compared to pre-urbanization is shown on Fig. 1. The peak flow rate is increased and time to peak is decreased. In order to offset the urbanization effects detention storage basin is considered as an alternative for stormwater management. Detention storage volumes can be determined by using Eq. (1).

$$V = \int_0^{t_0} (Q_a - Q_b)\,dt \qquad (1)$$

where V = storage volume (m^3), t_0 = intersection time of recession curve of undeveloped and developed runoff hydrograph (min), Q_b = undeveloped discharge (m^3/s), and Q_a = Developed discharge (m^3/s).

In this study, storage policy is defined as the detention basin volume required to decrease the peak flow rates in developed land use to the level prior to development for a given flood frequency. Deten-

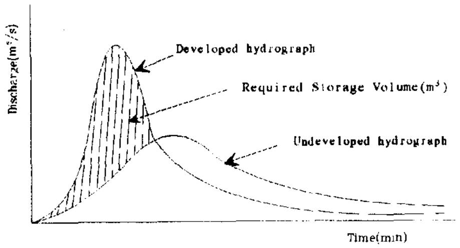


Fig. 1. Undeveloped and Developed Runoff Hydrograph

Table 1. Detention Basin Volume versus Storage Policies

Storage policy (years)	Detention basin volume (m^3)
5	48,268
10	61,106
20	69,195
30	75,345
50	83,797
100	100,465

tion basin volumes versus storage policies are listed in Table 1.

In this study, outlet works of detention basin consist of weir and orifice. The discharge of detention basin is based on the assumption that water stored is released through 2 orifices with diameter 1,000mm under specified depth and the weir with width 100m as the depth is increased.

Table 2 lists results of the effect of flood frequencies on the hydrologic response for undeveloped and developed land use. The ratio of developed peak flows over undeveloped peak flows shown on Table 2 is 2.03 for the 5-year rainfall frequency, decreasing to 1.45 for the 100-year. Detention storage volumes required to restore the undeveloped peak flow rates are 0.048, 0.061, 0.069, 0.075, 0.084, 0.100 (m^3/m^2) for 5, 10, 20, 30, 50, 100-year flood frequency respectively.

The required land for detention storage varies depending on variable depth of detention storage. The detention volumes can be evaluated using Eq. (1) and land area of detention basin is determined according to basin depth. The ratios of the land required over watershed area for the 100-year return period are shown on Fig. 2.

As the results of analysis, for depth 1m the percentage of land required for detention storage is as high as 8% and the amount of the land required for detention storage is as low as 1.5%.

A peak outflow and storage volume are associated with each detention storage policy and flood frequency, and from this, two variables are defined for comparison, including the runoff fraction stored (RFS) and peak reduction factor (PRF). The variables have the following form:

$$RFS = \frac{V_r}{V_r} \tag{2}$$

where RFS = runoff fraction stored, V_r = stored volume in basin (m^3), and V_t = inflow hydrograph volume (m^3).

$$PRF = 1 - \frac{Q_{po}}{Q_{pi}} = \frac{Q_{pi} - Q_{po}}{Q_{pi}} \tag{3}$$

$$PRF = \frac{V_r}{V_t} = \frac{V_t - V_o}{V_t} = 1 - \frac{V_o}{V_t} = f(PRF) \tag{4}$$

Table 2. Effects of Various Storage Policies on One-Square-Kilometer Catchment Hydrograph Peak Flows and Time-to-Peak

Land use	Flood frequency and rainfall depth					
	5-year 87.0㎜	10-year 102.3㎜	20-year 116.4㎜	30-year 124.3㎜	50-year 134.2㎜	100-year 147.3㎜
Undeveloped	11.8 cms 115 min	15.8 cms 110 min	19.6 cms 110 min	22.2 cms 110 min	25.1 cms 110 min	28.9 cms 110 min
Developed (Not facility)	23.9 cms 110 min	28.6 cms 110 min	32.6 cms 110 min	35.2 cms 110 min	38.0 cms 110 min	41.8 cms 110 min
Developed 5-year policy (0.048 m^3/m^2)	11.0 cms 125 min	24.2 cms 115 min	31.9 cms 110 min	34.1 cms 110 min	37.7 cms 110 min	41.1 cms 110 min
Developed 10-year policy (0.061 m^3/m^2)	5.5 cms 125 min	12.3 cms 125 min	23.3 cms 120 min	30.2 cms 115 min	34.9 cms 110 min	39.9 cms 110 min
Developed 20-year policy (0.069 m^3/m^2)	5.1 cms 130 min	5.8 cms 130 min	16.7 cms 120 min	24.7 cms 120 min	31.4 cms 115 min	36.9 cms 110 min
Developed 30-year policy (0.075 m^3/m^2)	4.9 cms 130 min	5.5 cms 130 min	11.7 cms 125 min	19.3 cms 120 min	26.6 cms 120 min	35.0 cms 115 min
Developed 50-year policy (0.084 m^3/m^2)	4.6 cms 130 min	5.2 cms 130 min	5.8 cms 130 min	12.0 cms 125 min	19.6 cms 120 min	29.2 cms 120 min
Developed 100-year policy (0.100 m^3/m^2)	4.1 cms 130 min	4.7 cms 125 min	5.2 cms 130 min	5.5 cms 130 min	5.8 cms 130 min	15.5 cms 125 min

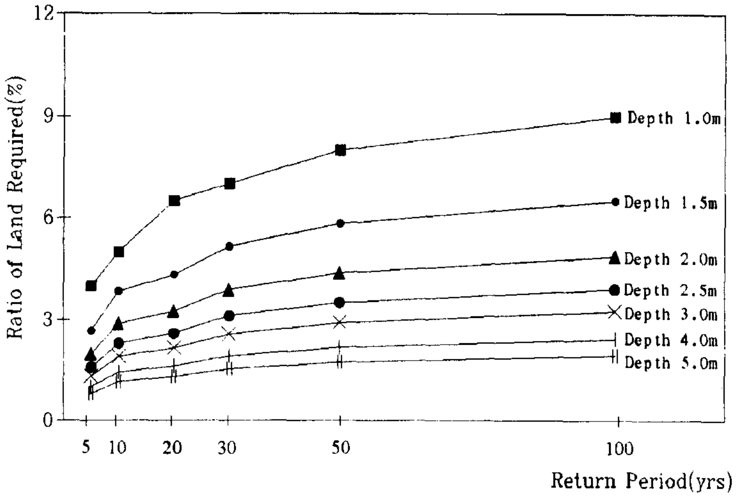


Fig. 2. Ratio of Land Required according to Detention Basin Depth (20-year Return Period)

where PRF = peak reduction factor, Q_{pi} = peak inflow hydrograph (m^3/s), Q_{po} = peak outflow hydrograph (m^3/s), and V_o = outflow hydrograph volume (m^3)

Eq. (3) indicates the stored volume in basin which is not released to down stream and detention basin factor (DBF) can be obtained from Eq. (5).

$$DBF=\frac{1-Q_{po}/Q_{Pi}}{V_r/V_t}=\frac{PRF}{RFS} \tag{5}$$

When the DBF is one, the storage volume which is not released to down stream is the same as stored volume in basin and when the DBF is greater than one, the detention storage volumes are more efficient.

Fig. 3 shows that the relationship between peak reduction factor and runoff fraction stored is not a straight line. A linear relationship would imply that if 50% flow reduction is required, then 50% runoff storage must be provided. Values above the straight line indicate that less storage is needed to achieve a specific peak reduction; however, values below the straight line indicate that more storage is needed for the same peak reduction.

A breakthrough point in the curve occurs when it crosses the straight line, reaching an equilibrium point with a slope equal to one. The slope of the curve is called the detention basin factor (DBF). When the DBF is greater than one, detention storage volumes are more efficient for the drainage area. A guideline for detention design is adopted for this paper which states that detention volumes with DBF less than one should be avoided because they are inefficient.

4.2 Analysis Result at the Hypothetical Watershed

The analysis applied to the hypothetical unit catchment is performed for three 10-square kilometers hypothetical watershed to determine the size and location of detention storage basin for a given flood frquency. Three different watershed shapes are formed with 10 unit catchment design shapes,

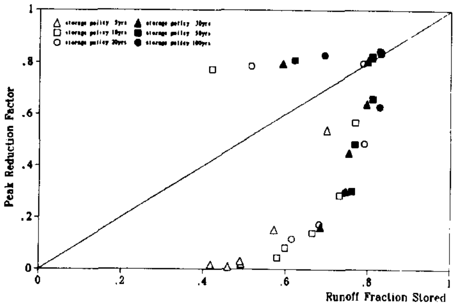


Fig. 3. DBF according to Storage Policy

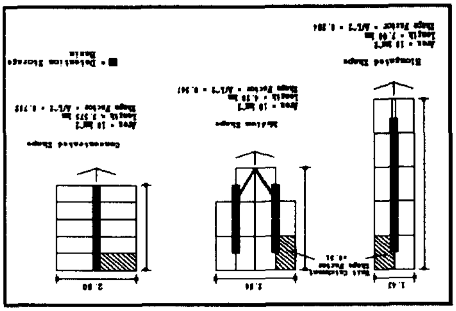


Fig. 4. Shape of Hypothetical Watershed

including an elongated shape (SF=0.204), a concentrated shape (SF=0.782), and a medium shape (SF=0.567). Fig. 4 shows the three watershed shapes analyzed.

The results of the effect of shape on the hydrologic response for undeveloped and developed land use in case of no detention storage basin in the watershed and placing the detention storage basin shown on Fig. 4 are listed on Table 3.

From Table 3, the elongated shape E has shortened 10 minutes in time–to–peak for the 5–year flood frequency and 5 minutes for the other frequencies. The medium shape M and the concentrated C have shortened 5 minutes for the 5–year and 10–year flood frequency and there is no variation in time–to–peak for the other frequencies.

The concentrated shape has the highest peak flow rates as expected, because the time to peak is the shortest. The ratio between developed peak flow rates over undeveloped is found to be around 2.5 for the 5–year frequency and watershed shape E, decreasing to 1.7 for the 100–year. For the 5–year frequency and watershed shape C, the ratio is around 2.2, decreasing to around 1.5 for the 100–year.

The ratio of peak flow rates of watershed is larger than that of unit catchment comparing Table 3 to Table 2 of results of unit catchment and this indicates that peak flows rates according to urbanization is increased as the size of watershed is increased.

Table 4 lists detention storage volumes for different watershed shapes and flood frequencies. The concentrated shape which has the highest peak flow rate is expected to require more storage than the other shapes. For the 20–year flood frequency and watershed shape C, detention storage volumes required to store the undeveloped peak flow rates are 0.034 m^3/m^2, of drainage area and the watershed land requirements for 2.5m detention basin depth are 1.11% of the watershed area. For the 20–year flood frequency, the catchment level requires 0.069 m^3/m^2 to decrease the peak flows to the natural leve; however, at the watershed level only 0.034 m^3/m^2. Therefore the watershed level will take advantage of detention storage volumes and requires less storage volumes than the catchment level.

5. Effect of Detention Basin in Real Watershed

To analyze the effect of detention basin on real watershed with regard to the hydrologic characteristics at the hypothetical unit catchment and watershed, the effect of runoff restrict at Jamsil 2 and Seongnae 1 detention pond area is hydrologically analyzed assuming that detention basin is located in inlet point of the area.

5.1 Basic Data

ILLUDAS model is used to analysis, and to prevent the storage effect due to capacity deficiency of existing sewer line, the design mode of ILLUDAS model is used. Design rainfall of the 5, 10, 20,

Table 3. Result of Hydrologic Response according to the Development Level for Shapes of Hypothetical Watershed

Return period (year)	Undeveloped peak flows (m³/s) and time-to-peak (min)			Developed peak flows (m³/s) and time-to-peak (min)			Developed Peak Flows / Undeveloped Peak Flows		
	E	M	C	E	M	C	E	M	C
5	52.1 155	76.8 135	86.3 130	128.5 145	171.1 130	186.9 125	2.47	2.23	2.16
10	71.6 150	104.4 130	116.5 130	154.0 145	204.2 130	223.0 125	2.15	1.96	1.91
20	91.0 150	131.6 130	146.4 125	177.4 145	234.4 130	255.8 125	1.95	1.78	1.75
30	104.5 150	150.2 130	166.8 125	192.8 145	253.7 130	276.7 125	1.85	1.69	1.66
50	119.1 150	170.3 130	188.8 125	209.1 145	274.3 130	299.2 125	1.76	1.61	1.58
100	138.7 150	197.2 130	218.2 125	230.7 145	302.0 130	329.0 125	1.66	1.53	1.51

Table 4. Detention Storage Volumes and Land Requirements for Different Watershed Shapes

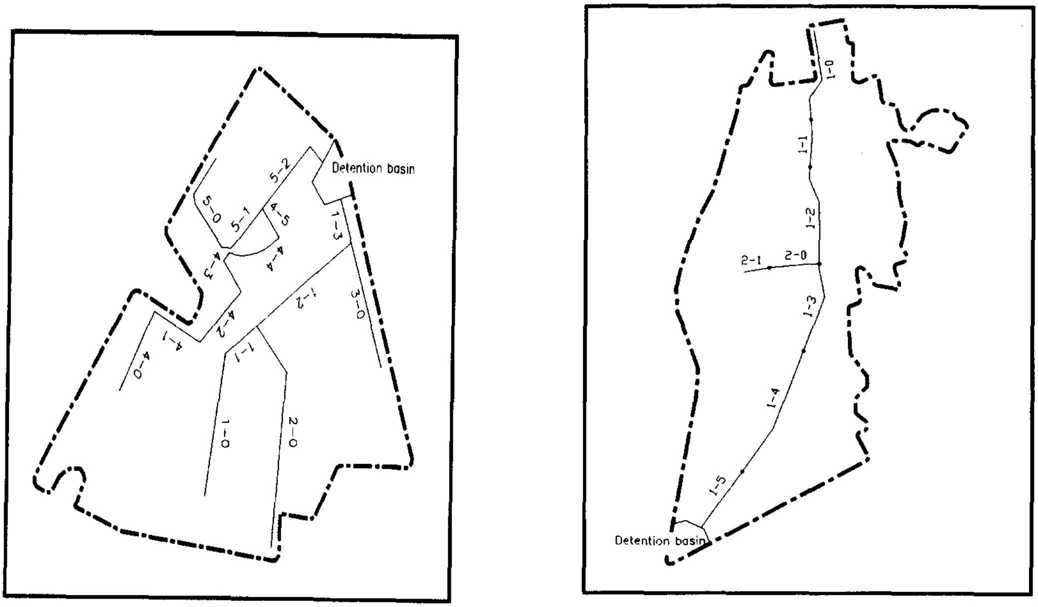
Return period (year)	Detention storage volume (m³)			Land requirements (m²)		
	E	M	C	E	M	C
5	225,064 0.023m	212,920 0.021m	228,539 0.023m	77,235 0.77%	77,229 0.77%	77,235 0.77%
10	286,319 0.029m	270,578 0.027m	291,036 0.029m	97,753 0.98%	97,752 0.98%	97,762 0.98%
20	331,940 0.033m	313,312 0.031m	337,087 0.034m	110,721 1.11%	110,711 1.11%	110,702 1.11%
30	365,183 0.037m	344,660 0.034m	370,840 0.037m	120,562 1.21%	120,553 1.21%	120,562 1.21%
50	407,085 0.041m	383,588 0.038m	413,017 0.041m	134,086 1.34%	134,075 1.34%	134,053 1.34%
100	480,622 0.048m	449,036 0.045m	488,096 0.049m	160,743 1.61%	160,714 1.61%	160,716 1.61%

30, 50, 100-year return period which is distributed to 4 rainfall patterns of Huff method is used.

The drainage area and the sewer system of Jamsil 2 and Seongnae 1 detention pond area are shown on Fig. 5.

5.2 Analysis of Runoff Fraction Stored with Detention Basin

Large areas that can control the flood in urban area are decreased as idle lands are developed for housing. The areas are not available and cost much for construction. Therefore the use of public site



(a) Jamsil 2 Watershed (b) Seongnae 1 Watershed

Fig. 5. Drainage Lines of Jamsil 2 and Seongnae 1 Watersheds

Table 5. Possible Lands of Detention Storage Basin in Jamsil 2 Watershed

Name of land	Width (m)	Length (m)	Area (m²)	Remarks (Drainage line)
Bangee middle school	130	170	22,100	1-0
Bangee primary school	105	165	17,325	2-0
Jamsil primary school	135	120	16,200	1-2, 3-0
Jamsil middle school	90	150	13,500	5-1
Jamsil high school	115	170	19,500	1-3

Table 6. Watershed Characteristics of Seongnae 1 Watershed

Line No.	Area (ha)	Length (m)	Line No.	Area (ha)	Length (m)
1-0	23.1	235	2-1	4.2	246
1-1	33.7	268	1-3	32.9	614
1-2	34.3	449	1-4	50.7	702
2-0	26.5	271	1-5	14.5	307

is considered preferentially, and also use of pre-public property in land and existing city park may be considered for flood control.

Selected lands for detention basin placement, considering the land use of Jamsil 2 watershed, are given on Table 5.

Possible lands for detention basin at Jamsil 2 watershed to retain the stormwater temporarily is generally under 20,000m² as shown on Table 5. If the depth of detention basin is about 1m, total detention volumes would be under 20,000m³. Four types of detention basin volumes, 5,000m³, 10,000m³, 20,000m³, 50,000m³, are determined to seize the effect of the detention basin. Single detention basin is placed at a point as shown on Table 5 alternatively and the change of inflow hydrograph is analyzed.

In Seongnae 1 watershed, land is not available anywhere in a watershed. Therefore the effect of detention basin is tested supposing that hypothetical land is located in each drainage line. The watershed characteristics are given in Table 6.

The rate of runoff fraction stored variation is calculated using Eq. (6) with detention basin placement.

$$DS_r = \frac{RFS_a - RFS_b}{RFS_b} \times 100 \tag{6}$$

where DS_r = rate of runoff fraction stored variation (%), RFS_a = runoff fraction stored after detention basin placement, and RFS_b = runoff fraction stored before detention basin placement

For the case when the detention basin is placed at any given point of watershed, the effect of detention basin is analyzed using runoff fraction stored and detention basin factor to seize the effect of peak flow restraint of the detention basin.

From the result of this study, it is shown that the larger the volume of detention basin is, when the detention basin is located in the upper portion of watershed, the more effectively the peak flow restrained.

5.3 Relationship between Detention Basin Volumes and Maximum Rate of Runoff Fraction Stored Variation

Storage load of detention pond located at the outlet of watershed will be reduced with detention basin placement. The reduction effect is affected by the size of detention basin volumes and design rainfall. To examine the reduction effect of the storage load in regard to detention basin, the relationship between detention basin volume and the maximum rate of runoff fraction stored variation is analyzed with the runoff fraction stored variation that happened when the detention basin is located at any place and the detention basin volumes that caused the maximum reduction effect of runoff fraction stored.

As the watershed area and runoff characteristics of Jamsil 2 and Seongnae 1 watershed are different, dimensionless detention basin volume which is the ratio between detention basin volume over total volumes is used to understand the relative value from the detention basin volume in this study.

The relationship between the dimensionless detention basin volumes and maximum rate of runoff fraction stored variation is shown on Fig. 7. From Fig. 7, as the detention basin volumes are increased the rate of runoff fraction stored variation is decreased. For the design rainfall, the rate of runoff fraction stored variation of Huff's 4th Quartile is larger than any other Huff's Quartile.

Therefore, when the detention basin should be placed at the watershed to cope with increasement of runoff volume due to urbanization and storage load of detention pond is determined voluntarily, required volume for the effect can be evaluated from Fig. 6. Table 7 lists the optimum regression equations of Fig. 6. From these equations required detention basin volumes corresponding to the rate of runoff fraction stored variation can be obtained.

5.4 Relationship between Detention Basin location and Rate of Runoff Fraction Stored Variation

As the detention basin volumes is determined, the detention basin should be placed at the point where the storage load is minimized in detention pond.

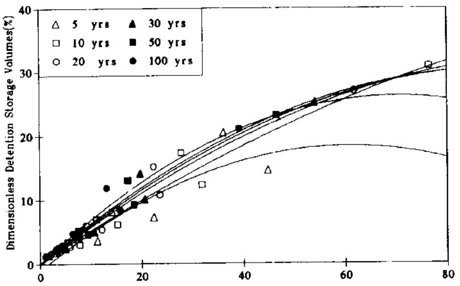
At the urban area where the watershed area is so small and the flow length is not long, there is little difference of time to peak between after detention basin and before detention basin. But peak flow rates is decreased and the effect of runoff fraction stored is reduced. This seems to be a result of detention basin volumes being very small compared to total volumes. Detention basin located on the most upper of each tributary is most effective in reducing the storage load in the detention pond.

When detention basin is located at land suggested in Tables 5 and 6, the relationship between the storage load in detention pond and upstream area of detention basin placement is analyzed. Dimensionless upstream ratio in Eq. (7) is used to understand relative value of area.

$$\mathrm{DUAR} = \frac{A_u}{A} \tag{7}$$

where DUAR = dimensionless upstream area ratio (%), A_u = upstream area of detention basin (ha), and A = total watershed area (ha)

Table 8 lists upstream area of detention basin and dimensionless upstream area ratio.



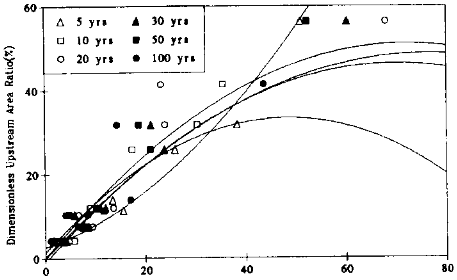


Fig. 6. Relationship between Dimensionless Detention Storage Volumes and Maximum Rate of Runoff Fraction Stored Variation (Huff's 3rd Quartile)

Fig. 7. Relationship between Dimensionless Upstream Area Ratio and Maximum Rate of Runoff Fraction Stored Variation (Huff's 4th Quartile)

Table 7. Regression Equation between Dimensionless Detention Storage Volumes and Maximum Rate of Runoff Fraction Stored Variation

Rainfall pattern	Frequency (year)	Optimum regression equation	Correlation coefficient
Huff's 1	5	$V_p=-.16916+.51786\ DSr-.00245\ DS_r^2$	.91084
	10	$V_p=.26409+.53164\ DSr-.00172\ DS_r^2$	.97907
	20	$V_p=.50756+.56294\ DSr-.00206\ DS_r^2$	.97304
	30	$V_p=.50617+.61570\ DSr-.00249\ DS_r^2$	.97360
	50	$V_p=1.0487+.63188\ DSr-.00336\ DS_r^2$	.94788
	100	$V_p=1.4684+.61571\ DSr-.00321\ DS_r^2$	.94198
Huff's 2	5	$V_p=-1.2769+.66348\ DSr-.00557\ DS_r^2$	.90229
	10	$V_p=.31345+.51376\ DSr-.00158\ DS_r^2$	.97793
	20	$V_p=.03616+.61814\ DSr-.00268\ DS_r^2$	.97694
	30	$V_p=.12610+.64485\ DSr-.00294\ DS_r^2$	.97592
	50	$V_p=.23598+.68877\ DSr-.00412\ DS_r^2$	.97381
	100	$V_p=.82565+.69136\ DSr-.00452\ DS_r^2$	.95304
Huff's 3	5	$V_p=-.98076+.64120\ DSr-.00526\ DS_r^2$	.89763
	10	$V_p=.19723+.52601\ DSr-.00163\ DS_r^2$	.97859
	20	$V_p=-.05674+.61743\ DSr-.00290\ DS_r^2$	.98361
	30	$V_p=-1.6579+.66036\ DSr-.00341\ DS_r^2$	.98470
	50	$V_p=.03276+.67100\ DSr-.00364\ DS_r^2$	.98372
	100	$V_p=.04112+.74845\ DSr-.00533\ DS_r^2$	.97671
Huff's 4	5	$V_p=-1.1185+.60853\ DSr-.00543\ DS_r^2$	.87631
	10	$V_p=.39210+.46128\ DSr-.00111\ DS_r^2$	.97576
	20	$V_p=.21125+.53417\ DSr-.00206\ DS_r^2$	.97846
	30	$V_p=.12676+.57143\ DSr-.00257\ DS_r^2$	.97925
	50	$V_p=.19036+.59154\ DSr-.00286\ DS_r^2$	.98007
	100	$V_p=.03801+.69161\ DSr-.00476\ DS_r^2$	.97644

Remarks) V_p : Dimensionless detention storage volumes (%)
DS_r : Rate of runoff fraction stored variation (%)

From the rate of runoff fraction stored variation according to the location of detention basin placement for return periods and temporal patterns of design rainfall, dimensionless upstream area ratio and the rate of runoff fraction stored variation showed constant shape, as detention basin volumes is increased. Generally, as detention basin volumes is increased, dimensionless upstream area ratio is also increased and when dimensionless upstream area ratio is over 40%, the maximum rate of runoff fraction stored variation is decreased. This indicates that detention basin can be located at midstream for large size basin and upstream for small size basin.

The relationship between dimensionless upstream area ratio and the maximum rate of runoff fraction stored variation for each volume are shown on Fig. 7 and the result of regression analysis is given in Table 9.

In the design of detention basin, the size of detention basin can be determined using regression equations in Table 7. The location of detention basin can be determined using regression equations in

Table 8. Upstream Area of Detention Basin and DUAR

(a) Jamsil 2

Location	Upstream area (ha)	DUAR (%)	Location	Upstream area (ha)	DUAR (%)
1-3	385.91	98.951	5-1	30.00	7.692
1-2	191.60	49.128	2-0	44.60	11.436
3-0	16.80	4.308	1-0	124.00	31.795

(b) Seongnae 1

Location	Upstream area (ha)	DUAR (%)	Location	Upstream area (ha)	DUAR (%)
1-0	23.1	10.500	1-4	205.4	93.364
1-1	56.8	25.818	1-5	220.0	100
1-2	91.1	41.409	2-0	26.5	12.045
1-3	154.7	70.318	1-0	30.7	13.955

Table 9. Relatioship between Dimensionless Upstream Area Ratio and Maximum Rate of Runoff Fraction Stored Variation

Rainfall pattern	Frequency (year)	Optimum regression equation	Correlation coefficient
Huff's 1	5	$DUAR = .32243 + .98943\,DS_r - .00157\,DS_r^2$	.98402
	10	$DUAR = .91399 + 1.0517\,DS_r - .00427\,DS_r^2$	.98687
	20	$DUAR = .98808 + 1.2337\,DS_r - .00517\,DS_r^2$	.97250
	30	$DUAR = .70065 + 1.5760\,DS_r - .01509\,DS_r^2$	.93856
	50	$DUAR = 5.0513 + .95368\,DS_r - .00390\,DS_r^2$	.83999
	100	$DUAR = 6.2740 + .01469\,DS_r + .28738\,DS_r^2$	.98320
Huff's 2	5	$DUAR = 4.2452 + .01704\,DS_r + .31408\,DS_r^2$	.99345
	10	$DUAR = -2.6503 + 1.5518\,DS_r - .01012\,DS_r^2$	.98680
	20	$DUAR = -.18621 + 1.4092\,DS_r - .00751\,DS_r^2$	.98136
	30	$DUAR = -.45482 + 1.7554\,DS_r - .01827\,DS_r^2$	.95978
	50	$DUAR = .00711 + 1.9390\,DS_r - .02248\,DS_r^2$	.94899
	100	$DUAR = 5.3977 + 1.0824\,DS_r - .00454\,DS_r^2$	.83700
Huff's 3	5	$DUAR = .37345 + 1.0854\,DS_r - .00422\,DS_r^2$	.98578
	10	$DUAR = -2.1553 + 1.6866\,DS_r - .01204\,DS_r^2$	.98678
	20	$DUAR = -3.8277 + 2.0320\,DS_r - .01698\,DS_r^2$	.97291
	30	$DUAR = -.51117 + 1.5491\,DS_r - .00908\,DS_r^2$	.98318
	50	$DUAR = 1.8933 + 1.2795\,DS_r - .00920\,DS_r^2$	.91409
	100	$DUAR = 1.5870 + 1.7809\,DS_r - .02979\,DS_r^2$	.80241
Huff's 4	5	$DUAR = 3.7328 + .01106\,DS_r + .43129\,DS_r^2$	.98778
	10	$DUAR = -.37100 + 1.2940\,DS_r - .00416\,DS_r^2$	.99413
	20	$DUAR = -3.5760 + 1.8233\,DS_r - .01373\,DS_r^2$	.97748
	30	$DUAR = -.10763 + 1.3739\,DS_r - .00711\,DS_r^2$	.98212
	50	$DUAR = .23416 + 1.5190\,DS_r - .00845\,DS_r^2$	.98098
	100	$DUAR = 1.9280 + 1.4083\,DS_r - .01161\,DS_r^2$	.89981

Remarks) DUAR : Dimensionless upstream area ratio(%)
DS_r : Rate of runoff fraction stored variation(%)

Table 9 of catchment area concept.

6. Conclusion

This study suggests the alternative concept of detention basin design replacing the concept of reducing the storage from a detention pond at downstream of the watershed in Korea. The alternative concept indicates that detention basin is located at any points within the watershed considering the land use to reduce the volume of the detention pond and pump station.

Hydrologic response characteristics under different rainfall frequencies, land use stages, drainage patterns, detention storage policies in regard to urbanizing progress are seized at hypothetical unit catchment and watershed of area 1 ㎢ and 10 ㎢. Jamsil 2 and Seongnae 1 watershed are selected as real watershed and the regression equations to determine the size and location of detention storage basin are suggested.

Table 7 and Table 9 from the results of this study provide the equations to be selected to determine the size and location of detention basin.

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