Hydrologic Study Report
for
Single Lot Detention Basin Analysis

Prepared for:

City of Vista, California

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Executive Summary

The City of Vista (City) retained the services of Tory R. Walker Engineering (TRWE) to develop design criteria for small onsite storm water detention basins at proposed projects within the City. This report contains the results of hydrologic analyses prepared for a range of typical onsite conditions of small development projects.

TRWE developed four rating curves for single lot detention basins in the City of Vista. The rating curves can be used to estimate the detention volume needed to reduce the increase in 100-year peak flows, based on the increase in impervious area for the lot. The four rating curves were developed based on five projects designed by Tory R. Walker Engineering, Inc. and seventeen hypothetical example projects. Scenarios covered by the rating curves include pipe storage for new construction on level lots, pipe storage for new construction on steep lots, pipe storage for redevelopment projects, and projects using surface storage.

An additional set of four curves was developed for approximate orifice outlet sizing on detention basins. The curves are specific to 48” diameter pipe or the surface storage topography used for this study. Other pipe sizes may be used, however. When designing an outlet orifice, it is suggested that the orifice rating curves be used as a starting point, and that the peak outflow be calculated with the orifice equation and compared to the pre-development flow rate.

Results of this analysis are limited to projects with an increase of less than 1.0 acre in impervious area, and lots with an overall slope of less than 10%.

1. Introduction

This report discusses the results of the study that was performed for the City of Vista to determine rating curves for single lot detention basins. The projects used to develop the rating curves included five projects performed by Tory R. Walker Engineering, Inc (TRWE) in the City of Vista, and 17 hypothetical scenarios for a wide range of residential and commercial developments. The scenarios included detached residential, attached residential, and commercial land uses on lots ranging in size from 0.25 acres to 1.00 acres. For this study, a maximum lot size of 1.00 acres was selected as the upper limit for the rating curves. Projects that propose more than a 1.00 acre increase in impervious area should be analyzed on a project by project basis.

2. Methodology

To determine the detention volume necessary to detain runoff from a watershed, a runoff hydrograph showing the relationship of the volume of runoff leaving the site over time needs to be known. The hydrograph analysis software used for this study was the US Army Corps of Engineers Hydrologic Engineering Center - Hydrologic Modeling Software (HEC-HMS), version 3.0.1. This software was developed by the Corps of Engineers for runoff modeling, and allows the user to select from a variety of precipitation patterns, hydrograph transformations, and watershed loss methods. The software is available from the HEC website (http://www.hec.usace.army.mil/).

For this study, all of the example projects and hypothetical scenarios were set up to reduce the 100-year flow rate after development to the pre-development flow rate. HEC-HMS models were put together for the pre- and post-development conditions for the 17 scenarios. The modeling approach follows the guidelines from Section 4 of the San Diego County Hydrology Manual. Model inputs included:

- Precipitation – Rainfall data for the model was taken from the Isopluvial Maps for the 6-hour and 24-hour 100-year storms from the Hydrology Manual. A 100-year 24-hour rainfall depth of 5.60 inches was used for this analysis. This depth is a representative average value for Vista. Rainfall was entered into the model using the “Frequency Storm” method. This is the method that most closely corresponds to the rainfall distribution in the Hydrology Manual. Due to the size of the watersheds (area less than or equal to 1.00 acre), no rainfall depth-area adjustments were necessary.
- Runoff Coefficient – The runoff coefficient used for this study was the Natural Resources Conservation Service (formerly SCS) Curve Number. Curve Numbers (CN) were taken from Table 4-2 in the Hydrology Manual.
- Initial Losses – Initial losses (I_a) in the watershed were calculated using the NRCS method empirical equation of losses being equal to 20% of the maximum potential soil retention (S). The losses were calculated using the following formulas:

$$I_a = 0.2 \cdot S$$

$$S = \frac{1000}{CN} - 10$$

- Lag Time – An initial time of concentration nomograph, commonly used throughout most of Southern California, was used to determine the times of concentration for the hypothetical scenarios. An example of the nomograph is included in Appendix B. The lag time was calculated as 80% of the time of concentration.

Key assumptions that were used to perform this study included:

- All development taking place on Type D soil. Type D soils, which are the prevailing soil type in the City of Vista, are clayey soils that have high runoff rates and low infiltration rates. Type D soils were also selected because they return the most conservative results.
- Outlets from all detention basins will function as orifices. This assumption was made since when the basins are at the highest stages, the outlets will be sufficiently submerged to function as orifices (depth greater than 1.5 times diameter).
- City of Vista is within Precipitation Zone Number (PZN) 2.0. PZN 2.0 is for average conditions, where soils are neither dry nor saturated.
- Detention basins were located at the most-downstream point in the lots. This location was selected due to the wide variety of possible detention basin locations, depending on the site layout design. In situations were the detention basin cannot be placed at the most-downstream point on a lot, the rating curves can be used to determine the detention from a portion of the lot, and the resulting flow at the discharge point from the lot can be determined by summing the peak flow rates.
- Drainage systems downstream of the detention basins have capacity for the flow, so there is negligible tailwater and the outfalls are controlled by the orifice (inlet control conditions).

3. Summary of Hydrologic Conditions

The rating curves for this study were developed based on 5 example residential projects and 17 hypothetical projects within the City of Vista. The differences between the projects included lot size, lot slope, existing impervious area, proposed development type, and proposed impervious area. The example projects are described in Table 1 and the hypothetical projects are described in Table 2.

Table 1: Example Residential Projects

Project No.	Land Use Description	Area (ac)	Exist Imp. (%)	Exist Imp. (ac)	Prop. Imp. (%)	Prop. Imp. (ac)	Δ Imp. (ac)	Slope
1	Residential on empty lot	0.136	9.0%	0.01	35.6%	0.05	0.04	4.1%
2	Residential on residential	0.132	18.5%	0.02	36.1%	0.05	0.02	3.9%
3	Residential on residential	0.238	27.1%	0.06	58.1%	0.14	0.07	16%
4	Residential on empty lot	0.670	0.0%	0.00	34.9%	0.23	0.23	16%
5	Residential on empty lot	0.390	7.0%	0.03	39.4%	0.15	0.13	27%

Table 2: Hypothetical Scenario Projects

Scenario No.	Land Use Description	Area (ac)	Exist Imp. (%)	Exist Imp. (ac)	Prop. Imp. (%)	Prop. Imp. (ac)	Δ Imp. (ac)	Slope
1	Residential on empty lot	0.25	0.0%	0.00	38.0%	0.10	0.10	2.0%
2	Residential on empty lot	0.50	0.0%	0.00	25.0%	0.13	0.13	2.0%
3	Residential on empty lot	0.75	0.0%	0.00	20.0%	0.15	0.15	2.0%
4	Residential on empty lot	0.25	0.0%	0.00	38.0%	0.10	0.10	10.0%
5	Residential on empty lot	0.50	0.0%	0.00	25.0%	0.13	0.13	10.0%
6	Residential on empty lot	0.75	0.0%	0.00	20.0%	0.15	0.15	10.0%
7	Residential on residential	0.25	30.0%	0.08	45.0%	0.11	0.04	2.0%
8	Residential on residential	0.50	20.0%	0.10	30.0%	0.15	0.05	2.0%
9	Residential on residential	0.75	15.0%	0.11	25.0%	0.19	0.08	2.0%
10	Townhouses on empty lot	1.00	0.0%	0.00	65.0%	0.65	0.65	2.0%
11	Townhouses on empty lot	1.00	0.0%	0.00	65.0%	0.65	0.65	10.0%
12	Townhouses on residential lot	1.00	20.0%	0.20	65.0%	0.65	0.45	2.0%
13	Commercial on empty lot	1.00	0.0%	0.00	85.0%	0.85	0.85	2.0%

Scenario No.	Land Use Description	Area (ac)	Exist Imp. (%)	Exist Imp. (ac)	Prop. Imp. (%)	Prop. Imp. (ac)	Δ Imp. (ac)	Slope
14	Commercial on residential lot	1.00	20.0%	0.20	85.0%	0.85	0.65	2.0%
15	Commercial on commercial	1.00	60.0%	0.60	85.0%	0.85	0.25	2.0%
16	Residential on empty lot	1.00	0%	0.00	40%	0.40	0.40	2.0%
17	Residential on empty lot	1.00	0%	0.00	40%	0.40	0.40	10.0%

4. Summary of Hydraulic Conditions

Two detention basin designs were considered for this study. The designs included an underground 48 inch diameter pipe and an aboveground depression with a grate inlet at the low point. Both of these designs incorporated an orifice outlet to the downstream system. Schematics of the outlet designs are included in Appendix B.

The diameters of the orifices were determined using the standard orifice equation, shown below. A schematic of an orifice and the location of the variables is included in Appendix B.

$$Q = C_d \cdot A \cdot \sqrt{2 \cdot g \cdot h}$$

Where:
Q = Flow through the orifice (cfs)
C_d = Orifice entrance coefficient (sharp-edged)
A = Area of orifice (ft^2)
g = Gravitational acceleration (32.2 ft/s^2)
h = Head on the orifice (ft), difference in elevation between water surface and midpoint of orifice.

5. Results

The results from the HEC-HMS analyses of the existing and proposed conditions are included in Tables 3 and 4. The results in Table 3 are the design solutions proposed for the example projects. The results in Table 4 are the hypothetical detention requirements for the different scenarios. In Table 4, the detention designs include 48 inch pipe for all of the scenarios, and surface storage requirements for six of the scenarios. For the pipes, the lengths required for detention are included. For this study, the freeboard in the pipes ranged from 0.08 to 0.52 feet, with an average of 0.21 feet. Additional iterations of orifice diameter and detention length in the HEC-HMS model were not performed once a result was found with less than 0.5 feet of freeboard.

Table 3: Results Summary for Example Projects

Project No.	Exist Q (cfs)	Prop. Q (cfs)	Δ Q (cfs)	Detention Design	Peak Storage (ft^3)	Maximum Head (ft)	Outlet Dia. (inches)
1	0.49	0.61	0.12	Surface	57	1.22	2.50
2	0.48	0.59	0.11	Surface	57	1.13	2.50
3	1.23	1.36	0.13	20' of 24"	65	1.66	2.75
4	2.86	3.56	0.70	42' of 42"	379	2.99	3.00
5	1.64	2.07	0.43	25' of 48"	209	2.33	5.00

Table 4: Results Summary for Hypothetical Projects

Project No.	Exist Q (cfs)	Prop. Q (cfs)	Δ Q (cfs)	Detention Design	Peak Storage (ft^3)	Maximum Head (ft)	Outlet Dia. (inches)
1	0.88	1.31	0.43	22' of 48"	266	3.51	4.0
2	1.62	2.18	0.56	40' of 48"	462	3.25	5.5
3	2.32	3.02	0.70	50' of 48"	597	3.34	6.7
				Surface	266	1.91	7.8
4	1.04	1.37	0.33	14' of 48"	170	3.60	4.5
5	1.92	2.52	0.60	30' of 48"	370	3.63	6.0
6	2.79	3.57	0.78	40' of 48"	475	3.30	7.5
7	1.21	1.34	0.13	8' of 48"	100	3.68	4.8
				Surface	26	1.53	6.0
8	2.10	2.25	0.15	14' of 48"	174	3.66	6.3
				Surface	35	1.52	7.9
9	2.96	3.16	0.20	25' of 48"	301	3.43	7.5
				Surface	52	1.52	9.4
10	2.95	5.17	2.22	120' of 48"	1485	3.57	7.5
11	3.57	5.89	2.32	105' of 48"	1294	3.49	8.3
12	4.31	5.17	0.86	60' of 48"	741	3.51	9.0
13	2.95	5.58	2.63	135' of 48"	1668	3.57	7.5
				Surface	1041	2.44	8.3
14	4.31	5.58	1.27	75' of 48"	928	3.52	9.0
15	4.97	5.58	0.61	40' of 48"	492	3.44	9.9
16	2.95	4.44	1.49	95' of 48"	1154	3.44	7.5
				Surface	597	2.16	8.6
17	3.57	5.22	1.65	80' of 48"	993	3.56	8.3

The storage volume results shown in Tables 3 and 4 were plotted against the change in impervious area for the respective project and scenarios. On the plot, four different conditions became apparent with different detention requirements for equal changes in impervious area. The four conditions included pipe storage for new construction on level lots (2% slope), pipe storage for new construction on steep lots (10% slope), pipe storage for redevelopment lots, and surface storage for new construction on level lots or redevelopment. Figure 1 shows the four detention rating curves obtained from this study.

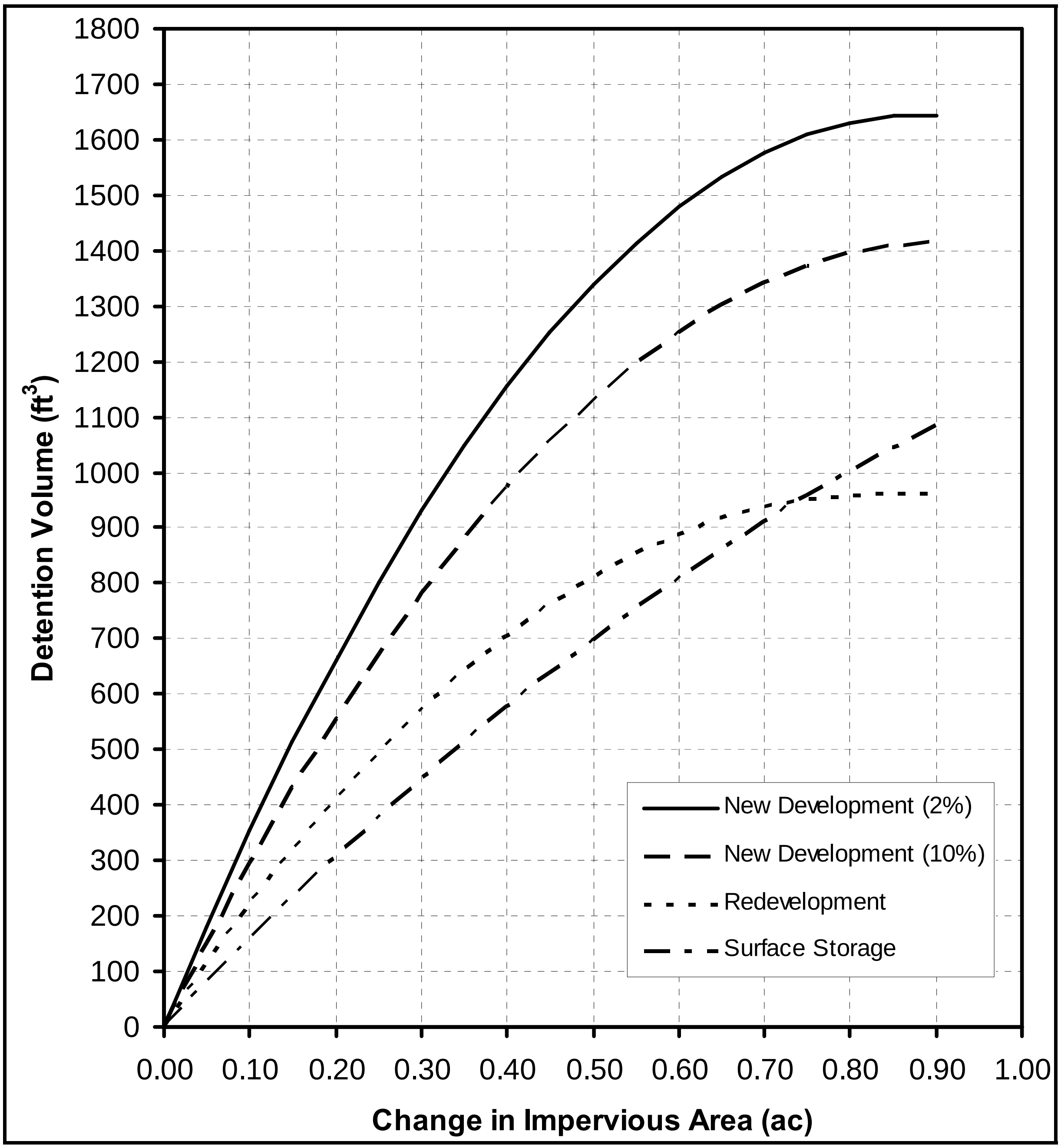

Figure 1. City of Vista Detention Basin Rating Curves

From Figure 1 it can be seen that of the three curves for pipe storage, new construction on level lots require the most detention volume, while redevelopment projects require the least detention volume. The reasoning for this difference is that the difference in the time of concentration between pre-development and post-development conditions is greatest for new construction on level lots and lowest for the redevelopment projects. The greater difference between the pre-and post-development times of concentration leads to a greater difference between the pre- and post-development peak flow rates, and detention is directly related to the difference between the pre- and post-development flow rates and the amount of time that the pre-development flow rate is exceeded.

The detention rating curve for surface storage shown in Figure 1 was developed based on a specific detention configuration (see Appendix B). The surface storage option required the least detention volume since more storage was available at a lower elevation. By storing more runoff at a lower elevation, it was possible to use a larger outlet orifice diameter since there was less head on the orifice. The difference between the detention designs is shown in the stage-storage curves for scenario 13, which is shown in Figure 2.

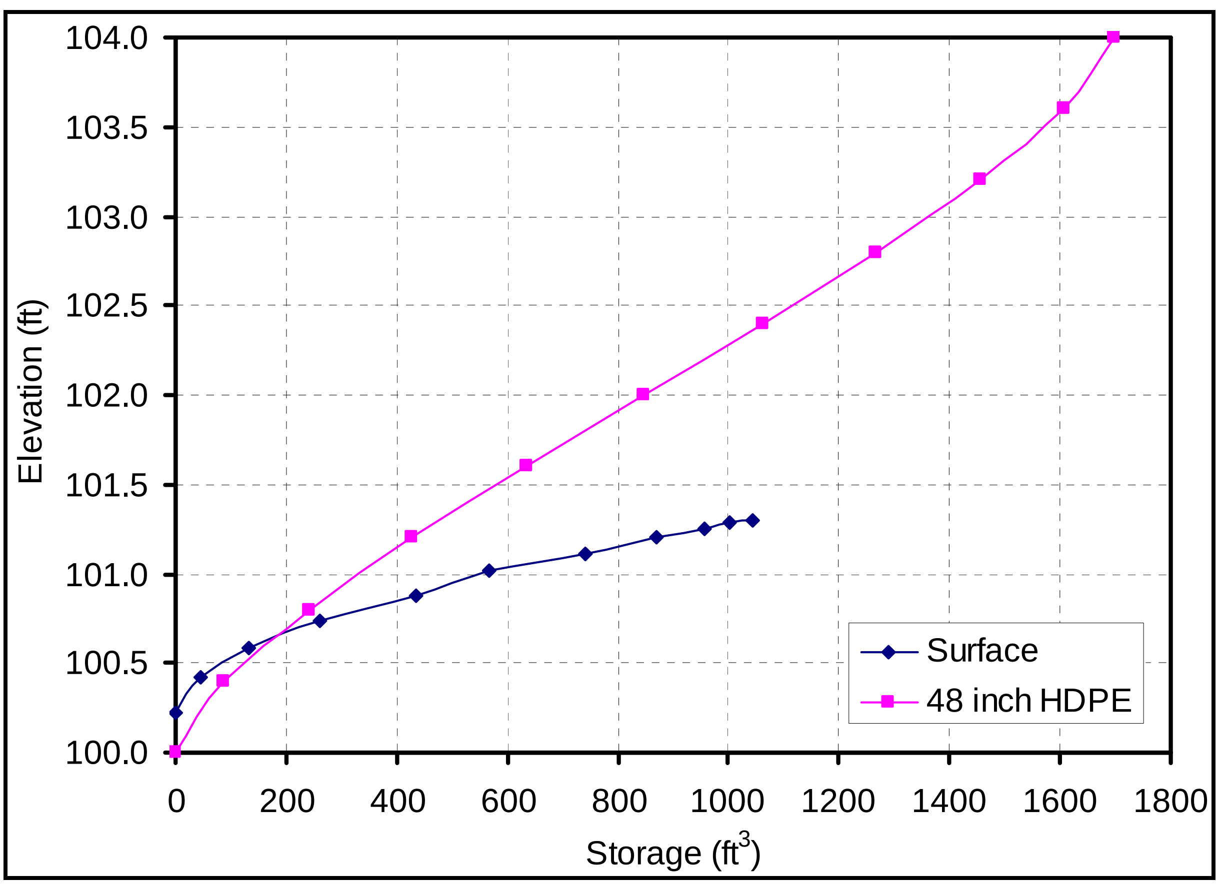

Figure 2. Scenario 13 Stage-Storage Curves

A separate group of rating curves was developed for the orifice outlet sizing. On these curves, the relationships between detention volume and orifice diameter are considered. As with the detention volume rating curves, the scenarios included level new development, steep new development, redevelopment, and surface storage. The orifice outlet rating curves are shown in Figure 3.

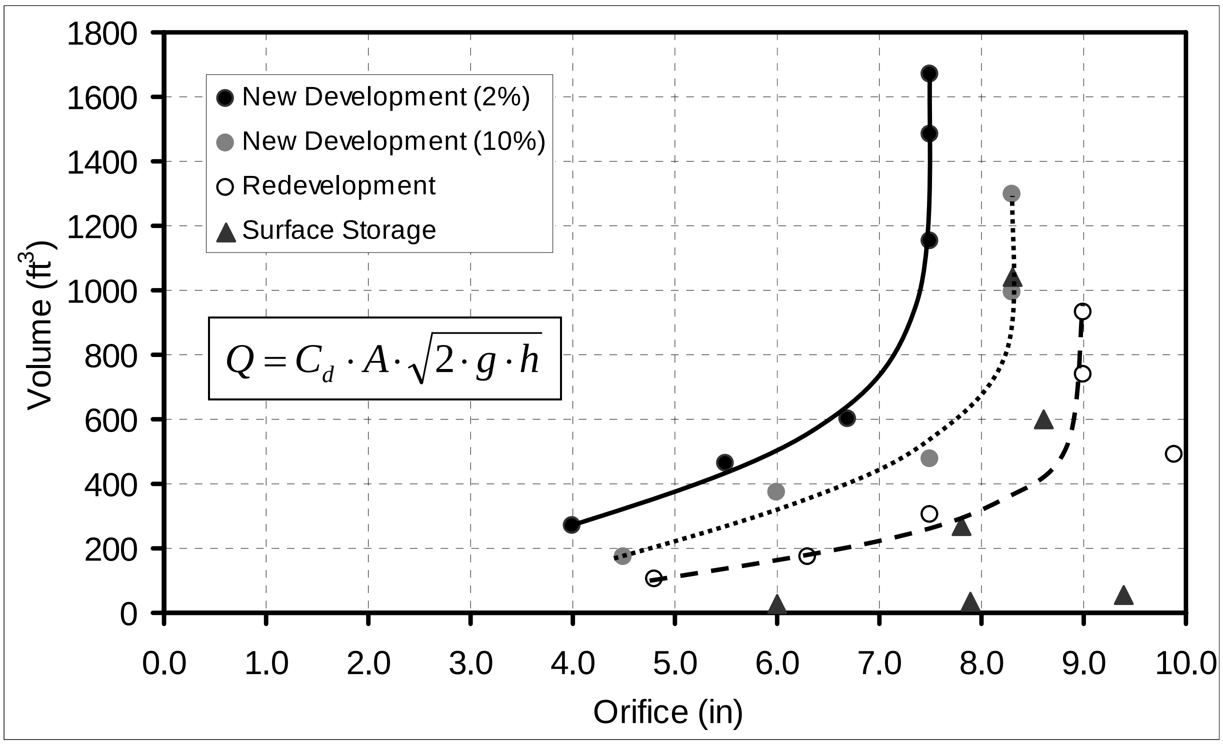

Figure 3. Outlet Orifice Rating Curves

As can be suggested from Figure 3, the trends for the orifice sizing are not as uniform as those used for detention volume determination, especially for redevelopment and surface storage situations. Because of this uncertainty, it is recommended that this chart only be used as a guideline for orifice determination. The design process would involve selecting an orifice diameter based on the rating curve if a 48” pipe is being used for storage, and then using the orifice equation to check the peak flow out of the basin. If a different storage pipe diameter or surface storage are being used, then the orifice diameter should be selected using the orifice equation.

It is recommended that the orifice equation should be used for the sizing of the outlet orifice diameter since the pre-development and post-development flows from the lot will be determined by the designer using the Rational Method for storm drain and inlet sizing (for small tributary areas, there is good correlation between Rational Method results and HEC-HMS results using the Frequency Storm). For underground storage basins, the head that should be used for the orifice equation can be determined by assuming the freeboard in the detention pipe matches the average freeboard of 0.21 ft from this study. Because of potential clogging, an overflow riser should be provided at this elevation to prevent the underground basins from overflowing onto the adjacent landscaping. The pipe detention schematic in Appendix B includes a table listing pipe full cross sectional areas, and cross-sectional areas for a condition when the depth is 95% of the diameter (average freeboard diameter from this study) for pipes ranging in diameter from 24 inches to 48 inches. The cross-sectional areas can be multiplied by the pipe length to determine storage volumes.

6. Conclusion

Four rating curves have been developed for a range of projects within the City of Vista. The rating curves have been developed to assist with designing detention basins for single lot projects. The volumes obtained from the rating curves are the detention storage volumes, and excess capacity should be provided to account for debris accumulation or partial blockage of the downstream system.

The limitations of the rating curves include projects with a change of impervious area greater than 1.0 acre, and projects on lots much steeper than 10%. In these types of situations, there is too much potential variation in the times of concentration to be accounted for with the rating curves.

7. References

1. *Hydrology Manual.* County of San Diego Department of Public Works, Flood Control Section. June, 2003.
2. *Urban Hydrology for Small Watersheds.* U.S. Department of Agriculture – Natural Resources Conservation Service, Publication TR-55. June, 1986.
3. *Handbook of Hydraulics:* Ernest F. Brater and Horace Williams King. 6th Edition. January 1996.
4. *Hydrology Manual.* County of Riverside Flood Control, Water Conservation District. April 1978.
5. *Hydrology Manual.* County of San Bernardino, Williamson and Schmid. August 1986.
6. *Hydrology Manual.* County of Orange. Williamson and Schmid. October 1986.

Appendix A. HEC-HMS Input and Output

- Precipitation Data
- Hypothetical Scenarios Existing Conditions
- Hypothetical Scenarios Proposed Conditions
- Hypothetical Scenarios Proposed Conditions with Detention
- Example Projects Existing Conditions
- Example Projects Proposed Conditions with Detention

Appendix B. Reference Information

- Underground Pipe Detention Basin Schematic
- Surface Storage Detention Basin Schematic
- Outlet Orifice Schematic
- Initial Time of Concentration Nomograph Example