City of Cambridge, Massachusetts

Department of Public Works

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APPENDIX D
DRAFT
Technical Basis for Stormwater Quantity Guidelines

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D. TECHNICAL BASIS FOR STORMWATER QUANTITY GUIDELINES

Below are the contents of a technical memo submitted by MWH to the City of Cambridge. The memo discusses evaluations of the Concord-Alewife area and conclusions upon which the City's stormwater quantity guidelines are based.

Introduction & Methodology

Potential impacts of re-development in the Concord-Alewife area are being evaluated using hydrologic and hydraulic modeling. The purpose of this memo is to outline a draft methodology for determining the required private onsite runoff retention for the 2-year to 25-year storm. The study area for this analysis is shown in Figure 1.

Modeling scenarios were developed based on applicable methods of reducing runoff in the Concord-Alewife Area. Overall stormwater management goals of the Concord-Alewife Rezoning Petition include increasing the minimum open space requirement for all uses to 15%, and also creating a permeable requirement of 25%. Types of runoff reduction technologies included in the analysis were green roofs (two variations), converting impermeable surfaces to permeable surfaces, and onsite storage. Since groundwater levels in the study area are relatively high, the use of many typical infiltration technologies, such as biofilters or porous pavement, is not applicable. However, green roof technologies have been successfully implemented in Cambridge (Sidney Street in Cambridgeport) and are an environmentally attractive and effective method of runoff reduction.

The analysis is based on the private development rule that the total volume of runoff generated between the 2-year storm peak discharge (present conditions) and the 25-year storm (CAM 004 model future conditions) shall be retained. The 2-year, 24-hr NRCS design storm event was simulated under existing conditions (2003) with a receiving water boundary condition varying in elevation from 0.5 to 3.0 feet NGVD. The 25-year, 24-hr NRCS design storm event was then simulated under future proposed conditions with a receiving water boundary condition varying in elevation from 0.5 to 6.4 feet NGVD. To obtain the runoff hydrographs for the Concord-Alewife study area, flow hydrographs in the modeled pipe network were strategically chosen and algebraically summed. Flows were summed as follows:

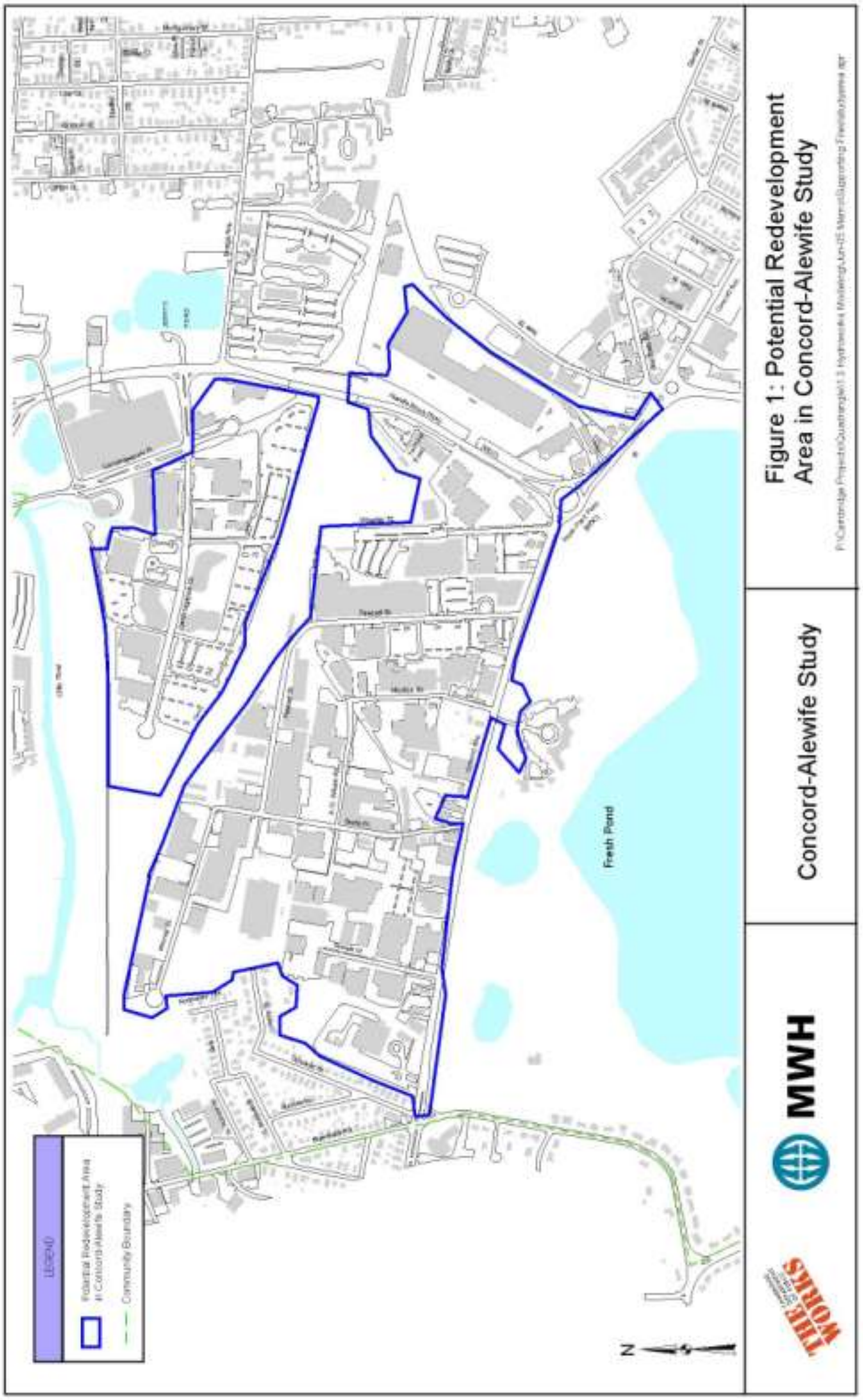


Figure 1: Potential Redevelopment Area in Concord-Alewife Study
Concord-Alewife Study
MWH
Fresh Pond
LEGEND
Potential Redevelopment Area in Concord-Alewife Study
Community Boundary

<u>Existing Conditions:</u>

Concord-Alewife Runoff = Flows from Wheeler Street outlet + Mooney Street Flows (towards Spinelli drain) + Wheeler Street Flows + Terminal Rd Flows – Flows from Drain Vault 5 – Sherman Street Flows

<u>Future Conditions:</u>

Concord-Alewife Runoff = Flows to Alewife Wetland Detention System + Flows from Wheeler Street outlet + Mooney Street Flows (towards Spinelli drain) + Wheeler Street Flows + Terminal Rd Flows – Flows from Drain Vault 5 – Sherman Street Flows

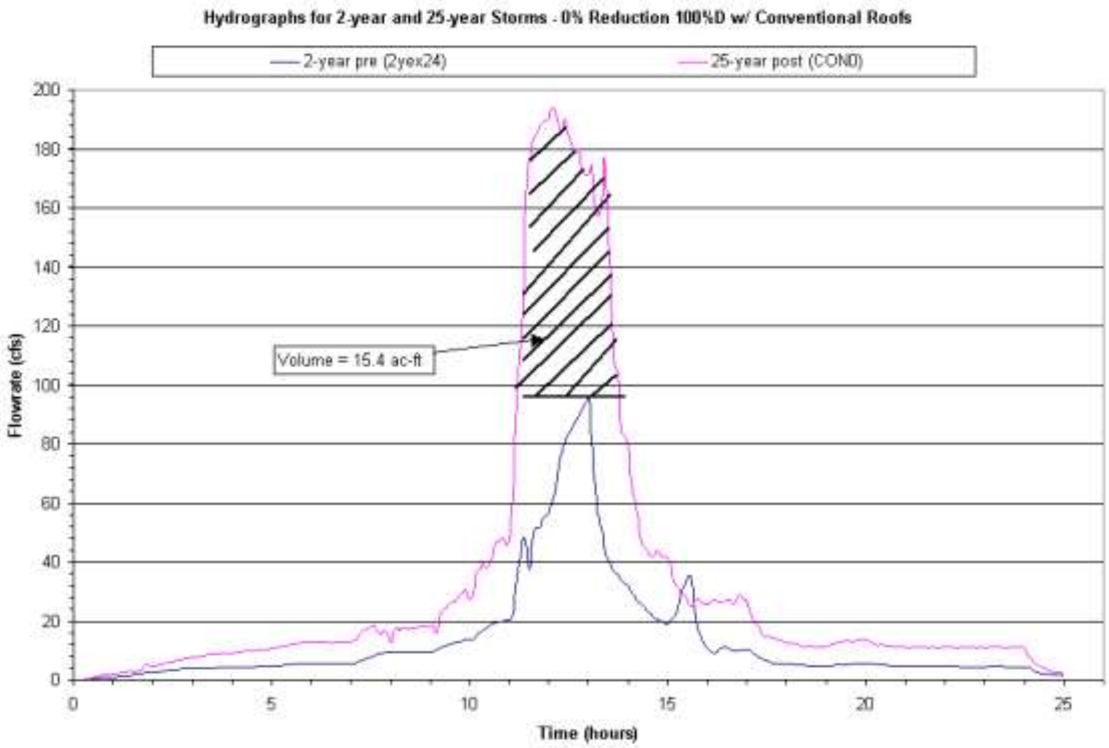
Runoff from roof surfaces, pervious ("green") surfaces, and pavement surfaces on private property was modeled. Public street areas were not included in this analysis. The total modeled study area contains 169 acres of private property with 149 acres of impervious area (roof + pavement).

Table 1 summarizes the roof configurations evaluated. For each type of roof configuration, simulations were performed for the 25-year storm under future conditions in the Concord-Alewife study area, with varying levels of impervious area reductions (e.g. private property pavement area reductions). The composite 25-year runoff hydrograph for the study area was plotted for each scenario and compared with the 2-year present conditions hydrograph. This is illustrated in Figure 2. The runoff volume difference between the 2-year peak discharge and the 25-year hydrograph was computed. This difference was assumed to be the quantity of storage required in order achieve the runoff retention goal. For the example in Figure 2, 15.4 ac-ft of storage is required to meet the goal for the study area.

TableA3.1: Modeled Roof Configuration Summary

Configuration	Description
Conventional Roof	
Green Roof Type 1	100% of the roof surface is "green"; Excess runoff is conveyed directly to the collection system
Green Roof Type 2	60% of the roof surface is "green" (excess runoff to roof storage compartment); 40% of the roof surface is modeled as conventional (impervious); All runoff is conveyed into a 4" deep storage chamber on the roof through a controlled outlet down to the collection system

Figure A3.2: Example 2y-25y Onsite Retention Requirement Calculation



Conventional roofs were modeled as impervious surfaces with a Manning's roughness ("N") value of 0.011. All green roofs were modeled as impervious surfaces with a Manning's roughness value of 0.35, which approximates the attenuation achieved by prairie grass type vegetation on the green roof. An initial loss of 0.3 inches was modeled based on results of pilot test data using extensive green roofs.

Green roofs with pervious surfaces were also evaluated; however, the impervious surface method was chosen to be conservative. Type 1 green roofs assumed that the entire roof area was utilized for green roof technology. Type 2 green roofs assumed that only the perimeter of the roof area (approximately 60% of the total roof surface) was assumed to be "green" and was pitched towards the center of the roof area, which acted as a detention basin (4 inches deep). Runoff from the "green" portion of the roof was assumed to be conveyed into the detention basin. In addition, the detention basin contained a throttled underflow to the collection system. The underflow for each model subcatchment was modeled as an orifice with a maximum discharge value that was adjusted such that approximately 80%-100% of the detention basin volume was utilized during the storm event. This type of green roof was successfully implemented on Sidney Street in Cambridgeport.

For the condition of no pavement reduction, all open space was assumed to have default type D soil parameters. For any scenario that includes pavement area reduction to increase permeability, the pervious surfaces were assumed to have a mix of soil types. The Horton equation parameters for this mix of soils was computed by assuming 10% B type soils, 60% C type soils and 30% D type soils. This blend of soil types was assumed typical for the Concord-Alewife area. This composite parameter set was then reduced by 10%.

Study Area Model Results

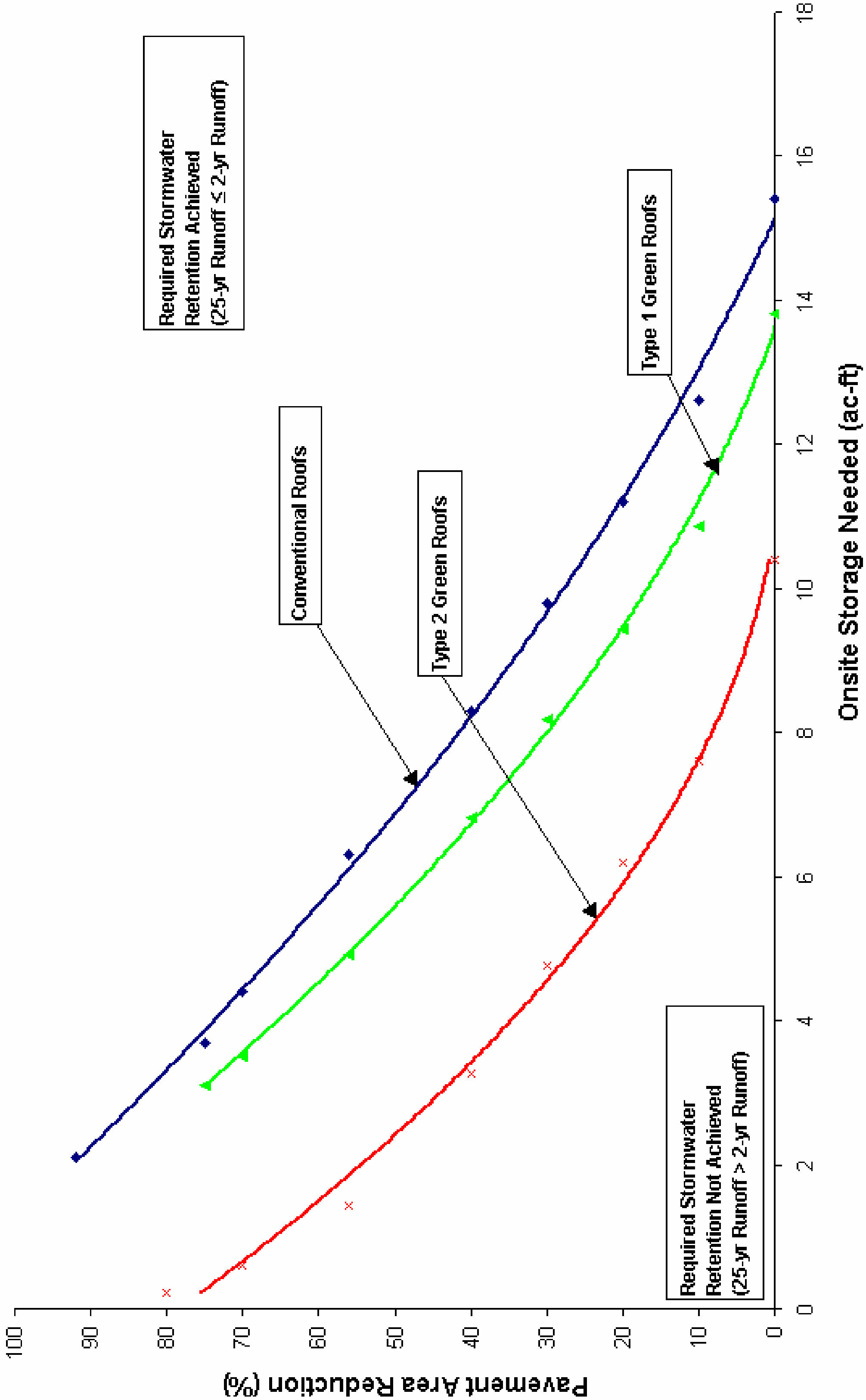
Figure 3 summarizes the results of the analysis. Three curves are drawn which represent the relationship between pavement area reduction and onsite storage required, for each type of modeled roof configuration. The amount of pavement area reduction to achieve the required runoff retention (i.e., pavement area converted to green pervious area) is plotted on the y-axis while the corresponding amount of required on-site storage volume is plotted on the x-axis. The runoff reduction goal is achieved if a point falls on the curve, or to the upper-right hand side of the curve. This plot represents the range of alternatives that could be used to satisfy the runoff retention requirement.

For a conventional roof configuration, if no reduction in pavement area is achieved upon development of the Concord-Alewife area, then a minimum of 15.4 ac-ft of storage would be required. As pavement area is reduced, less onsite storage is required. As expected, lower quantities of runoff were simulated for scenarios with green roof configurations, as compared to scenarios with conventional roofs. Therefore, the utilization of green roof technology may reduce the amount of required onsite storage in a development, as compared with using conventional roofs. Using Type 2 green roofs allowed for the least quantity of required onsite storage.

The curves in Figure 3 illustrate required storage volumes for the entire study area. In order to facilitate the use of these results for a subset of the study area, the required storage volumes were normalized by total impervious area and are plotted in Figure 4. The amount of pavement area reduction to achieve the required runoff retention (i.e., pavement area converted to green pervious area) is plotted on the y-axis while the corresponding amount of required on-site storage volume per impervious acre is plotted on the x-axis.

For example, if a potential development in the Concord-Alewife area has 5.0 acres of impervious surface and conventional roofs, and no pavement area reduction is proposed, then approximately 0.5 ac-ft of onsite storage would be required (0.1 ac-ft per impervious acre x 5.0 acres). Table 2 provides a summary of the model results that were used to plot the curves in Figures 3 and 4.

Figure 3: Private Development Requirements



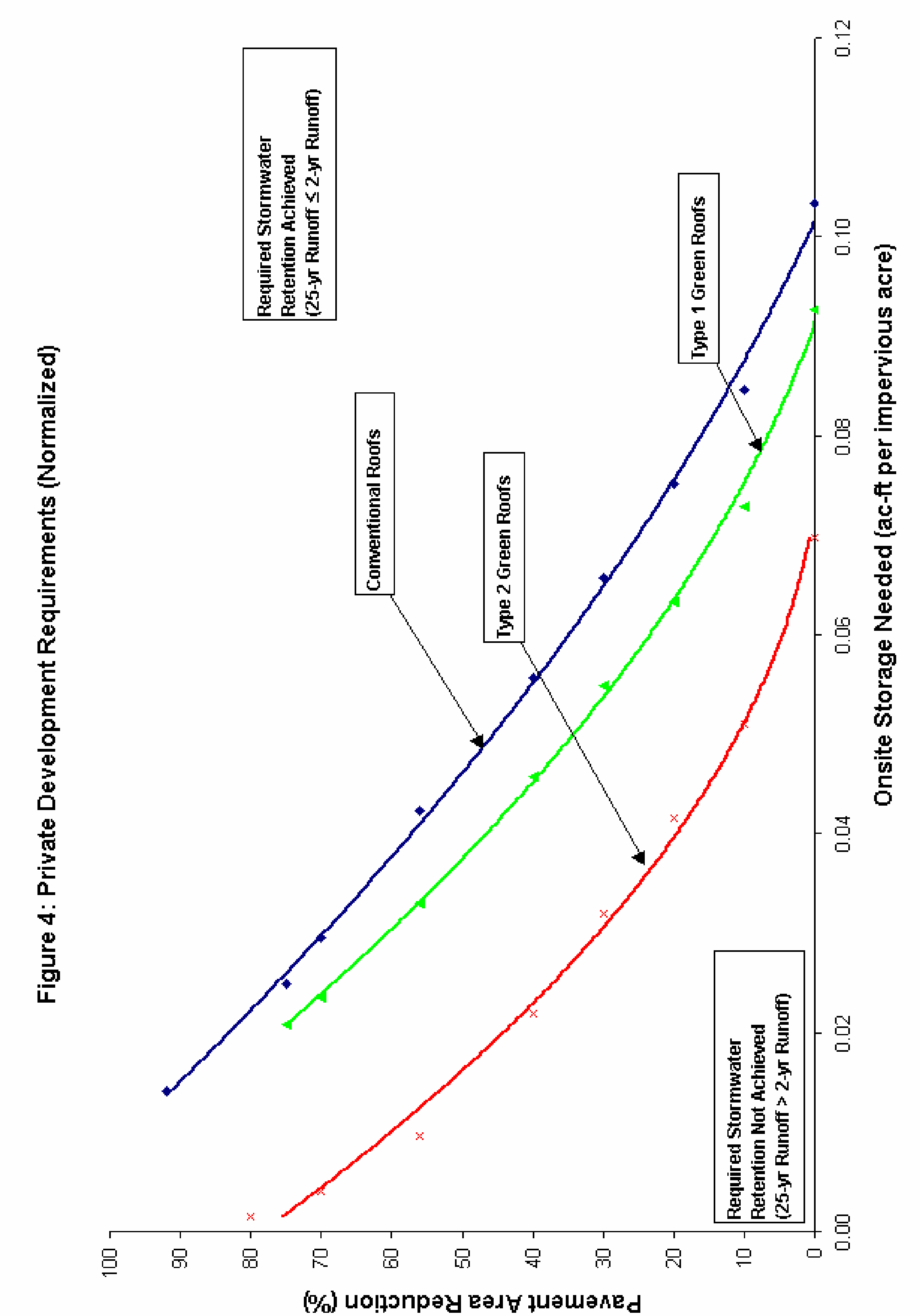


Figure 4: Private Development Requirements (Normalized)

Table A3. 2: Study Area Model Results Summary

Pavement Area Reduction (%)	Volume Difference Between 2y-25y Hydrographs (ac-ft)	Volume Difference Per Impervious Acre* (acre-ft/impervious acre)
Conventional Roof Configuration		
0	15.4	0.103
10	12.6	0.085
20	11.2	0.075
30	9.8	0.066
40	8.3	0.056
56	6.3	0.042
70	4.4	0.030
75	3.7	0.025
92	2.1	0.014
Type 1 Green Roof Configuration		
0	13.8	0.093
10	10.9	0.073
20	9.4	0.063
30	8.2	0.055
40	6.8	0.046
56	4.9	0.033
70	3.5	0.024
75	3.1	0.021
Type 2 Green Roof Configuration		
0	10.4	0.070
10	7.6	0.051
20	6.2	0.042
30	4.8	0.032
40	3.3	0.022
56	1.4	0.010
70	0.6	0.004
80	0.2	0.001

*Note: Computation used 149 acres of private property impervious area

Single Subcatchment Model Results

The procedure of calculating required retention requirements using the normalized method (Figure 4) was evaluated for a single subcatchment in the model. Similar to the procedure used to create the plots in Figure 3 for the entire study area, plots were also created by modeling only the single subcatchment. The subcatchment used has a total private property area of 8.55 acres, with 7.44 acres of impervious surface (roof + pavement). The 25-year runoff hydrograph for the subcatchment was plotted for each scenario and compared with the 2-year present conditions hydrograph. The runoff volume difference between the 2-year peak discharge and the 25-year hydrograph was computed. This difference was assumed to be the quantity of storage required in order to achieve the runoff retention goal. These model results were compared with results from computing runoff retention requirements using the normalized curves in Figure 4. Figure 5 presents this comparison.

As Figure 5 shows, using the normalized curves from Figure 4 results in similar required storage volumes as explicitly modeling the individual subcatchment. The variations in results between the two computation methods appear relatively consistent for each roof configuration type. This variation may be due to the fact that the normalized method uses results from an analysis of the entire Concord-Alewife catchment area, and these results are being compared with an analysis of just one single sub-basin within this catchment area. Assuming that the single subcatchment used in this analysis is a representative sample of the entire study area, scale factors could be developed to account for the variation. For example, for the conventional roof configuration and zero pavement area reduction, the scale factor can be computed as 0.95/0.77 = 1.23. An average for all conventional roof scenarios results in a scale factor of 1.19. Using a similar methodology, average scale factors for Type 1 and Type 2 green roof configurations were computed as 1.12 and 1.00. The average scale factor for Type 2 green roof configurations amounted to slightly less than one; therefore, to be conservative a factor of 1.0 was chosen. If the normalized approach is used to compute runoff reduction requirements for a given parcel with conventional roof types, then the computed volume difference can be multiplied by 1.19 to account for the average variation between using the normalized approach and the explicit hydrologic/hydraulic modeling approach. Figure 6 illustrates a revised version of Figure 4, after scaling factors have been applied to the normalized plot. This plot is recommended to be used for the computation of runoff reduction requirements.

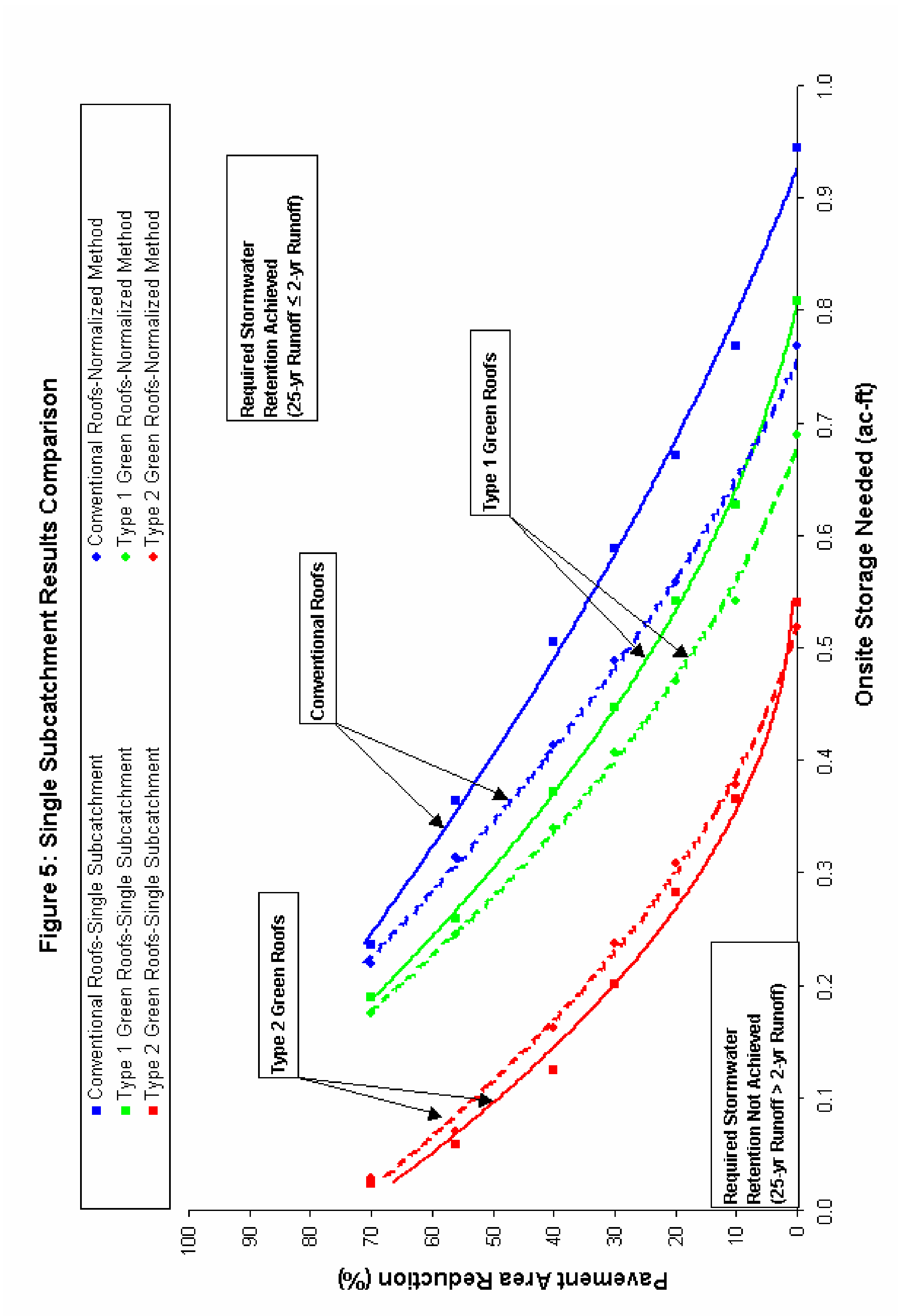
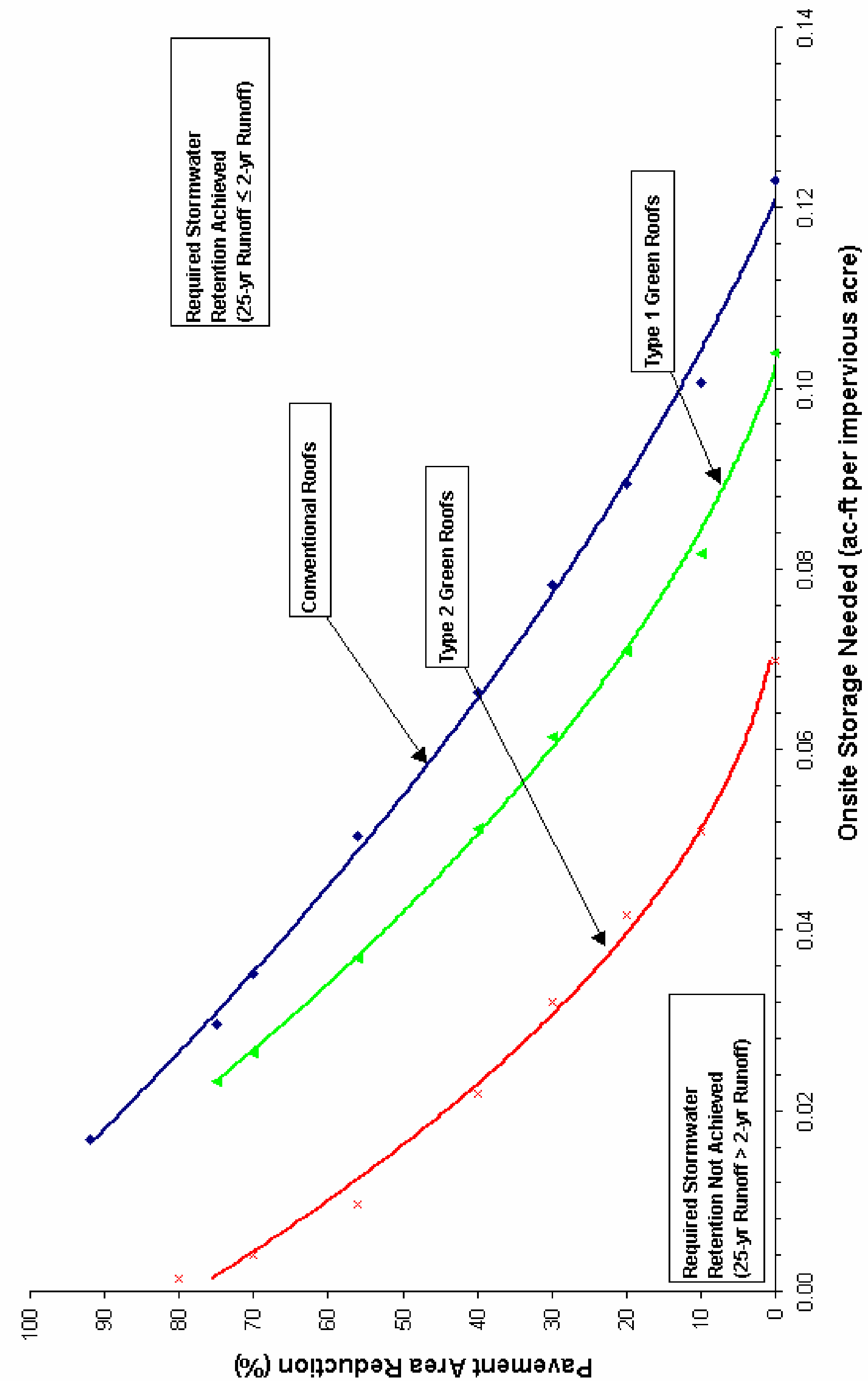


Figure 5: Single Subcatchment Results Comparison
Conventional Roofs-Single Subcatchment
Type 1 Green Roofs-Single Subcatchment
Type 2 Green Roofs-Single Subcatchment
Conventional Roofs-Normalized Method
Type 1 Green Roofs-Normalized Method
Type 2 Green Roofs-Normalized Method
Required Stormwater Retention Achieved (25-yr Runoff ≤ 2-yr Runoff)
Type 1 Green Roofs
Conventional Roofs
Type 2 Green Roofs
Required Stormwater Retention Not Achieved (25-yr Runoff > 2-yr Runoff)
Pavement Area Reduction (%)
Onsite Storage Needed (ac-ft)
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Figure 6: Private Development Requirements (Normalized and Scaled)



Example Computation with Normalized Curve Approach:

Assume a 2.0-acre parcel is to be developed in the Concord-Alewife area. This parcel has 1.8 acres of impervious surface (1.0 ac pavement + 0.8 ac roofs) and green roof Type 2 technology has been chosen as part of the solution to satisfy the 2y-25y runoff reduction requirement. First, the parcel must satisfy open space and pervious surface zoning requirements. According to these requirements, 25% of the parcel must have pervious surface, and 15% must be open space (half of the open space can be impervious surface and half can be pervious). Therefore, for this parcel, the 1.8 acres of impervious surface must be at least reduced to 1.5 acres, leaving 0.5 acres, or 25% (i.e. 0.5 ac/2.0 ac), pervious. It is assumed for this example that the pervious area also counts as open space, and therefore satisfies both the open space requirement *and* the pervious surface requirement. It is also assumed for this example that the 0.3 acres of impervious area reduction included only pavement area.

Reducing the pavement area of the parcel 0.3 acres (e.g. from 1.0 ac to 0.7 ac) is equivalent to a 30% (1.0-0.7 / 1.0) reduction. The developer has now satisfied both open space and perviousness requirements. The red curve in Figure 4-2 corresponding to Type 2 green roofs shows that for a pavement reduction of 30%, approximately 0.031 ac-ft per impervious acre would be the required onsite storage to meet the 2y-25y runoff retention requirement.

Therefore, the actual required onsite storage for this parcel is computed by:

(Onsite storage per impervious acre from Figure 6) x (Number of pre-development impervious acres in the parcel)
= (0.031 ac-ft / imp. acre) x (1.8 acres) = 0.056 ac-ft, or approximately 18,246 gallons

Thus, for this example, the developer has satisfied open space and pervious surface zoning requirements AND satisfied the 2y-25y runoff retention requirement, by doing the following:

- Converting the roof area in the parcel to Type 2 green roofs;
- Converting 0.3 acres of pavement surface area to pervious surface; and
- Providing 18,246 gallons of onsite storage.

The onsite storage could be implemented in a variety of ways depending on the location and other environmental factors, including shallow swales, ponds and underground tanks. However, the storage volume required for this example assumes that the configuration of the storage device is such that the total volume of runoff generated between the 2-year storm PEAK discharge and the 25-year storm is retained. In order to size the storage device at a volume of 18,246 gallons while satisfying this condition, the device would have to incorporate a control feature such as an inlet weir or an outlet throttle that would allow the storage volume to be utilized at the proper time during the storm event. Figures 7 and 8 show two graphical examples of actual required storage volume that satisfies the

2y-25y runoff retention requirement. Figure 7 shows the hypothetical quantity of storage required for a device that is not configured to capture runoff during a specific time during the storm event. Figure 8 shows the hypothetical storage volume that is required for a device that successfully incorporates controls that allow for proper timing of storage utilization.

It should be noted that the developer could have also satisfied the 2y-25y runoff retention requirement by converting more pavement area to pervious surface, requiring less onsite storage. For example, if the developer had chosen to convert 50% of the pavement area to pervious area (instead of the 30%), then the onsite storage requirement would have been only 0.017 ac-ft, or 5,539 gallons. Several combinations of roof type, pavement area reductions, and onsite storage can achieve the same runoff retention goal.

Figure A3.7: Storage Requirement For a Device With No Controls Incorporated

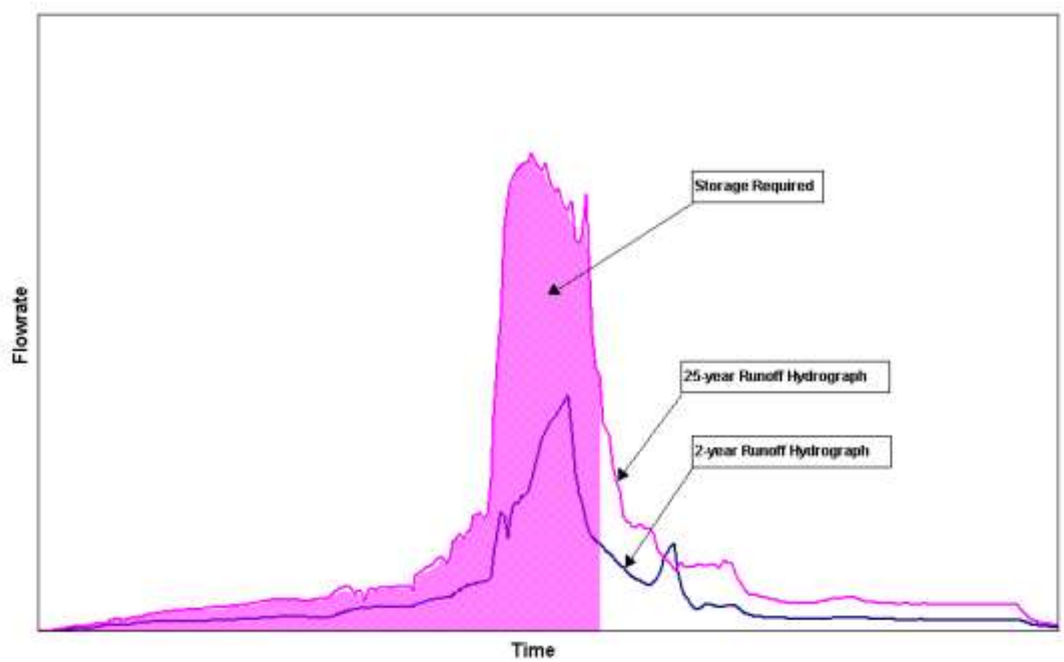
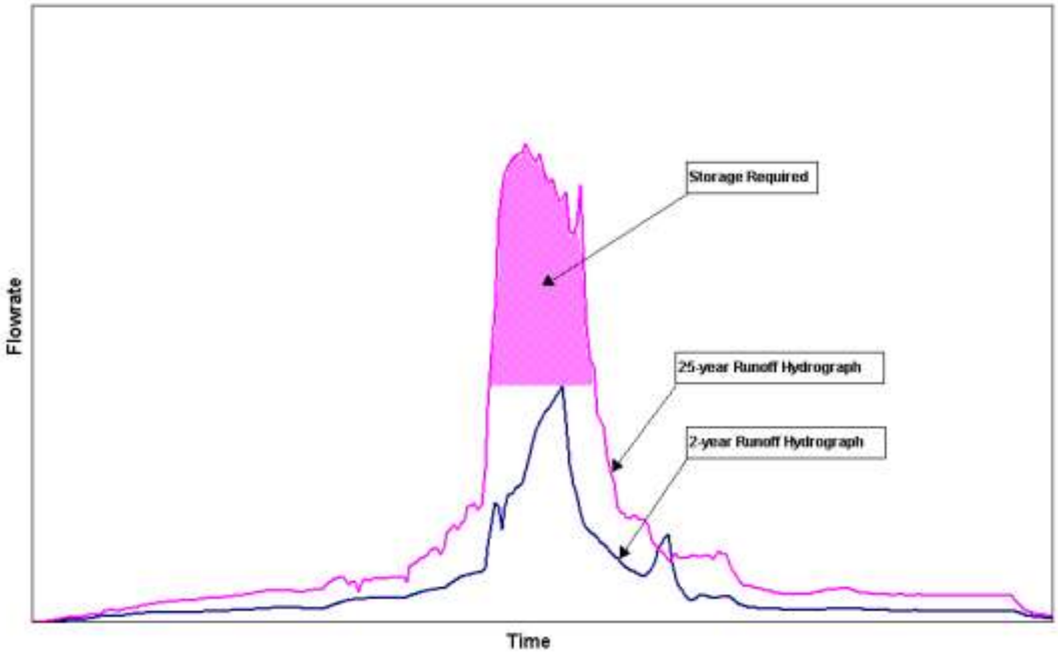


Figure A3.8: Storage Requirement For a Device With Adequate Controls Incorporated



Conclusions

It is recommended to use the normalized method for computing private development runoff retention requirements in the Concord-Alewife area. Using a hydrologic/hydraulic model to compute runoff retention requirements each time a development is proposed would be cost-prohibitive. The simplified method of using normalized values allows for a timely and reasonable computation of a potential developer's alternatives for achieving 2y-25y runoff retention goals.

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