2003

Stormwater Management in Cold Climates – A Historical Perspective

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SUMMARY

Stormwater management has evolved tremendously in sophistication and complexity over the last 25 years. Stormwater is now often managed as a resource rather than an enemy, requiring groundwater recharge as one component of an interconnected system of collection, treatment, infiltration, and detention systems. Management of stormwater in cold climates requires consideration of widely variable soil permeability and groundwater levels over the course of a year. This paper traces some of the evolutionary changes in stormwater management philosophy, and examines a case history illustrating problems that can arise from inadequate stormwater control within a subdivision.

STORMWATER REGULATORY OVERVIEW

Stormwater regulations in New England generally apply to residential, commercial and industrial projects that disturb even limited amounts of soil. Although the United States Environmental Protection Agency has regulations in place that regulate stormwater discharge for most projects, there is limited enforcement of the rules. Large projects may require State approvals, but in the majority of cases, stormwater management is primarily left to local control.

Most residential construction in New England takes the form of individual lot or subdivision development. Design is generally under the control of the local planning board, with involvement by the Conservation Commission, Zoning Board of Appeals, and Board of Health. Due perhaps to historical considerations, the boards generally hold independent hearings, often with little or no coordination, and may impose contradictory requirements on the developer. The fragmentation of authority, independent, complex and sometimes contradictory rules, differing viewpoints of the boards, and overlap of jurisdiction often leads to delay, higher costs, and overall frustration on the part of developers.

Regulations controlling stormwater illustrate in a nutshell the myriad of issues faced by developers when working with local regulatory boards. The situation in Massachusetts is a case in point. Local stormwater rules are generally developed by the Planning Board, but many Towns have rules enforced by the Board of Health, the Conservation Commission, or occasionally the Zoning Board of Appeals. The State of Massachusetts Department of Environmental Protection has adopted a policy on Best Management

Practices for stormwater control, but local government may adopt stricter regulations, or may ignore State guidelines if they adopt local rules.

Stormwater management regulations have generally become more restrictive over the past 25 years. The standards of practice have generally moved in the following sequence:

- 1960's: Very loose stormwater management practices. Limited or non-existent water quality practices. Stormwater controls generally included catch basins and manholes, possibly curb and gutter, and occasionally detention basins. The major goal was to move stormwater rapidly off developed lots to prevent local flooding, with limited consideration of downstream effects. Typically, subdivisions were constructed with no infiltrating structures, few if any detention structures, and no water quality practices.
- 1970's: Recognition of the potentially devastating impact of flooding caused by increase in impervious area became widespread. Stormwater management criteria evolved to include the requirement of maintaining the peak rate of runoff post-development at or below the peak rate of runoff pre-development for a specified storm event, often the 25 year storm. Subdivisions were often designed to include one or more detention basins, which acted to increase the time of concentration of the watershed. Very little attention was paid to pollution mitigation or groundwater recharge. Development of individual lots not within a subdivision remained essentially uncontrolled.
- 1980's: Stormwater policies evolved to incorporate water quality practices. Typical practices included water quality swales, two stage detention basins, artificial wetlands, deep sump catch basins, and turbidity control structures. Limited attention was paid to infiltration. Regulations generally applied to subdivisions, not to individual lot development.
- 2000's: Water quality practices are becoming more sophisticated. Infiltration of stormwater is becoming a common practice, requiring that detention ponds be evaluated for infiltration capability. Detention ponds are becoming larger, and require long term maintenance plans for operation. Stormwater management regulations often incorporate regulations limiting the volume and rate of runoff. These regulations make stormwater management much more complex, sometimes requiring use of sophisticated groundwater modeling programs to evaluate groundwater mounding and infiltration rates. Individual lots still have very limited control, exemptions for agricultural practices are widespread, and enforcement of rules varies widely from one location to another. Note that many New England towns still operate under the 1960's management model.

Cold weather issues are particularly important in New England, which is well known for having four distinct seasons, including often long and harsh winters. Cold weather stormwater management issues include:

1. Soil stabilization using vegetation is limited to the growing season, which may be as short as May 1 to October 1 in northern areas. If work proceeds out of season, expensive stabilization using fabric may be necessary.

2. Spring generally produces the most difficult conditions, including high groundwater levels, maximum streamflow, and saturated soils. Stormwater control during Spring runoff generally places maximum stress on the system.
3. Design of infiltration practices must recognize the substantial variation in soil percolation rates during the year. Soils which may be quite permeable in the summer may exhibit near zero permeability when saturated in the Spring, when maximum infiltration is necessary.
4. Frost depths up to 5 feet are possible, which can radically alter the properties of soils with respect to runoff potential, slope stability, and percolation rates. Designers must account for the unfortunate fact that stormwater systems need to function effectively 12 months out of the year, under very different weather and soil conditions.

STANDARDS OF APPROVAL

There are three common flow standards applied to stormwater management in New England. The most common standard dates to the early 1960's, and requires that post-development peak runoff be limited to pre-development peak runoff. The justification for this regulation is to limit downstream flooding from the project. Some jurisdictions allow a small increase in peak runoff (typically specified as a percent of pre-development peak flow). Many jurisdictions require that this test be applied to the entire boundary of the project, thereby preventing a project from reallocating flow from one part of a watershed to another.

Development inevitably increases peak flow both by increasing the runoff curve number and by reducing the time of concentration of the watershed. The most common technique for reducing peak flow post-development is to include one or more detention ponds within the development. The detention ponds increase the time of concentration of the watershed, and reduce peak outflow by storing a portion of the flow as live storage in the pond. Detention ponds may be designed to infiltrate a portion of the inflow (sometimes called retention ponds), or they may be treated as essentially impermeable basins.

Dry ponds are designed to drain within a relatively short period of time, often specified by rule. Some towns require that storms up to a certain frequency, commonly 25 years, drain within 24 hours, whereas the 100-year storm may be allowed to drain over a longer period, often 72 hours. Wet ponds are designed to retain water year round, and are often designed as artificially created wetlands.

Until recently, detention ponds were rarely designed to infiltrate stormwater. Infiltration greatly increases the complexity of analyzing the hydrology of the project, and raises a variety of difficult design and maintenance issues. Early detention ponds also were typically designed without a forebay, making them vulnerable to siltation, clogging of the outlet works, and overtopping. More recently designed detention ponds may incorporate stone lined inlet channels to reduce pollutant loading, fine particle traps such as deep sump catch basins or stormwater particle traps, and often incorporate a hard bottom forebay to allow for easy removal of accumulated silt and debris.

A number of towns in New England have recognized that a non-infiltrating detention pond simply extends the time base of the runoff hydrograph, resulting in reduced peak flow, but allowing for increased volume of runoff. For various reasons (some poorly understood even by those who adopted the rules), a number of towns have passed regulations seeking to limit the total volume of runoff, as well as the peak flow. In practice, the only realistic way to limit the volume of runoff is to infiltrate a portion of the flow, therefore many projects now incorporate one or more infiltration structures into the design.

Calculation of Infiltration

The rate of groundwater infiltration depends on a variety of factors, several of which are very difficult to estimate:

1. **Permeability of the soil**: May be estimated using percolation tests, in-situ borehole tests, or grain size analysis. The most accurate methods rely on slug testing of monitoring wells, using either a rising head or falling head test.
2. **Groundwater table**: Infiltration rates typically decrease as the groundwater table rises, due to reduced permeability of the soil as it becomes fully saturated, and reduced hydraulic gradient. Estimating the seasonal high groundwater level may be done using soil mottling or groundwater monitoring wells. Analysis of exfiltration from ponds generally assumes a groundwater level at seasonally high level, and may incorporate groundwater mounding analysis to compute exfiltration over time.
3. **Detention basin geometry**: The size and shape of the basin greatly influence groundwater infiltration. Square basins infiltrate better than long, narrow basins. The depth below grade of the bottom of basin is often critical. The size, shape and depth of the basin are often dictated by site constraints.
4. **Stormwater hydrograph**: Generally developed using SCS TR-55 or TR-20 methodology. Calculation of drain time for the pond depends on the design hydrograph, combined with the basin geometry and estimated soil percolation rate.

Infiltration may be estimated using a two or three-dimensional groundwater modeling program such as MODFLOW or MODRET. Estimating infiltration by multiplying the area of the detention basin by the percolation rate (the *simplified* approach) will generally greatly overestimate infiltration, and is generally an unreliable technique. Errors with this method include failure to account for unsaturated versus saturated hydraulic conductivity, changes in the hydraulic gradient as groundwater mounding develops, and the difference between horizontal and vertical hydraulic conductivity.

CASE HISTORY

The following case history involves a forensic examination of the failure of a stormwater management system at the Cote d'Or subdivision in Bedford, New Hampshire. Flooding and siltation of the existing Whippoorwill Lane subdivision located downgradient of Cote d'Or, and constructed some 40 years ago, resulted from an unfortunate combination of wet weather, inadequate design, and poor construction practices.

Cote d'Or Subdivision

The Cote d'Or subdivision is a 42 lot, upscale subdivision off McAllister Road in Bedford, New Hampshire. Design began in 1999, and construction of the roads got underway in 2001. The subdivision covers approximately 105 acres, with lot size ranging from approximately 2 acres up to a maximum of almost 5 acres. The subdivision is constructed over two drumlins, and includes natural slopes up to approximately 35 degrees.

The subdivision is part of a watershed of approximately 550 acres that drains through Whippoorwill Lane, an older subdivision located about 120 feet lower in elevation than the majority of Cote d'Or (see Figure 1). All but 5 acres of Cote d'Or drains through the Whippoorwill Lane neighborhood before draining into Bowman Brook shortly after passing through a dammed pond used as a fire suppression water supply by the Town.

The soils in the subdivision include silty loams at the tops of the hills, which typically have high groundwater tables and have low hydraulic conductivity. The majority of soils within the subdivision are hydrologic group B and C, with a few pockets of group D soils in lower lying areas, and several wetlands between the drumlins. Prior to development of the subdivision, the land was heavily wooded, including a mix of deciduous and coniferous trees. The pre-development runoff curve number for most of the developed area is estimated to be between 65 and 70.

Hydrologic Analysis

The hydrologic analysis of the proposed subdivision included several key assumptions that were not realized in practice:

1. The estimated impermeable area per lot (exclusive of the public road system) was assumed to be approximately 4,000 square feet. Due to the large size of the majority of houses, the actual impermeable area per lot appears to be between 6,000 and 8,000 square feet.
2. The design assumed that substantial storage would be realized from ponding upstream of several culvert crossings of the main access road. Due to a variety of factors, some of the culverts appear to have been installed lower than anticipated, and very little storage has actually been realized. No detention ponds or other artificially created stormwater storage basins are called for in the plan.
3. The design plans call for a maximum of 2 acres of disturbed earth at any given time within the subdivision. Unfortunately, there are no local procedures in place to enforce this restriction, and up to 15 acres of disturbed soil have been present during maximum buildout periods.

The summer of 2003 was significantly wetter than usual, including two short but intense storms in August. The storm of August 4, 2003 created flooding conditions at Whippoorwill Lane, including deposition of significant amounts of silt on the main subdivision road. Damage to septic systems, wells, basements, the fire pond, and the road itself resulted (see Figure 3). Flooding of this sort has apparently not been experienced in the close to 50 year history of Whippoorwill Lane, and occurred as a result of a storm estimated to have been less than 2 inches of rain in one hour.

During the ensuing investigation into the causes of the flooding, several factors became apparent:

1. The lots immediately uphill of Whippoorwill Lane had been severely disturbed, with minimal installation of silt fencing and haybales to retard flood flow and soil erosion (see Figure 4). The result was migration of large amounts of silt from the top of the hill to the bottom, directly onto Whippoorwill Lane.
2. The estimate of 4,000 square feet of impervious surface per lot significantly underestimated the actual development. The effect was to underestimate the average runoff curve number, leading to an underestimate of storm flows.
3. Due to a variety of complications, several of the culverts that were intended to provide storage were apparently installed below design grade, leading to a reduction of flow storage to near zero within the subdivision.
4. The subdivision proved to be very popular, and multiple contractors have been building large houses simultaneously (see Figure 5). The result has been extensive soil disturbance occurring over as many as 15 lots simultaneously, leading to exposure of more acres of soil than anticipated in the erosion control plan. Erosion control measures have generally been ineffective and weakly enforced.
5. Town regulations do not require preparation of individual lot grading plans. The result was that the steepest lots on Burgundy Terrace were stripped with no final grading plan in place, and no detention structures planned.

Recommended Solutions

The subdivision roads have been substantially completed, and most of the houses have either been constructed or are under construction. Because the subdivision has been approved by the Town, it is not feasible to undertake extensive redesign of the roadway system or lot layout. Options for reducing stormwater flow and siltation have therefore concentrated on management techniques and structural measures that can be implemented without regrading existing roadways or changing lot lines.

The remediation efforts to date have concentrated on flood flow reduction and erosion control. There is a parallel effort underway to analyze current Town regulations to see if strengthened regulations are necessary to prevent future damage from new subdivisions as the Town continues to develop.

Flood Control

We identified the need for additional artificially created detention storage on site. Three lots immediately uphill from Whippoorwill Lane along Burgundy Terrace have been identified as significant contributors of siltation and stormwater to Whippoorwill Lane, and we have proposed installation of two detention ponds and a series of stone lined channels to transport stormwater to the ponds. Construction of the ponds is challenging because the only area available within the lots is at the bottom of a hill currently graded to a nearly 1:1 slope. This limits the available area, and requires careful design of feeder channels to minimize the transport of silt that might otherwise fill the basin and reduce its effectiveness.

Construction of the basins during the winter season is potentially difficult, due to the impossibility of establishing vegetative cover between the end of October and early April. We have considered use of geotextile fabric to stabilize otherwise erosion prone soils.

Temporary Erosion Control

Poor erosion control practices during construction were a significant issue for this project. Temporary erosion control is often seen as an unnecessary expense by site contractors, who may hope that dry weather eliminates the need for extensive protective measures. Unfortunately, the wet summer of 2003 included a series of intense storms that carried silt and debris downhill to Whippoorwill Lane, leading to resident complaints (see Figure 6).

The Town of Bedford has no special regulations covering temporary erosion control during construction, and generally relies upon State and Federal regulation to minimize problems. Due to limited resources, there was little or no federal or state oversight on this project, and common erosion control techniques such as installation of haybales and silt fencing, excavation of temporary detention ponds, and use of erosion control fabric were not effectively utilized. Ultimately, the Town issued a cease and desist order on several lots preventing further construction, and arranged for hydroseeding of bare slopes along Burgundy Terrace prior to the end of the growing season (early October).

Lessons Learned

The flooding and erosion problems at Cote d'Or were entirely avoidable, and point to several important lessons.

1. Hydrologic assumptions need to be updated and validated during construction. The construction of very large houses, and the consequent development of more impervious area than anticipated, required adjustments in the design that unfortunately never occurred.
2. Installation of culverts and other structures must be carefully monitored to insure compliance with design intent. At least one culvert was apparently deliberately lowered during construction, without consideration of the probable impact of the field modification on the stormwater design. In my experience, field modification of design plans is common, and often occurs without careful analysis of the impact of the changes on design intent.
3. The stormwater design was based on the assumption that significant storage would occur upstream of several culvert crossings. It appears that little or no storage was in fact realized, due to a variety of factors. Design of the culvert crossings with upstream flow control structures would have allowed for tuning of the system to maximize storage. Relatively simple structures such as manholes equipped with stoplog weirs and low flow bypass weirs (split flow structures) would have allowed bypass of low flows, while storing water during storm events.
4. No infiltration systems were designed for this project. Much of the soil is hydrologic class B, therefore infiltration likely could have been implemented. Town regulations require that post-development peak flow must not exceed pre-

development peak flow, however there are no volumetric or recharge requirements.

5. Erosion control during construction must be vigorously enforced, or it is unlikely to be a contractor priority. Individual lot grading is the most probable source of sedimentation, yet individual lots are often not inspected as part of overall subdivision construction (often only the roads are subject to engineering inspection). Towns should consider extending field monitoring to individual lots.
6. Flooding and sedimentation are most likely during construction, when soils are exposed. Therefore, it makes sense to enforce limitations on the total amount of soil that can be exposed at one time. This may require limitations on the number of lots that can be constructed simultaneously, the amount of soil per lot that can be disturbed, or may require use of mechanical stabilization techniques during construction. Unfortunately, most Towns appear to carefully control road construction, while paying limited attention to lot construction, where numerous small contractors may be involved in building. Towns may need to require that the subdivision contractor develop a comprehensive erosion control plan for the subdivision, that individual contractors are required to adhere to when they build out individual lots.

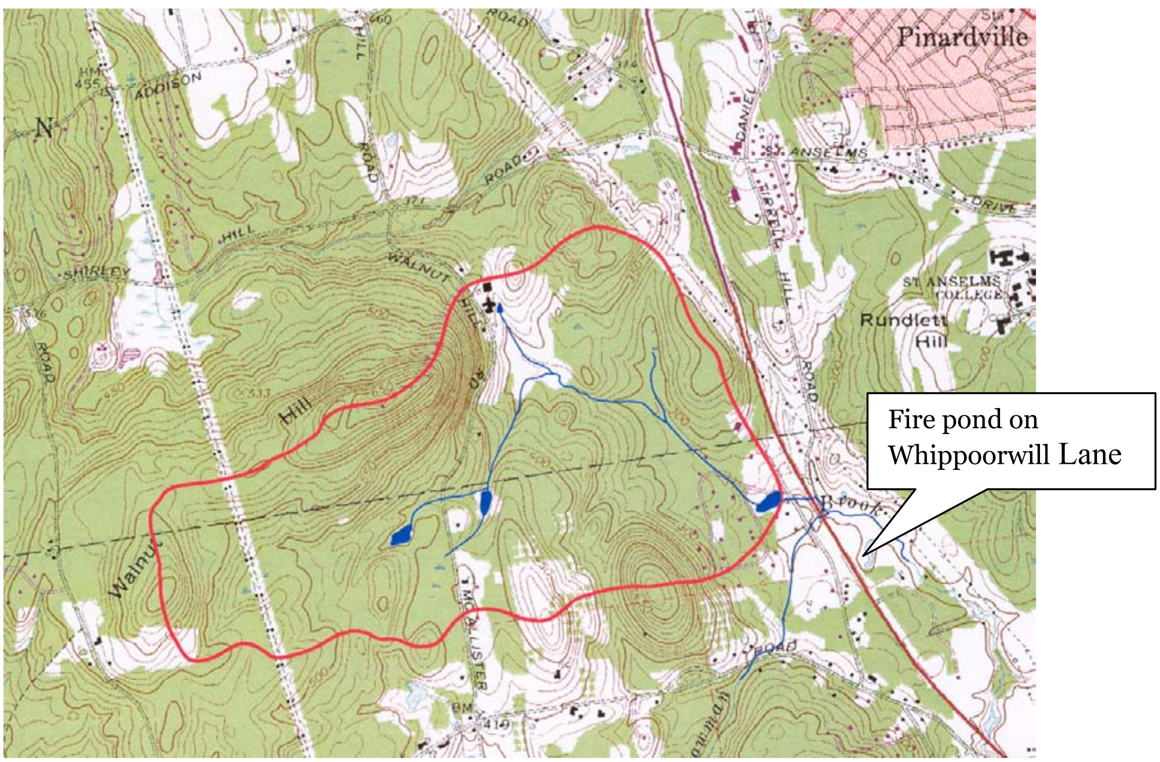

Figure 1: Whippoorwill Lane drainage area

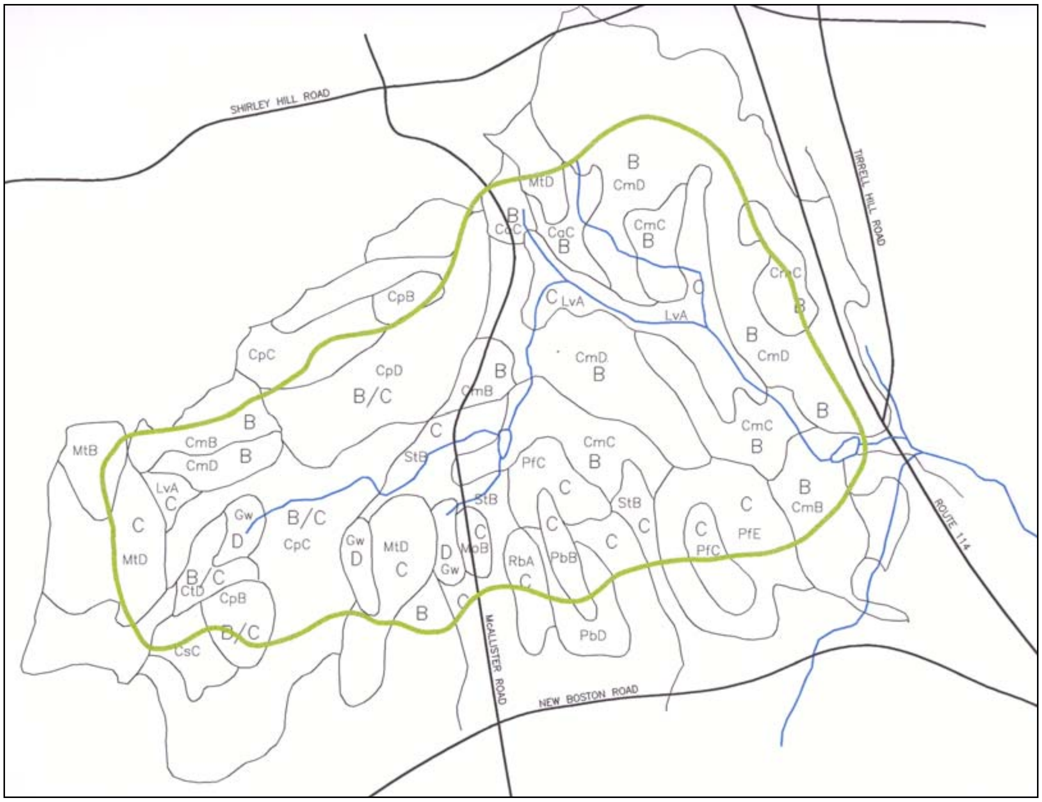

Figure 2: Cote d'Or soil types

Figure 3: Flooding across Whippoorwill Lane August 2003

Figure 4: Disturbed soil off Burgundy Terrace. This photo was take after hydroseeding

Figure 5: House with 8000 square feet impervious area on Burgundy Terrace

Figure 6: Erosion gulley in poorly stabilized soil