STORMWATER RECOVERY FOR COMMERCIAL & INDUSTRIAL REUSE

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Stormwater recovery, also commonly known as rainwater harvesting has been practiced since ancient times and is enjoying somewhat of a revival due to the potential to reduce consumption of treated water, costs and the perception of sustainable green operations. For commercial and industrial properties, the recovery of stormwater represents a largely untapped, low cost, green sustainable resource.

Stormwater recovery has broad application for the following facilities:

- HVAC cooling water and cooling towers
- Industrial process water
- Boiler feedwater
- Powerplant cooling and process water
- High purity water applications
- Irrigation and landscape water
- Potable water potential

Forecasting the potential stormwater recovery for larger sites with significant water demands requires accurate predictive simulation models that rely upon historical precipitation and climatic data.

This paper presents the criteria needed to evaluate the potential recovery from sites, water quality issues and costs.

Estimating Runoff Volumes

Representative stormwater design methods (such as USDA, NRCS, SCS, rational methods) for estimating runoff are applicable for large scale storm events and do not correlate well with micro storm events [Pitt, 1999] which invariably constitute over 90% of the annual average rainfall depths [Guo, Youseff]. Traditional methods significantly under-estimate the runoff from micro storm events. Pitt [1999] investigated and developed micro or small storm hydrology for various types of impervious areas and clayey or sandy soils and demonstrated that the runoff coefficient, Rv is variable and dependent upon rainfall depth. This is in contrast to the Curve Number, CN (NRCS) approach in which the CN remains constant and independent of rainfall depth. Based on Pitt's work, regression equations were developed to provide analytical solutions of the runoff coefficient Rv (a ratio of runoff to precipitation event depth). These regression equations for various impervious surfaces and soils and a representative curve are presented in Figure 1.

The methodology used in this paper was based on utilizing Pitt's small storm hydrology for storm events up to and including 2 inches in depth and the NRCS method for events greater than 2 inches in depth. This method is based on daily simulation modeling to estimate stormwater runoff using historical daily precipitation records, calculated Runoff Coefficients (Rv) and adjusted curve numbers to predict daily runoff over an extended 30 to 40 year period. Since runoff from lower intensity precipitation events is more accurately predicted by Pitt's procedure, this methodology would more accurately reflect runoff than the standard traditional method used for higher intensity synthetic rainfall events. (Above two inch rainfall depths there was good correlation of the NRCS CN method with actual runoff data.)

Runoff for storm events greater than 2 inches is estimated using the NRCS Runoff Equation (USDA, 1986):

$Q = (P - Ia)2 / ((P – Ia) + S)$

Where, Q = daily 24 hour runoff (in)

P = daily 24 hour rainfall (in)

S = potential maximum retention after runoff = 1000/CN -10

Ia = initial abstraction (in) = 0.2S

CN = Curve Number – soil and cover conditions

Substituting Ia = 0.2S into Eq [1] yields: $Q = (P – 0.2S)2 / (P + 0.8S)$

Standard CN is then adjusted to reflect the actual moisture level in the ground due to rainfall of the preceding days (Antecedent Moisture Conditions – AMC). A different CN is assigned under standard, dry and wet conditions, which is obtained from the Antecedent Moisture Condition (AMC) Adjustment Table (National Engineering Handbook):

If the summation of precipitation (rainfall) of the preceding five days is less than Ia/2 of that day, a CN dry condition is used; otherwise if daily precipitation exceeds Ia of that day, a CN wet condition is employed; if less than Ia, the CN standard is used.

The adjusted CN is then used to find S, and substituted into Eq. [2] to obtain an estimate of daily runoff in inches. The daily runoff is estimated by multiplying the runoff for the tributary watershed area to provide volumetric runoff in cubic feet.

The runoff procedure is estimated based on these significant factors:

- Daily rainfall from NOAA, State or University databases
- Rv, runoff coefficient derived from Pitt's data
- Soil type: clayey, sandy; Hydrologic Group Soils
- Type of impervious area: roofs, roads, parking lots
- Curve Number, which indicates the soil and cover condition
- Surface area of watershed
- Evaporation from the detention pond surface
- Available Pond Storage and potential overflows

Figure 2 illustrates the runoff simulation modeling process which is accomplished utilizing spreadsheets developed from NRCS equations and Pitt's methodology.

A detention storage pond is considered to be essential for storing of accumulated runoff for large sites. Evaporation of pond water is considered in the analysis, which varies seasonally. During most of the spring and winter seasons (December to February), evaporation is considered negligible due to low ambient temperatures. To account for the pond water evaporated, historical daily pan evaporation records in inches is obtained from available state and federal data sources.

Once an individual site's watershed boundary is established with the watershed attributes identified, the model is constructed incorporating climatic data and equations for runoff, evaporation and pond storage. Each year is modeled to generate a Runoff Mass Diagram as presented in Figure 3. This figure presents the cumulative runoff fro the site's watershed over a one year period. The actual recovery rate is shown with a dashed line and this is limited by the maximum Makeup Water Demand (MWD), (Segment 5).

The cumulative runoff (solid line) includes losses due to evaporation based on an existing or assumed pond surface area. [Many sites have existing stormwater detention ponds which were designed for attenuation of peak storm events. These ponds can be employed as recovery ponds while still maintaining their attenuation functionality].

Detention Pond Volume Requirements

By examination of Figure 3, comparing the vertical scaled distance between the maximum MWD and the cumulative runoff, an estimation of the pond volume capacity can be determined. This capacity would be sufficient to prevent loss of accumulated runoff. Each year is examined to determine a pond capacity. A sensitivity analysis is run, as presented in Figure 8, to assess runoff recovery % as a function of pond capacity. The cost benefit of additional pond capacity would then be weighed in terms of additional water savings versus additional pond construction and operation costs.

Pond water overflow creates a minor loss of the total amount of stormwater recovered. The overflow quantity is controlled mainly by the following three factors:

- Runoff quantity – controlled by precipitation
- Available pond storage volume
- Withdrawal rate – limited by the MWD

Pond water overflow is estimated quantitatively in the spreadsheet.

Water Demands

The water demand for recovered stormwater is dependent on the type of facility and process requirements. For an industrial facility with a cooling water demand capacity due to cooling towers, the respective Makeup Water Demand for recovered stormwater would be based on the cycles of concentration as follows.

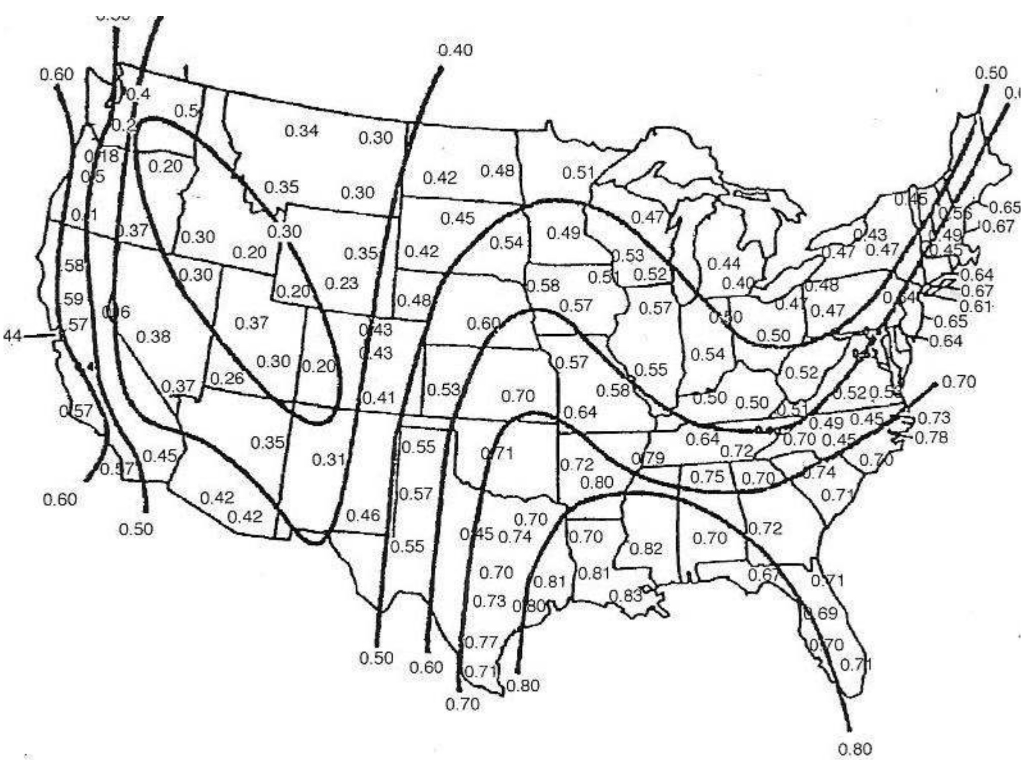
	4 Cycles	**7 Cycles**
10 MW		
- GPM, GPD	91.4, 131,600	80.00, 115,200
40 MW		
- GPM, GPD	365.6, 524,464	320.0, 460,800
100 MW		
- GPM, MGD	914, 1.32	800, 1.15

Simplified Method of Runoff Estimation

A simplified method of estimating runoff for recovery purposes has been developed by GEA based on use of Pitt's method and investigations of rainfall event-depth distributions for various meteorological zones in the U.S. as described by a probability exponential function as follows [Wanielista and Yousef, 1993, Guo and Hughes, 2001]: $P_D = 1 - e^{Po/Pm}$

Where: P_D = Probability, cum; Po = Precipitation depth Pm = Average rainfall-depth

Using the following average event-rainfall depth map of the U.S., Pm can be estimated for a specific site.



Average event-rainfall depths for the United States. (EPA, 1986)

Incorporating the discrete probabilities for each rainfall event depth into a spreadsheet and then calculating the Runoff Coefficient (Rv) based on Pitt's Method, an average annual runoff can be estimated as illustrated in the abbreviated spreadsheet example calculation below:

RAINFALL EVENT-DEPTHS PROBABILITIES

P = 1-e^-Po/Pm

Po = Precip depth   P= Non-exceedance probability

Pm = avg rainfall event depth   100-P =PROBABILITY OF OCCURRENCE

Pm= 0.6

Pann= 44 inches

					% Imp, Clay Soil		20% Impervious, Clay Soils			
P	Po	Po/Pm	100-P	Pctg	Rv	^Ro	0.100	0.050	0.050	0.800
0	0	0	100		-0.052	0.000	-0.127	0.000	0.000	0.000
0.154	0.1	0.167	84.65	15.35	0.028	0.000	0.247	0.956	0.462	0.002
0.283	0.2	0.333	71.65	13.00	0.081	0.002	0.518	0.961	0.548	0.005
0.393	0.3	0.500	60.65	11.00	0.118	0.004	0.655	0.963	0.585	0.008
0.487	0.4	0.667	51.34	9.311	0.145	0.005	0.728	0.964	0.609	0.010
0.987	2.6	4.333	1.312	0.238	0.261	0.002	0.889	0.991	0.955	0.002
0.989	2.7	4.500	1.111	0.201	0.261	0.001	0.890	0.992	0.976	0.002
0.991	2.8	4.667	0.94	0.171	0.261	0.001	0.890	0.994	0.994	0.002
0.992	2.9	4.833	0.796	0.144	0.261	0.001	0.891	0.995	0.995	0.002
0.993	3.0	5.000	0.674	0.122	0.261	0.001	0.891	0.996	0.996	0.001
				99.33						
		Avg. RO per event depth				0.1277				0.2054
		Ratio RO/Avg. Ev-depth				0.2129				0.3423
		Avg. annual Runoff				9.3683				15.059

Utilizing this simplified method, predictions of annual runoff recovery were developed for two different areas: NY – Figure 6 and Denver – Figure 7, based on various percentages for % Impervious Cover and soil types – clayey and sandy soils. As shown in Figure 6 for NY, with a 40% Impervious Cover, an estimated 438,000 to 563,000 gallons per acre can be recovered. For the Denver area, the recovery would range from 153,000 to 198,000 gallons per acre. Losses due to evaporation and overflows would have to be accounted for and deducted from these estimates using methods described previously in this paper.

Stormwater Quality and Treatment

Rainwater contains negligible hardness, Total Dissolved Solids(TDS), has a near neutral pH and is free from minerals, salts and man-made contaminants. Once rainwater contacts the ground surface it picks up sediment, minerals, organic substances and other contaminants. In studies GEA has conducted at eight sites around the country, runoff from sites with impervious areas constituting over 65% of the surface area have had the following constituents: TDS <60 mg/L; Hardness <20 mg/L; TSS <5 to <80 mg/L. As the percentage of pervious area increases in the runoff collection system, TDS, TSS and Hardness increases and in areas with clayey soils, the amount of colloidal material increases significantly. Levels of TSS and TDS have been detected at >200 mg/L and > 600 mg/L respectively at some sites.

Since the Water Quality requirements for most cooling applications including Cooling Towers necessitates that TDS = <1800mg/L; Hardness=<100mg/L and TSS =< 5mg/L – water treatment to remove TSS and colloidal matter becomes a necessity.

Figure 4 presents a Process Treatment Schematic that illustrates the treatment process we have employed at facilities to treat stormwater. Results have been fairly consistent with water quality (after treatment) as follows: TSS= <2 mg/L; TDS <40 to <200 mg/L. Chemical treatment has consisted of the following regimesdepending upon raw water quality: - Anionic Polymer with or without: Alum or PAC.
Jar Testing and Settling Tests were initially conducted to establish chemical treatment requirements. Flash mix and slow speed mixing followed by tube settlers were utilized to provide the treatment along with a 5 micron multichamber filter as safeguard.

Figure 5 illustrates a Stormwater Collection and Treatment System for a facility in the Mid-central States. Submersible pumps and pipelines were installed to convey the stormwater from Collection ponds to the Stormwater Treatment System.

Stormwater Costs

Construction costs from eight facilities –which included the treatment system, pond modifications, pipelines, pump stations, new pond construction, electrical and misc. work –ranged in cost from \$0.24 to \$1.19 per 1000 gals, with a median of \$0.76 per 1000 gals. Operating and maintenance costs for the pump stations, treatment systems, and ponds ranged from \$0.36 to \$0.95 per 1000 gals. with a median of \$0.52 per 1000 gals. Overall costs averaged about \$1.25 per 1000 gals. Compared to municipal water which is typically \$2-4 per 1000 gals, sstormwater represents a potential savings.

For HVAC and Cooling Tower Makeup water applications, the potential savings are even greater due to the generally lower TDS and hardness of the recovered stormwater. For several sites we found improvements in the the Cycles of Concentration from CR=4 to CR=8 or higher. This generated significant savings both in terms of water savings and in Cooling Tower Chemicals which were the result of reduced blowdown to the sewer. These savings ranged from \$2.34 to \$3.80 at several sites –which generates a net overall savings to the facilities of about $1 to $2.50 per 1000 gals.

Summary

Methods for the estimation of Stormwater for reuse have been developed and provide a more accurate means of forecasting future water reuse planning needs. Estimates of stormwater treatment costs and potential savings are presented. The benefits of stormwater reuse will be explored in a more lengthy presentation.

REFERENCES

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