THE FEASIBILITY AND DESIRABILITY OF STORMWATER RETENTION ON SITE

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Abstract: The retention of stormwater on-site with the goal of mimicking pre-development hydrology is increasingly being required or encouraged for new and redevelopment projects. The recently adopted Municipal Separate Storm Sewer System (MS4) NPDES permits require retention on site of runoff from storms up to the water quality design storm via infiltration, evapotranspiration and/or harvest and use. In addition the recently issued technical guidance for implementing the stormwater runoff requirements of the Energy Independence and Security Act (EISA) Section strongly promotes retention of stormwater on site.

The feasibility and desirability of retaining stormwater on site up to a specific design storm has not been vetted technically on a national or regional scale. For example, there has been almost no consideration of the natural water balance in technical guidance. Often infiltrated volumes must be increased over natural conditions in order to match pre-development surface runoff volumes, yet there has been little consideration for whether increasing infiltration over natural conditions may be an issue. There has also been almost no assessment of the circumstances necessary for rainwater harvesting systems to work well for stormwater management. This paper presents some of the considerations for retaining on site and proposes conceptual criteria for determining whether it is feasible and/or desirable to do so.

The paper reviews and discusses the general precipitation and runoff patterns for California and the west coast; the natural water balance and changes to that balance under developed and low-impact development conditions; under what conditions infiltration is feasible and desirable with examples of evaluations; what levels of evapotranspiration can be achieved; and finally presents some examples of the use of rainwater harvesting as a means to retain stormwater on site. Example modeling scenarios of rainwater harvesting for irrigation and toilet flushing are presented from Southern California and Portland, Oregon to highlight both the stormwater management results as well as impacts on potable water demand.

INTRODUCTION

There is increasing regulatory pressure to maximize or require the retention of stormwater on-site and/or match pre- and post-development surface runoff hydrology. For example, the recently adopted Ventura Municipal Separate Storm Sewer System (MS4) NPDES permit requires retention on site of storms up to the stormwater quality design storm (Standard Urban Stormwater Mitigation Plan – SUSMP depth of ¾ of a inch) via infiltration, evapotranspiration and/or harvest and re-use. There is an exception allowed for where it is not feasible to retain the entire volume: the project may then retain "only" 70 percent of the SUSMP storm on site and mitigate the remaining volume off-site. The North Orange County permit requires that infiltration evapotranspiration and/or harvest and re-use be used to manage the water quality design storm, unless determined to be infeasible. Section 438 of the Energy Independence and Security Act of 2008 requires Federal projects greater than 5,000 square feet "to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow." The EPA Technical Guidance for Implementing the Stormwater Requirements of Section 438 effectively requires retention on site of the 95th percentile storm event unless a site specific hydrologic analysis is performed. These documents have, in effect, "narrowed" the traditional definition of Low Impact Development (LID) to these elements (infiltration, evapotranspiration and/or harvest and use) versus the broader LID definition that included the above plus detention and bio-filtration in vegetation-based facilities that provide incidental infiltration and evapotranspiration, but have a surface discharge point (e.g. bioretention with underdrains).

USEPA as well has limited the definition of LID in some of their various guidance documents. For example, *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices, December 2007 (EPA 841-F-07-006)* includes the definition: "LID comprises a set of approaches and practices that are designed to reduce runoff of water and pollutants from the site at which they are generated. By means of ***infiltration, evapotranspiration, and reuse of rainwater***, LID techniques manage water and water pollutants at the source and thereby prevent or reduce the impact of development on rivers, streams, lakes, coastal waters, and ground water." It should be noted that other documents of EPA include definitions with the broader LID definition that includes detention, filtration and surface release.

To date, the retention of stormwater on-site has been primarily been accomplished via infiltration and to a much more limited extent evapotranspiration. Only in a few cases has rainwater harvesting been employed on a site scale for stormwater management (typically as a part of LEED certification). Uses for harvested water typically include non-potable uses such as irrigation and toilet flushing and in some cases process water for industrial uses.

The feasibility and desirability of retaining stormwater on-site up to some design storm has not been vetted technically on a national or regional scale. For example, in the EPA Guidance (*Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices, December 2007 (EPA 841-F-07-006)* there is virtually no assessment via monitoring or modeling information of the potential results of the case studies presented. It is primarily a compendium of anecdotal information. There has been almost no consideration of the natural water balance in technical guidance and, in fact, whether infiltrating more volume than in natural conditions (as would tends to result from matching runoff hydrology without matching ET) could cause problems. This paper attempts to present some of the considerations for retaining on site and whether it is feasible and/or desirable. It focuses on west coast examples, but the factors discussed are applicable to much of the west and beyond. The authors firmly believe that one should try to maximize the retention of stormwater on site, considering watershed and receiving waters, but that it should not be mandated in all cases as the required solution.

FACTORS INFLUENCING BMP PERFORMANCE

BMP Performance Fundamentals: Before introducing the considerations for retaining stormwater on site, it is important to understand what affects the performance of BMPs in general (Strecker, et. al., 2005). BMP performance is effected by the runoff patterns, pollutant types and forms, the storage volume and/or treatment rate, the ability to recover storage (for BMPs that rely on storage), the treatment processes for released flows (to surface waters or groundwaters), and operations and maintenance that affect the ability for the BMP to continue operations. The performance of the BMP can be thought of to be a function of three factors: (1) what percentage of the long term runoff volume does the BMP capture (i.e. what fraction enters the BMP and does not immediately bypass or overflow – referred to as the "percent capture"), (2) of the captured volume, what fraction is "lost" in the BMP (to infiltration, evapotranspiration, or other beneficial use – referred to as "percent volume reduction"), and (3) of the water that is captured and discharged back to the surface, what is the water quality. For retention-only BMPs, the only of these factors of interest is (1), all of which is assumed to be "lost" in determining BMP performance. For vegetated treatment BMPs, each is important.

Factors Specific to Capture Efficiency and Volume Reduction for Retention BMPs: The two fundamental factors influencing the ability of retention BMPs to capture, and thus reduce, runoff volumes are their unit storage and the rate at which this storage volume can be recovered. Unit storage volume affects the maximum amount of runoff from each storm that can be captured when antecedent conditions and processes during a storm are not considered. Storage volume can be provided in free water ponding (surface or subsurface) or in the pore spaces of amended soil or aggregate. The rate of storage recover (or draw down) influences the amount of storage that will be available at the start of a storm considering preceding storm event events and the

amount of additional volume that can be made available during the storm event. Methods for recovering storage include, surface discharge, evapotranspiration (ET), deeper infiltration, and use.

For storage-based BMPs including cisterns (harvest and use) and many infiltration systems, one of the most critical factors is the ability to quickly recover storage before the next storm event arrives. If the storage cannot be recovered quickly enough, then the amount of bypass becomes significant due to the storage being partially to nearly full when subsequent rainfall events arrive. This may be most true in the semi-arid western US, where precipitation patterns tend to be affected by the presence or absence of the high pressure ridge that in essence blocks low pressure storm systems. Once the ridge is absent, typically a series of storms arrives that are "back-to-back" until the high pressure ridge re-establishes. Storms arrive about every one to three days during this period. These back-to-back storms can result in storage-based BMPs that are full or partially full when the next storm arrives if the storage is not quickly recovered, which then causes significant bypass or overflow to occur. These subsequent storm events may account for the majority of average annual precipitation volume, particularly in Southern California. Drawdown rates are also important in other climates. For example, on the east coast precipitation events may be better distributed throughout the year, but still may come in sequences and at irregular intervals. The drawdown rate would have significant influence on amount of capacity in a BMP at the start of an event, and thus the amount of bypass that would occur.

Dependency of Performance on Seasonal Factors: In Southern California, most precipitation arrives from December to March. Figure 1 shows the monthly normal precipitation and reference evapotranspiration in Irvine, California. Monthly normals tend to mask the patterns that occur within specific months in the period of record. Figure 2 shows a typical precipitation pattern for the same gage, which includes the effect of 'back-to-back" storm events on a weekly timescale in an actual year. These weather patterns indicate that the recovery of storage on a sub-weekly time scale is critical to ensure that sequential storms do not by-passed or overflow BMPs. Based on typical storm patterns, it is suggested storage capacity should be regenerated within 2 to 3 days. This recommendation is similar to draw-down rates for extended detention systems for example.

For BMPs relying on infiltration, drawdown rates would not be expected to vary greatly throughout the year. However for BMPs relying on ET (e.g. greenroofs, cisterns with irrigation use), drawdown rates would vary greatly throughout the year. Figures 1 and 2 show the seasonal pattern of ET potential in comparison to rainfall. The relative timing of precipitation and ET should be considered in evaluating the effectiveness and feasibility of ET and storage and use BMPs. This is discussed further in the respective sections below.

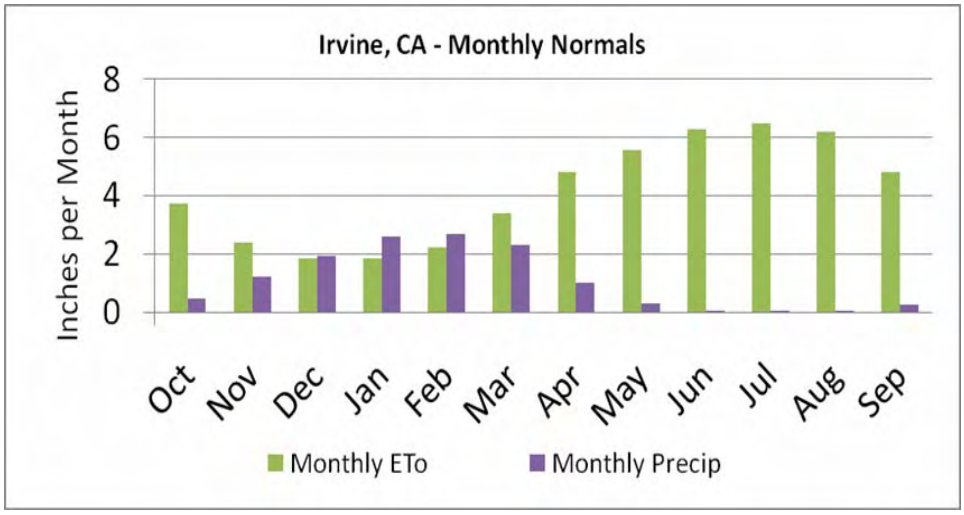

Figure 1. Monthly Precipitation vs. Monthly Evapotranspiration for Irvine, California.

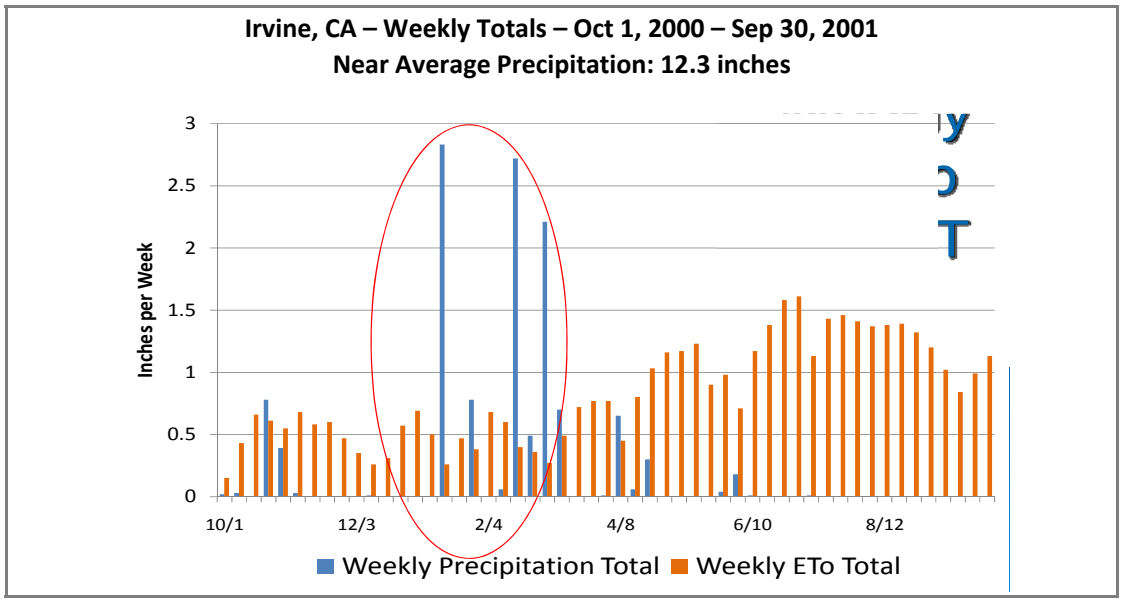

Figure 2. Typical precipitation pattern showing back to back storms at Irvine California for a Near Average Water Year.

CONSIDERATIONS IN STORMWATER RETENTION ON SITE

Infiltration: Infiltration is usually the first method that is employed when attempting to retain on site as when it can be accomplished, it is the most likely to be successful. The authors believe that three questions/issues should be addressed when considering infiltration strategies, including: Can you do it? Should you do it? If you do it, how should it be done?

Infiltration- Can you do it? The underlying soils greatly affect the ability to infiltrate. In much of Southern California (and the west) in urban areas, soils can be difficult for infiltration. Some practitioners have suggested soil amendments as a strategy for increasing infiltration. However, amending soils typically only addresses surface soils, so if underlying soils are still difficult for infiltration, soil amendments may only be increasing the storage available (vs. significantly increasing underlying infiltration rates).

Figure 3 presents a map that shows underling soils for the North Orange County, California permit area. It is expected that, in general, infiltration will only be successful in areas with A and B soil types. Of course, in mapping broader soils groups, there may be pockets where infiltration is more feasible. However the converse is also true. In this Orange County example, a little over 58% of the permit area has C and D soil types that would be unlikely to promote infiltration at an acceptable rate. Infiltration facilities that ignore low underlying infiltration rates in their design would tend to be full for much of the wet season, resulting in substantial bypass/overflow, greatly reducing retention on site. Infiltration facilities designed with lower infiltration rates in mind would have shallower allowable ponding depths and thus require a greater amount of site area, requiring lower development densities which, in turn, may be inconsistent with regional Smart Growth objectives. Maps like this should be developed prior to requiring infiltration or retaining on site to ascertain feasibility.

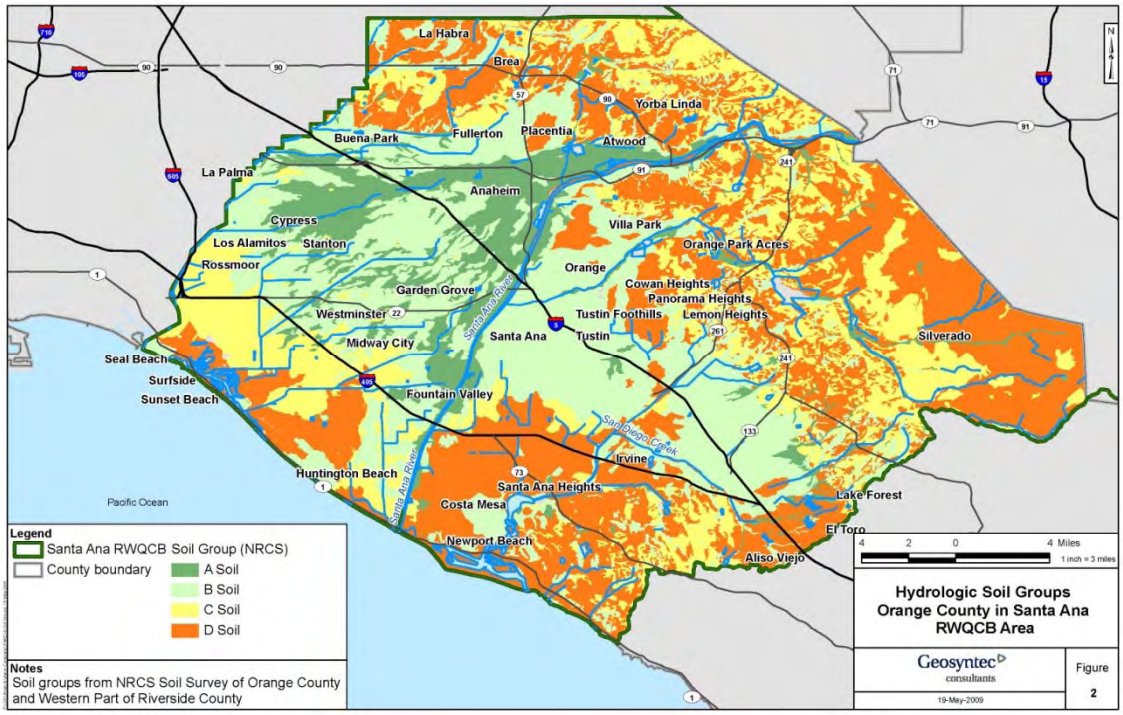

Figure 3. Soil types for North Orange County MS4 NPDES Permit Area

Infiltration- Should you do it? The next question is "should you or how much should you infiltrate?" In many areas there are unnatural (i.e. solvent) or natural (i.e. selenium) plumes or soil contamination that infiltration could negatively impact by either mobilizing, spreading and/or increasing surface discharges. Infiltration in industrial areas is often not desirable due to general concerns about groundwater contamination resulting from potentially-elevated pollutant concentrations in industrial stormwater runoff as well as the higher potential for larger spills. Infiltration is typically limited in areas with shallow groundwater to reduce the risk of contamination and/or concerns about basement flooding. Geotechnical issues associated with steep slopes or expansive soils may be an issue for infiltration. Finally, in some locations upgradient of an ephemeral stream, increased infiltration may cause undesirable habitat type changes downstream of the site due to increased periods of base flows that result in vegetation changes (e.g. conversion of dry wash to a thickly vegetated system). There has been a lack of consideration of the overall water balance effects that a "retention on site" requirement may have in terms of habitat.

As an example, Figure 4 presents a map of the North Orange County permit area that shows the areas remaining when considering of the ability of soils to infiltrate together with the above factors the area remaining within the permit area for consideration of infiltration was estimated to be less than 23 percent of the permit area, not considering local geotechnical issues, habitat issues, or regulated facilities (small contamination areas shown as blue or yellow dots). There are large urbanized areas that where infiltration would not be either feasible or desirable.

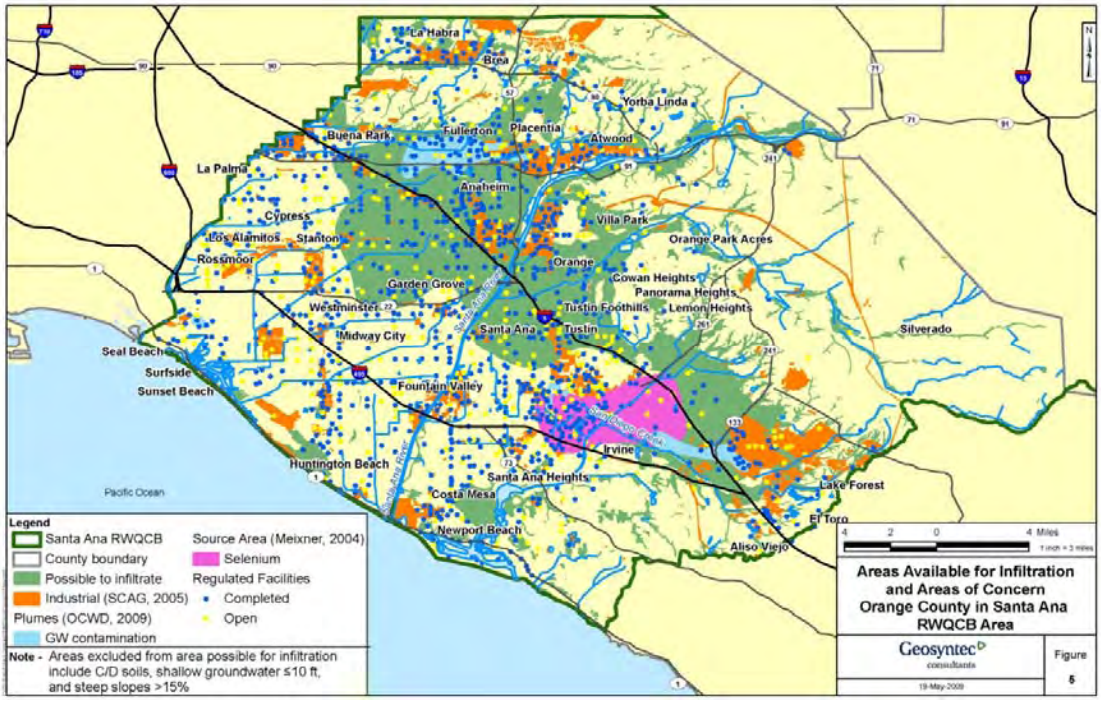

Figure 4.

Areas available for infiltration in the North Orange County Permit Area

Infiltration- How should it be done? Finally, infiltration should be done carefully to ensure that groundwater quality is protected and widespread facility failure does not occur. Proper treatment of infiltrating water should occur before this water reaches groundwater either via treatment with BMPs or ensuring that soils are adequate to provide treatment while passing infiltrating water. Infiltration facilities have often failed due to lacking or poor maintenance and operation of the facilities. One needs to think through how to design infiltration facilities to minimize maintenance issues, and also whether highly distributed infiltration facilities can be maintained adequately. Water districts that utilize groundwater should be involved in decisions, including permit decisions, about where and how to infiltrate stormwater such that groundwater supplies are protected.

Evapotranspiration – ET: After development there will be less area for evapotranspiration available, even with vegetated roofs or pervious pavements, especially in high density projects. Some have compared monthly or seasonal ET to precipitation levels to assess the potential for ET losses as a significant retain on site measure. This is inappropriate, in particular on the west coast with the tendency for back-to-back storm events. Figure 1 shows monthly normal comparisons of precipitation versus ET, while Figure 2 shows precipitation and ET on as weekly total for an example year. While the former suggests that ET nearly matches or exceeds precipitation on a monthly normal basis, it does not account for back-to-back storms or the fact that months with higher than normal rainfall would be the same months that correspond to lower than normal ET in the long term period of record. Figure 2 clearly demonstrates that ET cannot keep up with precipitation on a weekly basis in critical periods of an average year, even if one assumed that the entire site is available for ET. During these critical periods, the storage provided in soils would not have recovered in time for subsequent rainfall. While ET of stormwater should be maximized, it almost certainly will not be able to match pre-development levels and is likely a minor component of retaining stormwater on-site. High density projects in particular would not be able to have significant ET components without reducing density (even with roof systems such as green roofs).

ET is a very important consideration when assessing the ability to mimic pre-development runoff volume. Pre-development ET can range upwards of 80 to 97 percent of the precipitation on an average annual basis in the semi-arid southwest (Ng and Miller, 1980). It is very unlikely that pre-development ET will be matched post-

development due to reduction in vegetated open soils areas. So, the choice for development, particularly high density development, is to either have more runoff than pre-development or more infiltration, or a combination (unless harvest and use is included). This fact and its ramifications have not been considered during the development of on-site retention requirements that are focused on surface hydrology versus overall hydrology (including sub-surface hydrology).

Capture and Use (re-use): In most all cases where infiltration is not feasible or possible, the only significant option remaining to meet on site retention requirements is to capture (harvest) and use the stormwater. In North Orange County for example this would be the major option in about 77 percent of the permit area or more.

As discussed above, the key factor for success of capture and use of stormwater as a means to retaining water on site is the rate at which storage can be made available for subsequent events. This means having a demand for the capture water that is high enough, especially during the rainy season. The two most obvious uses for captured stormwater are for irrigation and toilet flushing. Other potential uses include process water for commercial or industrial purposes. Limitations on use of harvested water related to public health code and water rights are not the focus of this paper but should be considered in estimating the demand for harvested water. Scenarios including a single family residential development and an office building were conducted to illustrate the potential for capture and use of stormwater.

Capture and use – Residential Scenario: An example 100-acre residential catchment with 60 percent overall impervious area was evaluated using a continuous simulation model (SWMM) for a capture and use scenario. A tank (above ground storage) of 1.3 million gallons (equivalent to the runoff from the catchment resulting from a 0.8 inch storm event - the local water quality design event for North Orange County) was evaluated with toilet flushing and irrigation uses combined. Toilet flushing assumed 65 gallons per day per dwelling unit at 4.5 units per acre. For simplicity, irrigation demands were assumed to be the monthly average ET levels for the 30 acres of landscaped areas and it was assumed that irrigation was always on, even during rainfall (there irrigation demands during and after rainfall were significantly over-estimated in this analysis).

Long-term simulation models were run to ascertain the potential effectiveness of such a system for retaining runoff on-site in Irvine, CA and in Portland, OR as a comparison between dry and wetter west coast climates. Irvine runs made use of a co-located precipitation and ET gage located in Irvine with records from 1988-2008. Portland runs made use of co-located precipitation and ET records from a gage located in Aurora, OR (approximately 10 miles south of the Portland metro area) from 1998-2008. System performance is reported in Table 1. The Irvine, CA system was estimated to have an average annual capture of less than 50%, while the Portland example captured on average about one third of the runoff. Capture refers to the percentage of the total runoff volume that is retained and used. Both results are disappointing in terms of stormwater management especially if one assumes the bypass is not treated. In some years the capture rate was less than 25% for both systems. Figure 5 shows the variation in capture efficiency by water year in the Irvine scenario.

Table 1: System Performance for Residential Capture and Use Scenarios

Performance Metric	Irvine, CA	Portland, OR
Average Annual Capture Efficiency	48%	33%
Minimum Annual Capture Efficiency	24%	21%
Maximum Annual Capture	100%	64%

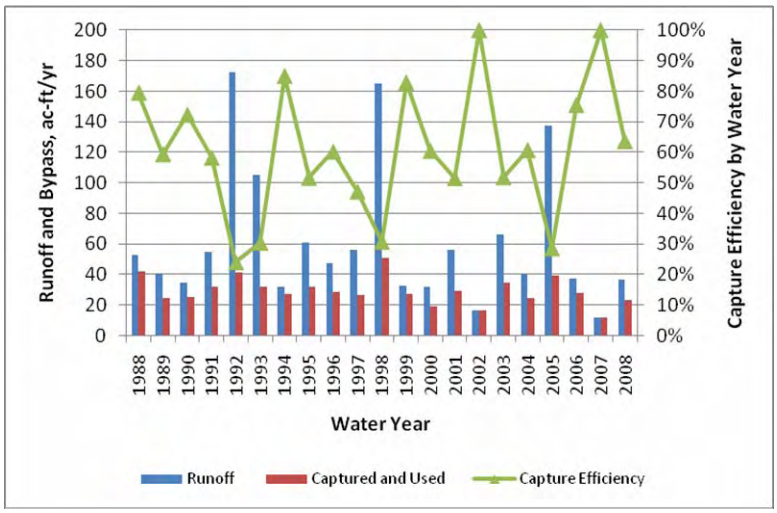

Figure 5. Predicted Annual Runoff and Capture for Example Cistern System in Irvine, California

For the Irvine example, potential pollutant removal results were evaluated in comparison to biofiltration with an underdrain (surface water release). A comparison of total loadings performance to a biofiltration system (using data from International BMP Database) with underdrains showed that the biofiltration system reduced total suspended solids (TSS) loads by about 63% compared to 48% or the cistern scenario. So, in this case, the assumption that retain on site is the most effective at reducing pollutant loadings is not valid, unless one also required treatment of the bypassed flows (in essence additional BMP treatment requirement).

Finally, the average annual potable water saved in the Irvine example was on the order of about 10 to 15 percent of the average annual demand. This is not insignificant; however, this finding must be interpreted with consideration of planting pallets and overall annual water demand, including demand during times when harvested rainwater is not available. To maximize irrigation use of harvested rainwater, drought tolerant planting pallets might not be employed and therefore overall water demand may not be reduced because these plants would require greater water than their drought-tolerant counterparts during the times when harvested rainwater is not available.

Capture and Use – EISA Section 438 Example: Another scenario was run for Irvine, doubling of the cistern tank size to 2.6 million gallons (equivalent to a 1.6 inch design storm). This is consistent with the 95th percentile rainfall depth in the Irvine area, which is one implementation option offered by the Section 438 Technical Guidance. Under this scenario, the capture and use level went up to about 57 percent. So, in this case, doubling the storage size resulted in another 9 percent of the runoff being captured and used. The performance of this system is clearly not consistent with the goal of EISA Section 438 to maintain or restore predevelopment hydrology. This emphasizes the point that the key to success for capture and use is being able to drain the cistern relatively rapidly. It also suggests the need for criteria in the EISA Section 438 Technical Guidance for determining when harvest and use BMPs can feasibly meet the stated goals.

Capture and use – Office Building Scenario: An office building scenario with indoor demand only was evaluated for comparison to the scenarios presented above. The Oregon Clinic is a 4-story medical office building located in eastern Portland, OR, with a roof area of approximately 33,000 sq-ft. The building was constructed with a 20,000 gallon cistern (equivalent to approximately 1 inch over the roof area) to offset the use of potable water for toilet flushing. For reference, the 95th percentile precipitation event in Portland is 1.0 inch, therefore this case study provides grounds to evaluate the applicability of the EISA Section 438 Technical Guidance in the Pacific Northwest.

The system included bag filters, a UV disinfection system, smaller tank for mixing harvested and make-up water, and a non-potable water distribution system. Over the first three years of operation, average daily toilet flushing demand has ranged from approximately 600 gpd to 2,000 gpd, with an average of approximately 1,200 gpd (1,600 gpd/ac). This demand can be compared to the toilet flushing demand estimated in the residential scenario of approximately 280 gpd/ac. Continuous simulation was performed to evaluate the performance of this system and the sensitivity of design parameters on performance. Figure 6 shows the results of this analysis for varying demand and cistern volume.

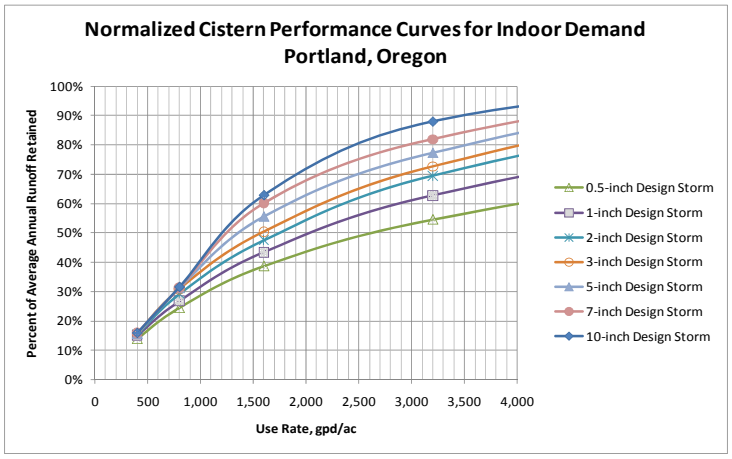

Figure 6. Normalized Cistern Performance Curves for Indoor Demand, Portland, Oregon

Based on the results shown in Figure 6, the Oregon Clinic would be expected to achieve approximately 45 percent reduction in average annual runoff volume for the area captured by the cistern. Doubling the volume of the cistern would yield an increase in average annual runoff reduction of approximately 5 percent while doubling the demand would result in an increase of approximately 20 percent. For low use rates, the benefit of adding storage is nearly negligible as the additional storage would stay full and bypass for much of the wet season.

As occupancy of the Portland Clinic has increased, demand has also increased. Figure 7 shows a plot of performance trajectory with increasing demand for the 1-inch design storage volume.

It is intuitive that with increasing demand the capture efficiency of the system would be expected to increase for a given storage volume. It may be less intuitive that the fraction of non-potable demand that can be met through rainwater harvesting decreases with increasing demand. This is a function of the limited supply of rainwater during dry summer months when demand persists. For higher demand scenarios, the storage draws down more quickly in the wet months and results in higher overall use of captured water, but exerts a higher demand during dry months when captured water is not available. This metric would likely exhibit different trends in parts of the country that receive more uniform rainfall throughout the year, such as much of the eastern United States.

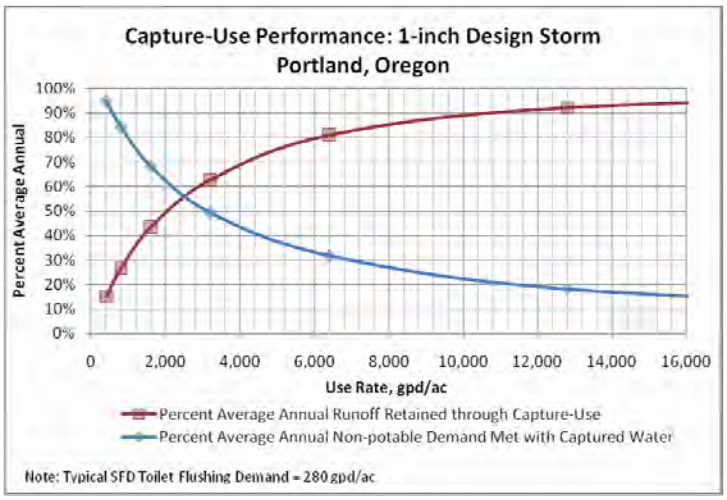

Figure 7. Normalized Cistern Capture and Supply Curves with 1-inch of storage, Portland, Oregon

It is important to note in this case study that a significant portion of the site was parking lot, which was not captured by the cistern. In many cases, capture and use of runoff from ground-level impervious areas may not be practicable.

Observations on Capture and Use: As illustrated in these examples, one should evaluate carefully potential scenarios to help ensure that choices made regarding retention on site requirements actually result in the desired results. Evaluation should consider land use and density assumptions as well as assessment of local precipitation and runoff patterns, irrigation needs, and ability to use water for toilet flushing or other non-potable uses. For capture and use to work, the storage must be quickly recovered. Irrigation typically is not an effective use for recovering storage quickly as irrigation needs during wet periods are minimal and in colder climates there is no irrigation demand for long periods. In addition, much of the arid southwest and other areas as well are encouraging the use of drought tolerant landscape pallets, which are likely more effective at reducing potable demand than capture and use for irrigation. These plant pallets typically do not withstand saturation for long periods via over-irrigation that would occur if irrigation use was maximized. Further, use of a water-loving plant palate to maximize the use of captured runoff during normal and wet years could actually exert an additional demand for potable water during dry years.

For toilet flushing to be effective, there needs to be a high enough ratio of Toilet Users To Impervious Area (TUTIA). Perhaps in high-rise condominiums, office buildings, institutional buildings, etc. the TUTIA ratio would be high enough to drain the tank sufficiently fast and in these cases capture and use should be considered.

There would be a “competition” with reclaimed water in much of the arid west. Reclaimed water systems tend to be somewhat limited due to low irrigation demands in the wetter and colder periods of the year. In addition, in some locations use of reclaimed water for toilet flushing is required in high density projects. If the use of captured rainwater results in the discharge of more treated wastewater effluent to receiving waters, the net benefit of captured stormwater would be reduced.

Finally, there is significant infrastructure that would be required to employ cistern and use on a site by site basis, including piping, storage, treatment, pumping, and separate piping (purple pipes). Questions about sustainability of these systems and the ability of jurisdictions to adequately monitor these systems to ensure reliable receiving water protection need to be explored and assessed.

Observations on EISA Section 438 Technical Guidance: The EISA Section 438 Technical Guidance Manual allows the use of two options for implementing Section 438 requirements: (1) retention of the 95th percentile precipitation event to the maximum extent technically feasible (MEFT), or (2) site-specific hydrologic analysis to ensure post-construction rate, volume, duration and temperature of runoff do not exceed the pre-development rates to the MEFT. Based on the scenarios introduced above, several observations can be made about the recently-release Section 438 Technical Guidance:

- The document should be supported by clear guidance on feasibility criteria (especially for identifying scenarios when capture and use would not meet goals of the Section).
- Continuous simulations approaches should be used to inform this guidance at least; perhaps it would be appropriate to develop continuous simulations tools for use in evaluations.
- For larger projects, invoking the option of a site-specific hydrologic analysis is critical to ensure that the goals of the Section are met.
- The 95% storm approach will likely result in "inefficient" BMP designs in many cases and will not work very well in most, unless drawdown times rates are considered.

SUMMARY

In summary:

- Infiltration is not broadly feasible, effective and/or desirable in many cases. It should be maximized where appropriate, but studies are needed to identify suitable areas and also identify areas where infiltration may not be appropriate.
- Precipitation/runoff patterns in California and much of the west limit the ability of evapotranspiration-based BMPs to achieve retention on site requirements. Evapotranspiration of stormwater should be maximized, but will not be a significant component of retaining stormwater on site in dense develop.
- Precipitation/runoff patterns coupled with landscaping and reclaimed water considerations limit the applications where capture and use of runoff can be effective. Generally, only scenarios with high indoor non-potable demand and no competing requirements to use reclaimed water can be expected to provide a complete and reliable stormwater solution. Capture and use should be maximized in these cases, but in other cases it should be carefully considered against other options such as biofiltration and discharge to determine which option is most effective in meeting stormwater management goals.
- The overall water balance should be considered when making choices on proper levels of infiltration versus surface runoff. Surface water regulators should consult with groundwater regulators when making these decisions.
- There needs to be more technical vetting of "retain on site" and stormwater harvest and use before these approaches are made mandatory.

Each watershed and site has unique soils, topography, groundwater, water quality, land uses, receiving water sensitivities, wastewater strategies, etc. which should be considered when evaluating retention on site as a requirement or strategy. The authors believe that management approaches that are "one size fit all" are not appropriate and in many cases would likely lead to undesirable results. The authors recommend that the proper stormwater management approach should include:

- Source controls
- Infiltration where feasible and appropriate
- Maximizing ET losses
- Harvest and use where it makes sense
- Capture and treat with effective (i.e. vegetated) BMPs where it makes sense

We believe that significant progress could be made by improving BMP selection and design guidance for all BMPs to better target unit processes (i.e. physical, biological, chemical treatment processes) to the pollutants and parameters of concern for each watershed.

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