Development and Implementation of Hydromodification Control Methodology

Support for Selection of Criteria

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Introduction

The ***Management Strategy - Example Criteria - Watershed Process*** table (Appendix A) was developed to provide a linkage between broad groups of stormwater management objectives (***Strategies***), specific examples of stormwater management criteria for each strategy from California and around the nation (***Criteria***), and how implementation of each criterion is anticipated to preserve or replace critical watershed processes identified previously during the project (***Watershed Processes***). Each ***Criterion*** is rated from a scale of 0 to 4 (using symbols) according to how well it performs for preserving or replacing each ***Watershed Process***. The three terms are shown in ***bold italics*** in this document to help communicate the linkage between them; note that the word "criteria" is left as normal text when used to discuss stormwater management criteria in general, outside of the context of the table and the specific ***Criteria*** that are evaluated in the table.

An additional table is provided showing examples of stormwater management techniques that cannot be easily rated, but are also judged effective for protecting ***Watershed Processes***. In total, these provide a toolbox that developers can use to meet overall stormwater objectives.

Support for Selection of Criteria

Management Strategies

While the term "hydromodification" is not used in the majority of past or present stormwater management manuals or ordinances, the concepts of protecting water quality, maintaining water balance, and preserving stream channel stability have been in the mainstream for decades. The ***Criteria*** presented in this review are grouped according to the following five broad ***Strategies***:

1. Flow Control
2. Water Quality Treatment
3. Preservation of Sediment and Organic Delivery
4. Land Preservation
5. Maintenance of Soil and Vegetation Regime

Flow Control encompasses a broad range of stormwater criteria for addressing hydraulic and hydrologic goals. Three sub-groups are included and defined below: *Storm Event Peaks*, *Flow Duration Matching and Storm Volume Control*, and *Retain/Infiltrate Volume*.

Storm Event Peaks. Use of detention storage for peak flow control has perhaps the longest history in stormwater management. Requirements for managing storm event peak flows grew out of need to provide flood control on a more localized scale in urban areas. Regulations typically mandate that post-development peak flows are less than or equal to pre-development peak flows for a series of intermediate and/or large design storm events (e.g., the 2-, 10-, and 25-year 24-hour events) – thus ensuring, at least in theory, that new development will not create additional flooding hazards.

Flow Duration Matching and Storm Volume Control. The need for storm event volume control was recognized in the late 1980's and came into mainstream use in the early 2000's. Peak control criteria were recognized as ineffective for mitigating channel erosion (Booth, 1989; MacRae, 1992, 1993; Bledsoe and Watson, 2001). The goal thus became to control the runoff from storm events in the 1-year to 2-year recurrence range, corresponding to the frequency with the highest risk potential for channel erosion (commonly correlated with the bankfull event), and by extension damage to aquatic habitat. Standards were promulgated to provide extended detention (minimum 24- to 48-hour drawdown time) for a sufficient volume to mitigate risk of channel erosion. A drawback of volume control criteria, however, is that the resulting outflow hydrograph does not necessarily match pre-developed conditions. In response, "flow duration matching" was first introduced in King County, WA in 1990 and became popular throughout many counties in California during the mid-2000's in response to hydromodification requirements from Water Boards. The objective is simple on the surface – match the aggregate duration of sediment-transporting discharges. The specific criteria are rather complex and technical in their implementation; this is necessary because there has to be an objective statistical basis to *measure* compliance; in other words one cannot simply perform a subjective visual comparison of peak frequencies and flow durations.

Retain/Infiltrate Volume. None of these preceding ***Flow Control Strategies*** address the full range of flows from the largest storm to baseflow during the driest time of the year. To address this gap, a handful of regulating authorities have implemented requirements for infiltrating runoff or retaining it onsite, without specific reference to the range of stream-channel flows that are affected or that can be measured to evaluate compliance or effectiveness. Goals include maintaining groundwater flow, reducing overall runoff volume, or both.

Water Quality Treatment criteria address urban sources of pollutants such as nutrients from fertilizer, metals from brake pads, pet waste, sediment from exposed soil surfaces, and solids washed off impervious surfaces. Use of stormwater control measures (SCM's) for treatment of pollutants in urban runoff became popular in the 1990's, as the focus of water quality programs moved from traditional end-of-pipe point source control to management of nonpoint sources. Impervious surfaces and soil compaction lead to an increase in runoff volume, but an important question faced by decision makers was (and still is) how much of the runoff should be treated. Early research by Schueler (1987) found a point of diminishing returns between percent capture of annual runoff and pollutant removal effectiveness, and that majority of pollutant mass tended to be carried in runoff during the beginning of storm events, called the "first flush," in many (but not all) climatological regions. Over the next several years, most stormwater programs developed treatment criteria targeting this first-flush volume, with regulations coalescing around treatment of the 85th to 90th percentile annual storm depth, called the Water Quality Volume. California programs took a more robust approach, adding flow-based criteria for SCM's that do not require storage volume (such as swales which treat via filtration), and publishing 85th percentile isopluvial maps to account for highly variable rainfall patterns across the state. While some SCM's designed for water quality treatment also have benefits for reducing peak flows and promoting infiltration and evapotranspiration, the primary reasons for their use are linked to the local water quality requirements, which reflect goals of protecting aquatic life, drinking water resources, and minimizing risk of disease resulting from contact with pathogens in water bodies.

Preservation of Sediment and Organic Delivery. Natural delivery of sediment and organic matter into the channel network are critical processes for the maintenance of various habitat features and aquatic ecosystems in the fluvial setting. While preservation of these functions is not a goal found in most stormwater regulations, it is often discussed qualitatively as the purpose in establishing or justifying riparian buffer requirements.

Land Preservation.

Open Space Requirements are sometimes used as a technique in stormwater regulation, especially when a receiving stream or reservoir has a high value placed on its protection.

Minimize Effective Impervious Area. There are several regulating authorities with requirements for limiting impervious area and directing runoff from impervious surfaces to pervious areas, rather than routing it directly to the storm drain (thus converting "effective" impervious area to "ineffective" impervious area, namely hard surfaces where the runoff can reinfiltrate into the ground instead of connecting directly to the channel network). These practices serve to reduce Effective Impervious Area.

Maintenance of Soil and Vegetation Regime

The need for water quality treatment "facilities" is widely understood in stormwater management, but the underlying reason for such a need is commonly recognized only partly. Although the import of new pollutants into a watershed is one dimension of water quality impairment, the greater cause is typically the isolation of soil and vegetation from the path of urban stormwater runoff. In an undisturbed watershed, the processes of filtration, adsorbtion, biological uptake, oxidation, and microbial breakdown (collectively termed the ***Watershed Process*** of "chemical and biological transformations" by the Joint Effort) provide extremely effective purification of most (though not all) contaminants, both natural and anthropogenic. The most obvious evidence of this is enshrined in Health Department rules, nationwide, that typically mandate no more than 100 feet of separation between a raw sewage discharge (via drainfield) and a human drinking-water supply. The effectiveness of this treatment does not rely on structural measures, but rather on the ability of natural soil and vegetation to purify water of most of its even most deleterious contaminants.

This management ***Strategy*** embraces not only the "natural" approach to water quality treatment and protection but also major components of how the rainfall–runoff relationship is attenuated in an undisturbed watershed. Evapotranspiration, infiltration, interflow, and deep recharge in an undisturbed watershed all reflect the presence of soil and vegetation; maintaining these elements is thus an obvious ***Strategy*** for protecting these processes as well. As such, this ***Strategy*** overlaps with several others: not only can it accomplish water quality treatment, but also it provides an effective (but non-engineered and so difficult to quantify) approach to stormwater volume-based flow control. In addition, if adjacent to water bodies it preserves the delivery of sediment and organics to waterbodies; and it is a (typically intentional) byproduct of any application of land-preservation ***Strategies*** as well.

Example Criteria

The ***Criteria*** are drawn from a cross-section of ordinances and regulations from municipalities, states, and the federal government. Examples from California were preferentially selected, but existing examples from this state are not broad enough in scope to address all of the ***Strategies***. In many instances, a regulating authority uses similar ***Criteria*** as provided in the table example; these are noted as "Similar Criteria" in highlighted boxes. Key assumptions regarding how the ***Criteria*** are related to the ***Watershed Process*** ratings are provided in italicized text.

It is important to note that the ***Criteria*** are not mutually exclusive among the ***Strategies*** – some meet multiple objectives. In addition, the ***Criteria*** are not presented in the more holistic context of the goals of their ordinance or requirement; often a regulating authority has multiple (and sometimes tiered) criteria for addressing several water resource management goals.

Watershed Processes

Each ***Watershed Process*** is discussed, both in the context of the natural setting and the developed landscape.

Overland flow

Precipitation reaching the ground surface that does not immediately soak in must run over the land surface (thus, "overland" flow). Most uncompacted, vegetated soils have infiltration capacities of one to several inches per hour at the ground surface, which exceeds the rainfall intensity of even unusually intense storms of the Central Coast and so confirms the field observations of little to no overland flow in undisturbed watersheds. In contrast, pavement and hard surfaces reduce the effective infiltration capacity of the ground surface to zero, ensuring overland flow regardless of the meteorological attributes of a storm, together with a much faster rate of runoff relative to flow over vegetated surfaces. Some stormwater practices work specifically to promote returning concentrated flow to overland flow on pervious surfaces (such as downspout disconnection) or prevent flow from concentrating in the first place (such as permeable pavement).

Infiltration and groundwater recharge

These closely linked hydrologic processes are dominant across most intact landscapes of the Central Coast Region. They can be thought of as the inverse of overland flow; most precipitation that reaches the ground surface and does not immediately run off has infiltrated. Their widespread occurrence is expressed by the common absence of surface-water channels on even steep, undisturbed hillslopes. Thus, on virtually any geologic material on all but the steepest slopes (or bare rock), infiltration of rainfall into the soil is inferred to be widespread, if not ubiquitous. With urbanization, changes to the process of infiltration are also quite simple to characterize: some (typically large) fraction of that once-infiltrating water is now converted to overland flow.

Interflow

Interflow takes place following storm events as shallow subsurface flow (usually within 3 – 6 feet of the surface) occurring in a more permeable soil layer above a less permeable substrate. In the storm response of a stream, interflow provides a transition between the rapid response from surface runoff and much slower stream discharge from deeper groundwater. In some geologic settings, the distinction between "interflow" and "deep groundwater" is artificial and largely meaningless; in others, however, there is a strong physical discrimination between "shallow" and "deep" groundwater movement. Development reduces infiltration and thus interflow as discussed previously, as well as reducing the footprint of the area supporting interflow volume.

Evapotranspiration

In undisturbed humid-region watersheds, the process of returning water to the atmosphere by direct evaporation from soil and vegetation surfaces and by the active transpiration by plants can account for nearly one-half of the total annual water balance; in more arid regions, this fraction can be even higher. Development covers soils with impervious surfaces and usually results in the compaction of soils when grading occurs. Native plants are often replaced with turfgrass, which typically have lower rates of evapotranspiration unless irrigated throughout the summer months.

Delivery of sediment to waterbodies

Sediment delivery into the channel network is a critical process for maintaining various habitat features in fluvial systems (although excessive sediment loading from watershed disturbance can instead be a significant source of degradation). Development commonly covers surfaces, and non-native vegetation may also prevent the natural supply of sediment from reaching the stream.

Delivery of organic matter to waterbodies

Introduction of allochthonous organic material into the stream network, either as fine organic material suitable for food or as coarse organic material that can provide physical structure and hydraulic resistance in the channel, is critical for maintaining aquatic life. Development may reduce the input of organic matter to streams, especially when native vegetation near streams is cleared or replaced with turfgrass.

Chemical/biological transformations

This encompasses the suite of ***Watershed Processes*** that alter the chemical composition of water as it passes through the soil column on its path to (and after entry into) a receiving water. The conversion of subsurface flow to overland flow in a developed landscape eliminates much of the opportunity for such transformations, and this loss is commonly expressed through degraded water quality.

Stream Stability

While an indicator of watershed conditions and not a ***Watershed Process*** itself, stream stability may be important to consider when development cannot achieve an adequate degree of performance for the other ***Watershed Processes***. This is more likely to occur as impervious footprints become large and overwhelm the ability of the remaining landscape to absorb development impacts, and where inadequate mitigation has occurred.

The following ratings are used in the table to link the performance of the ***Criteria*** to each ***Watershed Process***. Key assumptions regarding how the ***Criteria*** relate to the ***Watershed Processes*** are provided in italicized text.

Rating	Description
4 ●	***Criterion*** preserves or fully replaces the ***Watershed Process*** relative to natural conditions.
3 ◕	***Criterion*** substantially preserves the ***Watershed Process*** or replaces most of the process relative to natural conditions.
2 ◑	***Criterion*** partially preserves or replaces the ***Watershed Process***.
1 ◔	***Criterion*** minimally replaces a portion of the ***Watershed Process***.
0 ○	***Criterion*** provides no protection or support of the ***Watershed Process***.

Summary

The following ***Criteria*** provide the best overall protection of ***Watershed Processes***:

- Section 438 of EISA – Retain 95th Percentile Event

- City of Santa Monica – Urban Runoff Mitigation Plan
- City of Santa Barbara SWMP – Volume Reduction Requirement
- State of Delaware – Final Draft Stormwater Regulations

King County, Washington – Requirements for Sensitive Watersheds also scores highly, but the rankings are due primarily to the percentage of land left in an undeveloped state.

The four ***Criteria*** listed above share a common gap in their coverage of ***Watershed Processes***, namely the delivery of sediment and organic matter to waterbodies. Where these processes require protection, a buffer zone requirement is the most common and effective vehicle to address the gap.

Many areas within the Central Coast region require protection for only a subset of the ***Watershed Processes***, depending on their Watershed Management Zone classification. As a result, a one-size-fits-all approach is not likely to provide flexibility in the development of stormwater management requirements. Multiple techniques are likely to be needed to address varying objectives. It is also important to note that some ***Criteria*** (such as flood control requirements) may score poorly for individual ***Criteria*** but still have an important role in stormwater management by virtue of community needs or concerns.

References

Bledsoe, B.P. and C.C. Watson. 2001. Effects of Urbanization on Channel Instability. Journal of the American Water Resources Association. 37(2): 255-270.

Booth, D. B. 1989. Runoff and stream-channel changes following urbanization in King County, Washington: chapter in Gallster, R., ed., Engineering Geology in Washington, Vol. II: Washington Division of Geology and Earth Resources Bulletin 78, pp. 639–650.

MacRae, C.R. 1992. The Role of Moderate Flow Events and Bank Structure in the Determination of Channel Response to Urbanization. Resolving conflicts and uncertainty in water management: Proceedings of the 45th Annual Conference of the Canadian Water Resources Association. Shrubsole, D., ed. 1992, pg 12.1-12.21.

MacRae, C.R. 1993. An Alternate Design Approach for the Control of Instream Erosion Potential in Urbanizing Watersheds. Proceedings of the Sixth International Conference on Urban Storm Drainage, Sept 12-17, 1993. Torno, H.C., vol. 2, pg 1086-1098.

Schueler, T.R. 1987. Controlling Urban Runoff. Washington Metropolitan Water Resources Planning Board.

Appendix A: Management Strategy - Example Criteria - Watershed Process table

MANAGEMENT STRATEGY - EXAMPLE NUMERIC CRITERIA – WATERSHED PROCESS TABLE

Criteria Rating Description

Rating	Description
●	Criterion preserves or fully replaces the watershed process relative to natural conditions.
◕	Criterion substantially preserves the watershed process or replaces most of the process relative to natural conditions.
◑	Criterion partially preserves or replaces the watershed process.
◔	Criterion minimally replaces a portion of the watershed process.
○	Criterion provides no protection or support of the watershed process.

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

Management Strategy	Example Criteria	Watershed Processes: Overland flow	Watershed Processes: Infiltration and groundwater recharge	Watershed Processes: Interflow	Watershed Processes: Evapotranspiration	Watershed Processes: Delivery of sediment to waterbodies	Watershed Processes: Delivery of organic matter to waterbodies	Watershed Processes: Chemical/biological transformations	Stream Stability
Flow Control **Storm Event Peaks** Post-development peak flows match pre-development peak flows for a specific set of design storm events. *Note: Peak control basins are assumed to typically have pervious bottoms with some vegetation.*	<u>Santa Barbara County, CA – Flood Control</u> Requirements vary by location. For example, Santa Ynez Valley and South Coast – post-development peak flows do not exceed pre-development peak flows for the 2 through 100-year storm events. *Note: Santa Barbara is assumed to perform better than City of Durham; the basin will likely be larger to capture a fuller range of design storm volumes. Increased surface area provides more opportunity for infiltration and ET of frequent low volume storm events.*	○	◔	○	◔	○	○	○	○
	<u>City of Durham, NC – Peak Runoff Control</u> Post-development peak flows do not exceed pre-development peak flows for the 2-year and 10-year 6-hour storm events. *Note: Peak control basins in Durham are assumed to have a smaller basin footprint-to-drainage area ratio than in Santa Barbara, resulting in minimal influence on hydrology.* Similar Criteria – Santa Barbara SWMP (2-, 5-, 10-, and 25-year 24-hour events)	○	○	○	○	○	○	○	○

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

Management Strategy	Example Criteria	Watershed Processes: Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	Stream Stability
Flow Control **Flow Duration Matching and Storm Volume Control** The goal of both techniques is to reduce risk of downstream channel erosion. The goal of flow duration matching is for post-development hydrographs to match pre-development hydrographs across a wide range of storm events, taking both flow rates and duration of discharge into account. Ratings assume that hydromodification criteria with lower flow thresholds a fraction of Q_2 are typically met using structural practices that promote infiltration and ET (e.g., bioretention). These same practices provide a high degree of water quality treatment.	San Diego County – Hydromodification Plan • **Flow Duration.** For flow rates ranging from the lower flow threshold to the pre-project 10-year runoff event (Q_{10}), the "post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10 percent over and more than 10 percent of the length of the flow duration curve." • **Peak Flow Frequencies.** "For flow rates ranging from the lower flow threshold to Q_5, the post-project peak flows shall not exceed pre-project peak flows. For flow rates from Q_5 to Q_{10}, post-project peak flows may exceed pre-project flows by up to 10 percent for a 1-year frequency interval." *Note: The "lower flow threshold" is site-specific and depends on the level of protection needed for the receiving stream, based on screening method developed for the HMP. The lower flow threshold may be $0.1Q_2$, $0.3Q_2$, or $0.5Q_2$; in the absence of a downstream analysis, the value is set to $0.1Q_2$. The San Diego SUSMP and Hydromodification Plan promote site design options that retain some runoff in pervious areas, and practices that detain/treat the majority of runoff using practices that promote infiltration and evapotranspiration. Detention basins are viewed as a last resort when other options are not feasible. Since the default lower flow threshold is 0.1Q2, a given practice tends to have larger footprint requirements than those seen in other jurisdictions for the same practice.* Similar Criteria – San Francisco Bay Area Counties, Contra Costa County, Ventura County, Sacramento County	◔	◕	◕	◑	○	○	◕	◕

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

		Watershed Processes							
Management Strategy	**Example Criteria**	**Overland flow**	**Infiltration and groundwater recharge**	**Interflow**	**Evapotranspiration**	**Delivery of sediment to waterbodies**	**Delivery of organic matter to waterbodies**	**Chemical/biological transformations**	**Stream Stability**
Flow Control **Flow Duration Matching and Storm Volume Control (continued)**	<u>Western Washington State – Flow Duration</u> Post-project runoff durations from $0.5Q_2$ to Q_{50} shall not exceed pre-project runoff durations, where "pre-project" is defined as fully forested land cover unless the site was demonstrably prairie (modeled as "pasture") prior to settlement. *Note: Ratings assume Western Washington site designs provide somewhat less infiltration and emulation of interflow than those assumed for San Diego County. The $0.5Q_2$ lower flow threshold used in Western Washington is likely to result in a relatively lower capture volume.*	○	◑	◑	◑	○	○	◕	◕

Preserve/maintain ● ◕ ◑ ◔ ○ No benefit

		Watershed Processes							
Management Strategy	**Example Criteria**	Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	**Stream Stability**
Flow Control **Flow Duration Matching and Storm Volume Control (continued)** For volume control, a specified runoff volume (based on a design storm event) is captured and released over an extended time period.	Town of Huntersville, NC – Treatment Volume Control and treat increase in runoff volume between pre- and post-developed conditions for the 2-year 24-hour storm event (rural zones) or the 1-year 24-hour storm event (urban zones). Volume must be released over a minimum of 48 hours. Practices must be distributed throughout the site, with no drainage area larger than five acres. *Note: The ordinance places a strong focus on the use of LID practices for water quality treatment and volume control, and includes requirements for distributing BMPs throughout a site rather than having one BMP at the drainage area outlet. However, the relative treatment volume is lower than those specified for the Flow Duration Criteria examples (when accounting for the difference between Southeastern and Pacific Coast hydrology), and there is stronger reliance on detention facilities for addressing large storm event volumes. Ratings are assumed to be reduced for infiltration and interflow.*	◔	◔	◔	◑	○	○	◕	◑
	State of Maryland – Channel Protection Storage Volume Runoff volume from the 1-year 24-hour storm event must be detained and released over a minimum of 24 hours (12-hours in some locations). Note: Design criteria provide specifications for several types of structural practices, but the larger suite of requirements tend to favor the selection of wet ponds, and practices that promote infiltration and ET are less likely to be utilized. Ratings are assumed to reflect reliance on ponding basins for volume control and other requirements. Similar Criteria – State of Georgia, Knox County TN	○	○	○	◔	○	○	◑	◑

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

Management Strategy	Example Criteria	Watershed Processes							
		Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	Stream Stability
Flow Control **Retain/Infiltrate Volume** Runoff from all storms up to a threshold depth is retained on site and does not leave as surface runoff.	Section 438 of EISA – Retain 95th Percentile Event Prevent offsite discharge from runoff-generating events up to the 95th percentile precipitation event. This volume must be infiltrated, evaporated/transpired, or harvested for later use to the maximum extent technically feasible. *Note: To achieve high volume retention, there is a strong incentive to use as much of the pervious area for infiltration as possible. Practices such as downspout disconnection and redirection of runoff to pervious areas are likely to be used. By extension, site water quality is likely to be improved since runoff from the vast majority of storms is not allowed to leave the site. Ratings assume that capturing and retaining the 95th percentile event results in the use of a suite of practices that come close to returning the site to pre-development annual hydrology.*	●	●	●	●	○	○	◕	◑
	City of Santa Barbara SWMP – Volume Reduction Requirement Provide retention for the larger of the following two volumes: • The volume difference between the pre- and post-conditions for the 25-year, 24-hour design storm (the "pre-condition" means an undeveloped state) • The volume generated from a one-inch, 24-hr storm event *Note: The Santa Barbara volume reduction requirement applies to Tier 3 Large Projects, defined as > 4,000 ft^2 of new/replaced impervious surface. Tier 1 Small Projects and Tier 2 Medium Projects are exempt. Ratings assume that the requirement results in less volume retention than EISA. The exemptions are also assumed to decrease the overall effectiveness somewhat.*	◑	◑	◕	◑	○	○	◕	◑

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

		Watershed Processes							
Management Strategy	**Example Criteria**	**Overland flow**	**Infiltration and groundwater recharge**	**Interflow**	**Evapotranspiration**	**Delivery of sediment to waterbodies**	**Delivery of organic matter to waterbodies**	**Chemical/biological transformations**	**Stream Stability**
Flow Control **Retain/Infiltrate Volume (continued)**	State of New Jersey – Groundwater Recharge Two options are available. 1. The site retains 100% of its average annual pre-construction groundwater recharge volume, as shown by hydraulic/hydrologic analysis. 2. The increase in runoff volume between the pre-construction and post-construction 2-year storm event is infiltrated, as shown by hydraulic/hydrologic analysis. *Note: For a given site, the New Jersey volume requirement may be less than the EISA volume requirement, since the 95th percentile event is large enough to produce runoff in most regions, which would be in excess of the New Jersey volume. As a result, the ET benefit may be diminished. However, the New Jersey criteria place a strong focus on infiltration, so infiltration, interflow, and groundwater recharge are rated higher than EISA.*	◑	●	●	◑	○	○	◑	◔

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

Management Strategy	**Example Criteria**	**Watershed Processes** Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	**Stream Stability**
Water Quality Treatment Structural BMPs designed specifically for pollutant removal treat runoff from smaller, more frequent storm events.	City of San Diego – Water Quality Criteria • **Volume-based Treatment.** BMPs must treat (infiltrate, filter, or provide extended detention for settling) the volume generated by the 85^{th} percentile storm event. • **Flow-based Treatment.** BMPs must treat a maximum flow rate of runoff produced by a) a rainfall intensity of 0.2 in/hour or b) the maximum runoff rate produced by the 85^{th} percentile storm event multiplied by a factor of two. Similar Criteria – Los Angeles County SUSMP, Riverside County Stormwater NPDES Permit, Sacramento County *Note: The criteria do not require retention of the capture volume, so there is a cost incentive to developers to select flow-based BMPs (such as swales) or detention basins with gradual release rates. As a result, the first four Watershed Processes are assumed to have relatively low ratings. However, Riverside County requires development projects to use practices that promote infiltration first, then use bio-treatment if necessary, and use detention if there are no other alternatives. Depending on enforcement during design review, this requirement could improve the ratings for the first four Watershed Processes.*	○	◑	◑	◑	○	○	◕	◔

Preserve/maintain ● ◕ ◑ ◔ ○ No benefit

		Watershed Processes							
Management Strategy	**Example Criteria**	**Overland flow**	**Infiltration and groundwater recharge**	**Interflow**	**Evapotranspiration**	**Delivery of sediment to waterbodies**	**Delivery of organic matter to waterbodies**	**Chemical/biological transformations**	**Stream Stability**
Water Quality Treatment (continued)	City of Santa Monica – Urban Runoff Mitigation Plan All new development or redevelopment must retain the entire 0.75 inch storm event on site, using structural BMPs, nonstructural BMPs, and storm water reuse to evaporate/transpire, infiltrate, or utilize the captured volume. *Note: The plan was implemented to address water quality concerns; however, the criteria could also be classified as* Retain/Infiltrate Volume *under* Flow Control. *The first four* Watershed Processes *are rated highly since the criterion is sufficiently strict to promote the use of nonstructural and structural practices for infiltration and ET.*	◑	◕	◕	◕	○	○	◕	◔

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

Management Strategy	Example Criteria	Watershed Processes: Overland flow	Watershed Processes: Infiltration and groundwater recharge	Watershed Processes: Interflow	Watershed Processes: Evapotranspiration	Watershed Processes: Delivery of sediment to waterbodies	Watershed Processes: Delivery of organic matter to waterbodies	Watershed Processes: Chemical/biological transformations	Stream Stability
Water Quality Treatment (continued)	City of Santa Barbara SWMP – Water Quality Treatment Requirement • **Volume-based Treatment.** BMPs must treat (infiltrate, filter, or provide extended detention for settling) the volume generated by the 1-inch 24-hour design storm event. • **Flow-based Treatment.** BMPs must treat a maximum flow rate of runoff produced by a rainfall intensity of 0.25 in/hour for four hours. *Note: The Santa Barbara water quality requirement applies to Tier 3 Large Projects, defined as > 4,000 ft² of new/replaced impervious surface. For Tier 1 Small Projects, compliance is voluntary. Tier 2 Medium Projects are required to implement "Basic BMP Options" which include several nonstructural options for reducing runoff at the source.*	○	◑	◑	◑	○	○	◕	◔
	State of Maryland – Water Quality Volume Capture and treat runoff from 90th percentile storm event to achieve an 80 percent annual load reduction for post-development TSS and a 40 percent annual load reduction for post-development TP. Similar Criteria (TSS only) – State of New Jersey, State of North Carolina	○	◑	◑	◑	○	○	◕	◔

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

Management Strategy	Example Criteria	Watershed Processes: Overland flow	Watershed Processes: Infiltration and groundwater recharge	Watershed Processes: Interflow	Watershed Processes: Evapotranspiration	Watershed Processes: Delivery of sediment to waterbodies	Watershed Processes: Delivery of organic matter to waterbodies	Watershed Processes: Chemical/biological transformations	Stream Stability
Preservation of Sediment and Organic Delivery **Buffer Zones** Buffer zones are established adjacent to streams where development and disturbance are limited or excluded. Goals include habitat protection, water quality treatment of upland flow, and maintenance of woody debris, among others. The ratings assume low chemical and biological transformation potential; typically the majority of a development site (>80 percent) lies beyond the zone where runoff can enter the buffer as overland flow. Concentrated flow or piped flow would not be treated. Concentrated flow also carries a high erosion risk.	Teton County and Jackson Wyoming – Land Development Regulations for Protection of Waterbodies and Wetlands (Variable Width) • Major rivers – 150' • Streams with flow > 3 cfs or critical wildlife habitat – 50' to 150' • Wetlands – 30' No development is permitted in the buffers, and uses are severely restricted. Ratings assume that the required width (relative to the other examples) provides hydrology benefits by virtue of increasing the amount of undeveloped natural area, as well as targeting the portion of the landscape (stream corridors) with the strongest connection to hydrology. However, runoff from the developed footprint of sites may not receive any benefit if flow is piped through the buffers, or flow concentrates before entering the buffers.	◔	◑	◔	◔	◕	◕	◔	◔
	North Carolina TMDL Riparian Buffer Rules (50' fixed width) The Rule applies to intermittent and perennial water bodies. The first 30' landward of the edge of the water body must remain as undisturbed forest vegetation. The next 20' feet can have managed vegetation but activities are severely restricted. Existing uses are exempt from the rule if they were present at the time of adoption. The rules apply to all land uses. *Note: The rule addresses the concentrated flow issue by requiring that stormwater runoff must enter the buffer as diffuse flow, by using level spreaders or other devices. As a result, some credit is given to maintaining overland flow, even though the portion of the buffer in native vegetation is relatively narrow.*	◔	◔	○	○	◕	◕	◔	◔

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Preservation of Sediment and Organic Delivery **Buffer Zones (continued)**	<u>City of Napa – Municipal Code (20' fixed width)</u> The City requires a development setback of 20' from perennial and intermittent streams for channel erosion protection goals. No building is allowed in the setback, and the setback area is to be protected from access using fencing, etc. The area is to be maintained in a natural state. *Note: Natural vegetation requirements appear to be less strict in the Napa requirements than in the other examples, so* Delivery of Organic Matter *is rated less highly.*	○	◔	○	○	◑	◑	◔	◔
Preservation of Sediment and Organic Delivery **Buffer Zones (continued)**	<u>Santa Cruz – City-wide Creeks and Wetlands Management Plan (Variable Width)</u> The Plan maps the watercourses and known wetlands in the City and identifies development setbacks based on stream and channel type, habitat type, extent of existing riparian vegetation, wildlife habitat, and existing land use patterns. Each waterbody is placed in one of three categories: • Category A (125' or more) – high quality habitat, few gaps in the vegetated corridor, or special species • Category B (30' to 125') – limited riparian habitat in urban areas • Category C (no buffer)– low or no habitat value (e.g., concrete channels) A separate riparian corridor with restricted uses is established within the setbacks; the width of the corridor varies based on local conditions and protection goals. *Note: Santa Cruz is not rated differently than Teton County, but it provides an alternative method for achieving goals.*	◔	◑	◔	◔	◕	◕	◔	◔

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

Management Strategy	Example Criteria	Watershed Processes: Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	Stream Stability
Land Preservation **Open Space Requirements** A portion of a site is set aside either as natural area or for passive recreational use. In some cases the purpose is linked directly to hydrology and water quality goals. More often, land preservation is required for aesthetic or other reasons. The following examples reflect open space requirements specifically for hydrology/water quality.	<u>King County, Washington – Requirements for Sensitive Watersheds</u> In its Surface Water and Drainage Ordinance, King County has strict forest preservation requirements for select watershed areas. Clearing must be limited to a maximum 35 percent of the lot or plat area. If the approved permit requires a flow control and water quality facility, then clearing can be increased to 60 percent of the lot or plat area. *Note: The* Watershed Process *ratings assume the 35 percent clearing limit. The Sediment and Organic Matter delivery ratings assume that development avoids stream corridors in favor of upland areas.*	◕	◕	◕	◕	◕	◕	◑	◔
	<u>City of Bothell, Washington – Regulations for Sensitive Watershed Areas</u> To protect the ground and surface water within the Palm, Woods, and Cole Creek drainage areas, the City requires that forest cover on a development site not be less than 50 percent for lands zoned 10 units per acre, and 60 percent for lands zoned 1 or 5 units per acre. Forest cover is to be based upon the gross area of the total site, not just the lots. *Note: The* Watershed Process *ratings assume the 50 percent clearing limit. The Sediment and Organic Matter delivery ratings assume that development avoids stream corridors in favor of upland areas.*	◑	◑	◑	◑	◕	◕	◑	◔

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

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Land Preservation **Open Space Requirements (continued)**	Mecklenburg County, North Carolina – Undisturbed Open Space Requirements The post-construction stormwater ordinance stipulates that undisturbed natural open space area is required for all development unless mitigated offsite. The percentage of the natural open space area required depends on a project's built upon area: sites with less than 24 percent built upon area require a minimum 25 percent undisturbed open space; sites with between 24 percent and 50 percent built upon area require a minimum 17.5 percent undisturbed open space; and sites with greater than 50 percent built upon area, a minimum of 10 percent undisturbed open space is required. Previously disturbed areas can be re-vegetated to meet the requirement.	◔	◔	◔	◔	◔	◔	◔	○

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Land Preservation **Minimize Effective Impervious Area** Effective Impervious Area (EIA) represents the portion of the site with impervious surfaces that generates runoff directly to the site's drainage system. If runoff from impervious surfaces is allowed to flow onto pervious surfaces and infiltrate (i.e., disconnection), then EIA may be reduced.	<u>City of Bothell, Washington – Regulations for Sensitive Watershed Areas</u> In order to protect surface and ground waters and provide cool water sources, the City enacted a number of measures including limitations in EIA for new development and redevelopment. EIA shall not exceed 20 percent for lands zoned 5 and 10 units per acre, and 15 percent for lands zoned 1 unit per acre based upon the gross area of the total site. *Note: The EIA requirements are not particularly strict for the 1 unit per acre criterion. In addition, the requirements apply only to impervious surfaces and do not address clearing limits or preservation of natural vegetation. At a result, many of the ratings are relatively low.*	◔	◔	○	◔	○	○	○	○
	<u>State of Delaware – Final Draft Stormwater Regulations</u> Delaware's Draft Sediment Control and Stormwater Management Regulations require impervious area to be controlled such that there is no direct contribution of stormwater runoff (i.e., the equivalent of 0 percent effective impervious area). Specifically, the regulations require that after runoff reduction practices have been implemented on the disturbed area, the site's impervious area shall not directly contribute stormwater runoff during a rain event that has a 99 percent annual probability of occurring. While the regulations are under public review, they have been under development with stakeholder participation during the previous year. *Note: A high degree of disconnection should rate well for site hydrology, but does not guarantee protection of stream corridors. Flow directly to pervious surfaces may re-concentrate, especially for large storm events that would quickly inundate the infiltration capacity of site pervious area. The stream stability rating is assumed to reflect moderate protection.*	◕	◕	◕	◕	○	○	◕	◑

Preserve/maintain ● ◕ ◑ ◔ ○ No benefit

Management Strategy	Example Criteria	Watershed Processes: Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	Stream Stability
Maintenance of Soil and Vegetation Regime Soil and vegetation are maintained to allow treatment of precipitation via the physical and biological processes that occur in soil. These differ from *Open Space Requirements* in their goal of preventing soil disturbance to protect natural soil processes.	Seattle, Washington – Green Factor The purpose of this ordinance is to increase the quality and quantity of landscaping in urban areas. Numerous landscaping elements can be used to achieve the required Green Factor score for each zoning district. Of the different landscape element options a developer can choose in order to meet the required Green Factor score, landscape areas with a soil depth of more than 24 inches or more are given one of the highest multipliers or weights, essentially incentivizing soil preservation. Similar Criteria – Washington D.C. Green Area Ratio	Not rated since the benefit is scaled to the area of implementation. The Green Factor is discussed in more detail in the Example Programs table.							

	✓ **Approach addresses Watershed Process**	**Watershed Processes**						
Example Program	**Approaches**	**Overland flow**	**Infiltration and groundwater recharge**	**Interflow**	**Evapotranspiration**	**Delivery of sediment to waterbodies**	**Delivery of organic matter to waterbodies**	**Chemical/biological transformations**
Bay Area NPDES Permit Permittees must require "Regulated Projects" to implement one or more of the listed site design measures.	Direct roof runoff into cisterns or rain barrels for reuse. *Note: Rating assumes captured water is used for outdoor irrigation.*		✓		✓			
	Direct roof runoff onto vegetated areas.	✓	✓	✓	✓			
	Direct runoff from sidewalks, walkways, and/or patios onto vegetated areas.	✓	✓	✓	✓			
	Direct runoff from driveways and/or uncovered parking lots onto vegetated areas.	✓	✓	✓	✓			
	Construct sidewalks, walkways, and/or patios with permeable surfaces.		✓					
	Construct bike lanes, driveways, and/or uncovered parking lots with permeable surfaces.		✓					

✓ **Approach addresses Watershed Process**

Example Program	Approaches	Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations
Seattle Green Factor The Seattle Green Factor requires certain types of development to achieve a cumulative score by implementing a set of practices. While the stated purpose is to increase the quality and amount of planted areas, the practices address other goals including reducing runoff and improving water quality. Select practices are listed with some context about how they are scored.	Landscaped areas with a soil depth 24 inches or greater are given six times the credit of landscaped areas with soil depths less than 24 inches.		✓	✓	✓			
	For vegetation planted in landscaped areas, the highest credit is given for trees that are large at maturity (canopy spread of 26 to 30 feet)				✓			
	A very high credit (2 times the large tree credit in the previous approach) is given for preserving existing trees with trunks six or more inches in diameter.				✓			
	Green roofs	✓			✓			
	Permeable pavement	✓	✓	✓	✓			
	Vegetated walls receive a high credit to meet aesthetic goals of the program, but they do provide benefits to Watershed Processes				✓			
	A bonus is provided for using rainwater harvesting (i.e., cisterns) to supply 50 percent or more of annual irrigation to landscaped areas		✓		✓			