Balancing the Water Budget: the effect of plant functional type on infiltration to harvest ratios in stormwater bioretention cells

Lauren Krauss

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
In
Environmental Engineering

Megan Rippy, Chair
Brian Badgley
Stanley Grant

Dec. 16, 2020
Manassas, Virginia

Keywords: bioretention cells, infiltration, evapotranspiration, water budget, functional traits, turgor loss point, stomatal conductance, point of incipient water stress

Balancing the Water Budget: the effect of plant functional type on infiltration to harvest ratios in stormwater bioretention cells

Lauren Krauss

ABSTRACT

Stormwater bioretention cells (BRCs) are a variety of green stormwater infrastructure with the potential to restore pre-urban water balance, provided they can be tailored to infiltrate and evapotranspire (i.e., harvest) urban runoff in proportions consistent with pre-urban hydrologic conditions. This paper evaluates their capacity to do so, focusing on evapotranspirative harvest, which is relatively understudied, and the capacity of CSR (Competitve, Stress-tolerant, and Ruderal) functional type to serve as an overarching framework characterizing the water use strategy of BRC plants. The goal is to determine if harvest (and therefore the ratio of urban runoff infiltrated to harvested; the I:H ratio) might be fine-tuned to meet pre-urban values in BRCs through informed manipulation of plant community composition. This study focuses on 3 critical plant water use traits, the turgor loss point, the point of incipient water stress, and maximum stomatal conductance. A global plant traits meta-analysis identified degree of plant competitiveness and stress tolerance as significant determinants of all three water use traits, with stem type (woody vs herbaceous) also being significant, but only for turgor loss point. Based on these results, six water use scenarios appropriate for plants with different CSR type/stem type combinations were developed. BRC plants spanning the range of CSR types necessary to actionize these scenarios were determined to be available in eight major climate zones of the coterminous US, suggesting that regulating plant water use in BRCs using CSR is likely feasible. Hydraulic simulations (Hydrus 1D) were conducted for each scenario in all eight climate zones and revealed significant differences in evapotranspirative harvest and I:H ratios in simulated BRCs. Competitive woody plants had the highest evapotranspiration and lowest I:H ratios; 1.5-1.8 times more evapotranspiration and a 1.6-2 times lower I:H ratio than stress tolerant herbaceous plants, on average, across climate zones. Despite these significant differences, no simulated BRC in any climate zone was capable of reproducing pre-urban I:H ratios, regardless of plant type. More water was infiltrated than harvested in all scenarios and climates with the inverse being true for all pre-urban conditions. This suggests that absent additional sources of harvest (e.g., use of BRC water for nonpotable purposes such as toilet flushing and outdoor irrigation, or adoption of novel BRC designs that promote lateral exfiltration, stimulating "extra" evapotranspiration from nearby landscapes), BRCs will be unable to restore pre-urban water balance on their own. If true, then using BRCs in combination with other green technologies (particularly those biased towards harvest), may be the best path forward for balancing urban water budgets.

Balancing the Water Budget: the effect of plant functional type on infiltration to harvest ratios in stormwater bioretention cells

Lauren Krauss

GENERAL AUDIENCE ABSTRACT

The increase in paved surfaces in urban areas has led to a dramatic increase in the amount/speed of stormwater runoff entering natural waterways. Stormwater bioretention cells (BRCs) are a variety of green infrastructure designed to manage urban stormwater that can dramatically reduce the amount of runoff conveyed from paved surfaces to natural waterways. They do this redirecting or removing water from the system through infiltration – slowly filtering water down to the water table – and evapotranspiration – letting plants capture and transpire water back to the atmosphere, which is considered a form of water harvest. Harvested water is water that is captured locally (by plants or people) but not returned to local waterways. This thesis evaluates the extent to which different plant types (1. fast growing, competitive plants, 2. slow growing, stress tolerant plants, and 3. short-lived, weedy plants) can be used to regulate rates of infiltration and evapotranspiration in BRCs and bring urban flow conditions closer to pre-urban ones. Competitive plants, stress tolerant plants and plants with strategies between the two were found to significantly influence water use; higher transpiration was positively associated with competitiveness and negatively associated with stress tolerance. Current BRC vegetation guidelines in 8 major US climate zones include plants that possess this range of strategies, suggesting it may be possible to manipulate water use in BRCs by varying plant type. This was formally evaluated using model simulations where water use in BRCs was assessed under six plant scenarios falling along the competitive to stress tolerant plant strategy gradient. These

simulations revealed significant differences in the ratio of water infiltrated to evapotranspired in BRCs, illustrating that plant type meaningfully effects water use. The magnitude of this effect may be insufficient to return urban flow conditions to pre-urban ones, however. All BRCs infiltrated too much water suggesting that without additional water harvest, BRCs will be unable to restore pre-urban conditions. If true, then using BRCs in combination with other green infrastructure forms that prioritize harvest may be the best path forward for balancing urban water budgets.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1. INTRODUCTION

Green stormwater infrastructure such as bioretention cells (BRCs), also called biofilters or rain gardens, are an increasingly prevalent low impact development solution employed by municipalities to mitigate urban drainage problems [**Walsh et al., 2016, McPhillips and Matsler, 2018, Bell et al., 2020**]. BRCs capture overland flow from impervious surfaces and reallocate it to 1) subsurface drainage (i.e., shallow or deep groundwater – infiltrative BRCs), 2) plant uptake/evapotranspiration or human use – harvesting BRCs, or 3) some combination of the two - hybrid BRCs [**Askarizadeh et al., 2015**]. In the absence of reallocation by green infrastructure, most rainfall on impervious surfaces becomes overland runoff, which is routed (at high volumes and velocities) to formal drainage systems and eventually urban waterways, contributing to a slew of hydrologic, ecological, morphological, and water quality problems, known "collectively" as the urban stream syndrome [**Walsh et al., 2005, Walsh et al., 2016, Askarizadeh et al., 2015**]. While it remains unclear whether retrofitting urban catchments with green stormwater infrastructure can reverse the urban stream syndrome in its entirety [**Shuster and Rhea, 2013**, **Roy et al., 2014**, **Li et al., 2017**], retrofits have shown promise for mitigating some of its hydrologic symptoms (particularly peak flow rates and overland runoff volumes; **Bell et al., 2020, Jefferson et al., 2017**). However, restoring urban catchment hydrology is as much about managing how water from urban catchments is reallocated as it is about managing overall volumes and frequencies. Substantially less is known about the former, sometimes expressed as the capacity of green infrastructure to mimic "pre-urban water balance", which is increasingly recognized as a gold standard for urban catchment restoration and a key principle of urban stormwater management [**Askarizadeh et al., 2015, Walsh et al., 2016**, **Eger et al., 2017, Tavakol-Davani et al., 2019**].

When evaluating the capacity of a green infrastructure element to “mimic” pre-urban water balance on an annual basis, it is useful to consider the ratio of rainfall volume it infiltrates and harvests (the I:H ratio) at some acceptable level of overall runoff capture (i.e., few rainfall events) generate runoff in excess of the storage capacity of the system, limiting the production of overflow water that is not subject to reallocation or treatment [**Walsh et al., 2012**, **Askarizadeh et al., 2015**, **Eger et al., 2017**]. Using a simple annual bucket model for an urban catchment with Low Impact Development, LID, (based on Walsh et al., [**2012**]), Askarizadeh et al., [**2015**] illustrated that the ratio of I:H by green infrastructure required to maintain pre-urban water balance depended on only two catchment-level variables, mean annual rainfall (MAR) and pre-urban fraction of forest (f_F). For most combinations of MAR and f_F, more water needed to be harvested by green infrastructure than infiltrated to maintain (or restore) pre-urban flow regimes, which elevates the importance of harvest-based or hybrid green infrastructure elements like BRCs (which have the potential to mimic desired I:H ratios, exactly) as candidate stormwater management solutions [**Askarizadeh et al., 2015**]. Unfortunately, our understanding of the harvest (evapotranspirative) component of hybrid green infrastructure water budgets is limited, presently lagging our understanding of the infiltrative component [**Ebrahimian et al., 2019, Feng et al. 2016**]. This complicates efforts to evaluate the capacity of these systems (or in the future, pro-actively tailor them) to restore pre-urban catchment hydrology.

Although somewhat rare, mesocosm (and in some cases field-scale) studies of evapotranspiration by green stormwater infrastructure, suggest that harvest can be a significant component of green infrastructure water budgets, particularly in green roofs, where 30-88% of the stormwater volume reduction is attributable to evapotranspirative losses [**Di Giovanni et al., 2013**, **Embrahimian et al., 2019**]. Less is known about evapotranspiration in BRCs. However, because the catchment area to BRC area ratio tends to be quite large (i.e., the surface area available for evapotranspiration is small relative to the area of catchment BRCs receive inflow from), they might be expected to infiltrate more water than they evapotranspire, which could limit their capacity to restore pre-urban water budgets [**Brown et al., 2011**]. This would be consistent with work by Hamel et al [**2011**] and Li et al., [**2009**], where evapotranspirative harvest was the fate of only 2-19% of captured runoff volume. Some studies indicate, however, that evapotranspiration by BRCs can be substantial (responsible for >70% of their stormwater volume reduction in the growing season; **Wadzuk et al., 2015, Nocco et al., 2016, Embrahimian et al., 2019**), making it somewhat unclear where they fall on the infiltration to harvest spectrum.

Meteorological variables, catchment ratio, filter media depth and composition, ponding zone height, and vegetation type have all been shown to significantly influence evapotranspiration by BRCs, with the effects of vegetation type being among the least well characterized [**Carson et al., 2013, Meng et al., 2014, Nocco et al., 2016, DiGiovanni-White et al., 2018, Payne et al., 2018, Lundholm et al., 2015, Embrahimian et al., 2019**]. While it is recognized that evapotranspiration differs significantly among BRCs with different plant communities (see, for instance, **Nocco et al., 2016**), there is presently no agreed upon framework for translating a given BRC plant community composition into an expected evapotranspiration profile such that evapotranspirative harvest might be manipulated by engineers and landscape planners through careful plant selection at the design stage. In agricultural settings with monoculture crops we might use the Pennman Monteith equation and a species-specific crop coefficient to estimate evapotranspiration given measured meteorological variables [**Allen et al., 1998**], but the diversity of plant species used in BRCs across the continental US makes this approach daunting for green infrastructure. In effect, we require some kind of framework for classifying BRC plants into water use functional types such that we can account for the effect of functionally meaningful differences in BRC plant composition on evapotranspiration (and therefore I:H ratios) without necessitating species-level information on water use characteristics.

One likely possibility is universal adaptive strategy coined by Grime [**1977**], which recognizes 3 major plant functional types (C – competitive, S – stress tolerant, and R – ruderal), that have fundamentally different resource allocation strategies and above/below ground plant traits that reflect those strategies. Although originally framed in terms of nutrient (particularly nitrogen) allocation, work by Reich [**2014**] recognized that universal adaptive strategy theory can be considered part of a broader fast-slow plant economics spectrum that encompasses issues of water resource allocation (and therefore evapotranspiration) in addition to nutrients. In this framework, stress tolerant and competitive plant functional types are expected to exhibit traits that lie on opposing poles of the fast-slow plant economics spectrum, with plants that are more stress tolerant (slow) exhibiting traits that minimize water use and therefore maximize drought tolerance (e.g., low wilting point, low incipient water stress and low maximum stomatal conductance), and plants that are more competitive (fast) exhibiting traits that favor growth and are expected to maximize water use, such as high stomatal conductance (**Reich., 2014, Volaire, 2018**). Because C, S, and R functional types are associated with variation in plant water use, and it's relatively easy to classify plants to these functional types using simple leaf trait measurements and a series of globally calibrated equations developed by Pierce et al. [**2017**], CSR seems like an ideal candidate framework for exploring the relative capacity of different BRC plants to contribute to evapotranspirative harvest, and up or down regulate I:H ratios, in a way that could be meaningful for engineering practice.

In this paper we aim to do exactly this: evaluate the utility of CSR strategy as a framework for classifying common BRC plants into water use functional types that can be used to design for evapotranspiration (and help meet pre-urban I:H ratios) using green infrastructure. The paper is organized into three sections each of which addresses a possible feasibility barrier to moderating I:H ratios using CSR. Section 1 (*Is it theoretically possible?*) presents the results of a formal meta-analysis designed to determine if common plant-associated variables that regulate evapotranspiration in BRCs (for instance, wilting point, the point of incipient water stress, and maximum stomatal conductance) differ significantly by CSR strategy such that evapotranspirative harvest by these functional types might reasonably be expected to differ. Section 2 (*Are the tools available?*) takes a broad look at CSR types of recommended BRC plants in ~16 county and state BRC design manuals spanning eight Koppen-Geiger climate zones of the conterminous US. The intent is to determine what plant functional types are most common in BRCs and whether the raw material - e.g., range of functional types necessary to manipulate I:H ratios through CSR - is actually available across most climate regions. Finally, Section 3 (*Is the effect meaningful?*) takes the results of the meta-analysis from Section 1 and uses them as a basis for a series of scenarios featuring BRC plants with different CSR types and evapotranspiration-associated variables, including wilting point, the point of incipient water stress, and maximum stomatal conductance. These scenarios are used to evaluate the effects of different BRC plant choices on evapotranspirative harvest and I:H ratios in simulated BRCs from the 8 above-mentioned Koppen-Geiger climate zones using Hydrus-1D. We determine if 1) manipulating plant functional type significantly alters evapotranspirative harvest and/or I:H ratios, and 2) if any of the plant scenarios evaluated (in any climate zone) result in I:H ratios that mimic pre-urban water balance (estimated in accordance with the simple catchment bucket model proposed by Askarizadeh et al., [**2015**]).

2. METHODS

2.1. Is it theoretically possible?

2.1.1 Plant-associated variables that regulate evapotranspiration

Several key plant-associated variables regulate evapotranspiration (ET) in BRCs, including maximum stomatal conductance at full plant turgor, leaf area index (LAI), plant height, albedo, the turgor loss point (TLP), and the point of incipient water stress (IWS). The first three variables are themselves plant traits whereas the remainder are co-regulated by both plants and soil media. The TLP, sometimes referred to as the wilting point, is defined as the soil water potential where plants can no longer draw water to transpire (**Bartlett et al., 2012, 2014, 2016**). Plant species with the most negative TLPs are able to maintain evapotranspiration under the driest conditions. Beyond the TLP, water loss from a soil-plant system is primarily through evaporation (**Laio et al., 2001, Brodribb et al., 2003**). IWS lies at the other end of the spectrum, representing the soil water potential where plants first begin to reduce evapotranspiration as soils dry (**Laio et al., 2001, Daly et al., 2009**). Operationally, IWS is defined as the soil water potential where stomatal conductance is 90% of maximum **(Manzoni et al., 2014**); at less negative water potentials plants transpire at their maximum rate and at more negative water potentials transpiration declines, ceasing entirely once the TLP is reached. The maximum rate of evapotranspiration that can potentially be achieved (pET) depends on both plant-regulated variables (albedo, stomatal conductance, leaf area index, and plant height) as well as climatic variables (temperature, wind speed, relative humidity, and solar radiation), and can be described using the Penman-Monteith equation (**Allen et al., 1998**),

$$pET = \frac{1}{\lambda \rho_w} \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \qquad \text{EQ 1}$$

where R_n = net radiation (a function of albedo), r_s = surface resistance (a function of stomatal conductance and LAI), r_a = atmospheric resistance (a function of plant height), G = the soil heat flux, Δ = the slope of the saturation vapor pressure temperature relationship, $e_s - e_a$= the pressure deficit of the air, ρ_a = the mean air density at constant pressure, ρ_w = the mean water density at constant pressure, c_p = the specific heat of air, γ = the psychometric constant, and λ = the latent heat of water. Plants that are tall and have low albedo, high stomatal conductance, and high LAI have higher ET than plants that are herbaceous with high albedo, low stomatal conductance and low LAI.

Of the above-mentioned plant variables that regulate ET, we expect maximum stomatal conductance, TLP, and IWS to vary by plant functional type (C, S, or R), in accordance with the fast-slow plant economics spectrum described above [**Reich., 2014, Volaire, 2018**]. Albedo, LAI, and plant height are less likely to vary strictly by CSR type as they principally reflect non-resource related constraints (for instance growth form, in the case of plant height; **Moles et al. 2009**), rather than the resource-related ones pertinent to CSR (e.g., availability/allocation of nutrients and perhaps water; **Pierce et al. 2013**). For this reason, we will limit our assessment of relationships between CSR type and ET-associated variables to wilting point, incipient water stress and maximum stomatal conductance. Our formal meta-analysis procedure and Classification Regression Tree (CART) approach for identifying instances where plants of a given functional type exhibit significant differences in their ET-associated variables are described below.

2.1.2. ET-trait and CSR type Meta-analysis

Previously published data on wilting point (a.k.a. turgor loss point; TLP) was compiled using a Web of Science search (search date: 3/10/2020) for the terms “turgor loss point” and “leaf water potential". This search returned 97 articles, the majority (59) of which had been collated previously in other meta-analyses (e.g., **Bartlett et al. 2012, 2014, and 2016**), and were therefore redundant. Twenty-one articles that did not provide species-specific TLP information in an accessible form (i.e., a table, digitizable figure, or supplemental data file) were also excluded from analysis. The final 17 (including the Bartlett et al., meta-analyses) were compiled into a master datafile containing TLP values for 585 unique plant species. 130 of these species were classified by CSR type allowing variability in TLP as a function of CSR to be explored (**Table S1**). Two main approaches were used to classify plant species by CSR type: 1) species-specific reports of CSR type in the literature or 2) species-specific leaf trait measurements (i.e., leaf dry matter content; LDMC, specific leaf area; SLA and leaf area; LA), either from the literature or made by the authors, which were used to calculate CSR type in accordance with a series of globally calibrated equations developed by Pierce et al., [**2017**]. All leaf trait measurements made by the authors followed standard methods detailed in Corneilissen et al., [**2003**].

A similar meta-analysis approach was used to gather data on maximum stomatal conductance and incipient water stress (IWS). This time, the Bartlett et al., meta-analyses were used as a starting point. Because the Bartlett meta-analyses emphasize woody plants and are only current up to 2016, a Web of Science search was performed to gather additional publications for herbaceous plant species (search terms: "stomatal conductance"; "water potential"; "herbaceous" – *41 publications total*) and woody plant species evaluated post 2016 (search terms: "stomatal conductance"; "water potential"; "woody" – *40 publications total*). From this search 17 studies describing new datasets for leaf (or soil) water potential and stomatal conductance were identified and combined with those from the Bartlett meta-analyses. Maximum stomatal conductance values and IWS (expressed in terms of soil water potential) were either sourced directly from published tables or estimated using the following approach; Stomatal conductance (y) and leaf water potential (x) data were digitized, and linear, exponential, logistic and sigmoid curves were fit to the data using R statistical software. The best-fit curve for each species (i.e., the one with the smallest AICc value) was used to calculate maximum stomatal conductance (the theoretical maximum conductance at a leaf water potential equal to 0 MPa; see **Henry et al., 2019**) and IWS (leaf water potential at 90% of maximum stomatal conductance, subsequently expressed in terms of soil water potential using E2 (2));

$$\Psi_s = \Psi_l - \left(\Delta s, r + \Delta r, x + h_p(\Delta x, l)\right) \qquad \text{EQ 2}$$

where Ψ_s = the soil water potential ~ 10mm from the root, Ψ_l = leaf water potential, $\Delta s, r$ = the change in water potential between Ψ_s and soil adjacent to the root (-0.2 MPa), $\Delta r, x$ = the change in water potential between soil adjacent to the root and the root xylem (-0.1 MPa), h_p= plant height in meters, and $\Delta x, l$ = the change in water potential per meter plant height (-0.02 MPa). Each delta in EQ (2) represents a component of the soil-plant-atmosphere continuum, with representative values drawn from Nobel, [**2009**]. The median correction ($\Psi_s - \Psi_l$) resulting from EQ (2) was 0.36 MPa, with a maximum of 0.900 MPa (30 m tree) and a minimum of 0.303 MPa (dwarf shrub). CSR functional type information (compiled as described above) was available for a total of 91 plant species where stomatal conductance and incipient water stress were also known (**Table S2**). This dataset was used to explore variability in stomatal conductance and incipient water stress as a function of CSR type using Classification and Regression Trees (CART), getting at our first principle question: is it theoretically possible to manipulate these traits (up or down regulating water use in a consistent manner) through changing CSR type?

2.1.3. CART Analysis and CSR Scenario Development

CART was used to identify "split points" about which plants with more/less of a specific CSR strategy differed significantly in their water use variables. Separate regression trees were built for each variable (TLP, IWS and maximum stomatal conductance). Growth form (tree, shrub, forb, graminoid), and stem type (woody vs herbaceous) were included alongside C, S, and R in all analyses in the event that these common classification schemes were more predictive of differences in water use traits than plant functional type. For IWS and maximum stomatal conductance two additional variables were also included: 1) the method used to measure stomatal conductance (porometry or infrared gas analyzer), and 2) study age. These variables were included to check for artifacts in our meta-analysis approach; measurement method has been shown to influence estimates of stomatal conductance in other studies (see **Murray et al., 2019**) and rising CO_2 levels (approximated here using study age) are expected to influence stomata number and function, impacting both max stomatal conductance and timing of stomatal closure (**Engineer et al., 2016**). Explicitly accounting for both ensures that any patterns they generate in our combined dataset are not misattributed to other factors.

CART was employed for this analysis in lieu of alternative approaches such as multiple linear regression because it builds models using a binary series of if/else decisions. This makes it useful for scenario development as the model structure itself identifies both the significant independent variables that should be considered in scenarios, and the split point where differences in those variables lead to maximally different outcomes in a dependent variable of interest; in effect, the value ranges that should be explored for each independent variable to generate an exhaustive set of divergent scenarios are explicitly provided by the model.

CART models were constructed in R software using the package rpart (**Therneau and Atkinson, 2015**). Trees were grown to their full depth using mean squared error as the splitting criterion and then pruned using leave-one-out cross validation to a depth within 1 standard deviation of the minimum mean squared error (smallest tree method – **Therneau and Atkinson, 2015**). Pruned trees were used to develop 6 unique plant water use scenarios (featuring divergent maximum stomatal conductance, TLP and IWS values) for plants with different functional types. To ensure that BRC plants actually take on the full range of functional types included in these scenarios, a survey of "recommended vegetation lists" from published BRC design manuals was performed, classifying as many recommended plant species to CSR type as possible (detailed methods in **section 2.2**).

2.2. Are the tools available?

The coterminous US contains 17 distinct Koppen-Geiger climate zones, where each zone is defined based on seasonal temperature and rainfall [**Beck et al., 2018**] (**Fig. 1**). Six of these zones are only minimally present (covering less than 100,000 km^2). Of the remaining 11, BRC design manuals (county or state), complete with recommended vegetation lists, were available for 8. Attempts were made to identify at least 2 BRC vegetation lists per climate zone, although this was not always possible. Notably, some climate zones have many more vegetation lists than were evaluated here, as our intent was to conduct a representative (but not exhaustive) sampling of existing manuals to establish the average (and range) of CSR functional types present in each zone. County level design manuals were preferred over state (or regional) manuals as many states/regions span multiple climate zones (**Fig. 1**). In instances where state/regional design manuals were used, the climate zone for those manuals was determined to be the dominant climate zone for the respective state/region estimated using ArcGIS Pro 2.5.2 (**ESRI, 2020**).

The following climate zones (and state/county BRC design manuals) were evaluated in this study; 1) hot desert (Bwh), with design manuals from Pima and Maricopa counties in AZ [**Tucson LID, 2015, Conner et al., 2019**], 2) cold semi-arid (Bsk), with design manuals from Placer County CA, Salt Lake City UT, Denver CO, and Eastern WA State [**Utah LID, 2018, Carlson et al., 2013**], 3) hot-summer Mediterranean (Csa), with design manuals from San Diego CA, Placer CA, and the Southern CA Coast [**SDDM, 2016, Tahoe BMP, 2014, SoCal LID, 2010**], 4) warm summer Mediterranean (Csb), with design manuals from the Central CA Coast, Multnomah OR, and King WA [**Central Coast TAM, Olympia BMPs, 2016, SWMM, 2016**], 5) humid subtropical (Cfa), with design manuals from the states of AL, NC, SC, and FL as well as St. Luis MO, and Austin TX [**Dylewski et al., 2016, Ward and Banhunyadi, 2019, Ellis et al., 2014, Waickowski et al., 2018, Missouri GI, 2012, Austin ECM, 2014**], 6) hot summer humid continental (Dfa), with design manuals from the states of IN and WV [**Fishers SW TSM, Tabassum et al., 2012**], 7) warm summer humid continental (Dfb), with design manuals from the states of MI, MN, PA and VT [**Michigan LID, 2008, MSM Wiki, 2003, PA BMP, 2006, Vermont RGM, 2011**], and 8) warm summer Mediterranean continental (Dsb), with a design manual from Boise ID [**Ogle and Hoag, 2000**] (**Table S3**). Each county, state or region where a BRC design manual was sourced is highlighted in dark grey in **Fig. 1**.

Plant species from each design manual were classified by CSR type using the same approach detailed in section 2.1.2. **Table S4** provides a comprehensive list of these CSR classifications, organized by design manual and climate zone, that includes any references for leaf trait measurements used to calculate CSR in accordance with Pierce et al., [**2017**]. On average, 32% of recommended plant species were classified to CSR type in each climate zone (min of 9% in Bwh, max of 50% in Dfb; **Table S3**). As a check on the representativeness of these classified CSR subsets, the relative proportions of plant growth forms (graminoid, forb, shrub, tree) and stem types (woody, herbaceous) in each subset were compared to those from the full dataset for each respective climate zone, the idea being one form of subsample bias (over or under-representation of growth forms/stem types) can serve as a warning that other forms (e.g., pertaining to CSR type) may have occurred.

2.3. Is the effect meaningful?:

2.3.1 Hydrus Simulations:

The six plant water use scenarios developed in section 2.1.3 were evaluated using Hydrus-1D (which dynamically solves the Richard's equation for variably saturated flow), for a series of simulated BRC elements (one per climate zone; section 2.2), in order to determine if changes in water use variables that occur in response to shifts in CSR type significantly effect evapotranspirative harvest or I:H ratios in BRCs. All simulated BRCs had a surface area to catchment area ratio (CR) of 4.5% (consistent with reported catchment ratios on both the west and east coasts of the US; **Waller et al., 2018, Ambrose and Winfrey, 2015**), and a runoff coefficient (C_e) of 0.9, appropriate for simulating runoff from a paved surface such as a parking lot (**Nicklow et al., 2004 and 2006**). Filter media depth and ponding zone depth were set to 1 m and 0.3 m, respectively, reflecting typical design guidelines [**MSDM, 2000, Ellis. et al., 2014**]. Filter media composition was 55% sand, 35% silt, and 10% clay (e.g., sandy loam – selected based on [**MSDM, 2000**]). The Rosetta Lite Dynamically Linked Library (neural network option in Hydrus) was used to translate these values into water retention parameters and saturated hydraulic conductivity for use in the van Genuchten-Maulem soil hydraulic model in Hydrus. Model parameters include, the residual soil water content: $\theta_r = 0.042$ [-], saturated soil water content (i.e., porosity): $\theta_s = 0.390$ [-], bubbling pressure: $\alpha = 1.84$ [1/m], pore size distribution index: $n = 1.430$ [-], saturated hydraulic conductivity: $Ks = 0.0131$ [m/hr], and pore connectivity parameter: $l = 0.5$ [-]. All BRCs were initialized with saturated filter media.

BRC inflow (I) varied by climate zone and was estimated using the Rational method,

$$I(t) = (\mathrm{CR}/C_e + 1)P(t)\mathrm{CR}^{-1}C_e \qquad \text{EQ 3}$$

where $P(t)$ is precipitation (m), and the other variables have been described previously. Precipitation data were sourced from eight US Climate Reference Network meteorological stations (1 per climate zone; see black dots in **Fig. 1**). Stations were selected based on proximity to counties/states where BRC plant lists were sourced, and frequency/temporal coverage of station records (goal of four years of coverage between 2016 and 2020, with measurements reported at an hourly timestep).

Inflow into each BRC had three possible fates: 1) overflow: whereby inflow volumes accumulate in the ponding zone and exceed its capacity, 2) drainage: whereby inflow infiltrates into filter media and drains to an underdrain, typically a perforated pipe (seepage face boundary condition, pressure head = 0 m [**Meng et al., 2014, Pan et al., 2020**]), or 3) evapotranspiration: whereby inflow infiltrates into filter media and is subsequently taken up by plants and transpired or evaporated from the soil surface. Evapotranspiration in Hydrus is specified with *pET* as an upper bound, with the minimum allowed surface pressure head (*hCritA*) constraining the amount of water actually evaporated, and root water uptake functions constraining the amount of water actually transpired [**Simunek et al., 2013**].

In our simulations, *hCritA* was set to -500 m (lower than the wilting point across all water use scenarios but higher than the filter media's residual water content, expressed in units of pressure head (m), consistent with [**Daly et al., 2009, Simunek et al., 2013**]). Uncompensated root-water uptake was modeled as a function of pressure head using Feddes linear root-water uptake model [**Feddes et al., 1978, Simunek and Hopmans, 2009**]. This model was parameterized differently for each water use scenario evaluated. These, and all other scenario-specific differences were guided by our plant trait meta-analysis (section 2.1.2), and will be described in section **3.1**. From full saturation to the point of IWS (scenario dependent), root water uptake was allowed to occur at its maximum possible rate (the max transpiration rate; scenario and climate zone dependent). After the point of IWS, root water uptake declined linearly, reaching zero at the TLP, another scenario-dependent parameter [**Laio et al., 2001, Daly et al., 2009**]. The max transpiration rate for each scenario was determined by partitioning pET (estimated using the Penman Monteith equation; EQ 1) into transpiration (T_p) and evaporation (E_p) according to Beer's Law [**Qin et al., 2016**],

$$T_p = pET(1 - e^{-kLAI}) \qquad \text{EQ 4a}$$

$$E_p = pET(e^{-kLAI}) \qquad \text{EQ 4b}$$

and identifying the maximum T_p, where k is a constant governing radiation extinction by the vegetation canopy (set to 0.5 as in **Rechid et al., 2009**), and LAI is the leaf area index.

Meteorological input variables for Penman Monteith (temperature, relative humidity, solar radiation, and wind speed; EQ 1) were sourced from the same meteorological stations as precipitation (**Fig. 1**). Plant trait inputs to Penman Monteith (maximum stomatal conductance, plant height, albedo and LAI; see section 2.1.1) varied by water use scenario and/or climate zone. Traits varying by climate zone (i.e., albedo and LAI) are described in brief below.

Albedo was modeled as a function of snow cover, soil type, the type of plant community being simulated, and LAI. Snow hydrology was simulated directly in Hydrus using surface temperature from the above-mentioned meteorological stations as the upper boundary condition, a zero gradient lower boundary condition, and default values for snow melting and sublimation (0.43 m/h/°C and 0.4 [-], respectively) [**Simunek et al., 2013**]. When snow was present, albedo was set to 0.6 [**Jin et al. 2002**]. Otherwise, albedo was expressed as a function of vegetation phenology and characteristic plant and soil albedo following the recommendation of Rechid et al. [**2009**],

$$a = a_{soil}e^{-kLAI} + a_{canopy}(1 - e^{-kLAI}) \qquad \text{EQ 5}$$

where a_{soil} is the average soil albedo for each climate zone (estimated in ArcGIS using ESRI's US Soils Albedo layer; 30m resolution), and a_{canopy} is set to the typical albedo value for herbaceous or woody species, depending on the height of the plant community being simulated (a = 0.25 for simulations with short (0.5 m tall) herbaceous communities and a = 0.165 for taller (5 m) woody plant communities **[McEvoy et al. 2003, Barry and Chambers 1966, and Brovkin et al. 2013]**). The phenological (seasonal) component of albedo is due to LAI. Seasonal patterns in LAI were determined for each climate zone by 1) estimating average monthly mean LAI in ArcGIS Pro using the Global Monthly Mean Leaf Area Index layer by ORNL DAAC [**Mao and Yan, 2019**], 2) fitting eight Gaussian curves to the data (one per climate zone), and 3) scaling the fitted curves to reflect herbaceous (max LAI of 2) or woody (max LAI of 3) species for different water-use scenarios ([**Guo 2011**], **Fig. S1**).

2.3.2 Significance Testing – Evapotranspirative harvest and I:H ratios:

Hourly drainage and evapotranspiration timeseries from each Hydrus simulation were used to calculate annual I:H ratios, and cumulative annual evpotranspirative harvest for each water use scenario in every climate zone. A total of 36 I:H ratios and annual harvest estimates were made per scenario (one for each possible 12-month window in the 4-year timeseries of meteorological inputs described above), generating a distribution of possible I:H and annual harvest values for each scenario. A nonparametric bootstrap-based comparison of means (with correction for multiple comparisons) was used to identify scenarios with significantly different ($p < 0.05$ level) average I:H ratios or annual evapotranspirative harvest in each climate zone [**Manly, 2007**, **Westfall, 2011**] .

2.3.3 Comparison to pre-urban estimates:

The I:H ratio that BRCs must achieve to return the hydrology of an urban area to its pre-urban condition ($\mathrm{I{:}H_{pu}}$) in each climate zone, was estimated as described in Askarizadeh et al [**2015**],

$$\mathrm{I{:}H_{pu}} = 1/\left(\frac{0.230 + 0.206\log_{10}(\mathrm{MAR})}{f_F\mathrm{ET_F} + (1 - f_F)\mathrm{ET_H}}\right) \qquad \text{EQ 6a}$$

$$\mathrm{ET_F} = \mathrm{MAR}\left(\frac{1 + 2(1410/\mathrm{MAR})}{1 + 2(1410/\mathrm{MAR}) + \mathrm{MAR}/1410}\right) \qquad \text{EQ 6b}$$

$$\mathrm{ET_H} = \mathrm{MAR}\left(\frac{1 + 0.5(1100/\mathrm{MAR})}{1 + 0.5(1100/\mathrm{MAR}) + \mathrm{MAR}/1100}\right) \qquad \text{EQ 6c}$$

where MAR is the mean annual rainfall (the volume of rainfall per catchment per year), and f_F is the pre-urban fraction of forest. Average MAR and f_F were estimated for each climate zone using

ArcGIS Pro; MAR was estimated using a USGS layer of average annual rainfall for the period between 1971 and 2009 [**O'Donnell and Ignizio, 2012**], and f_F was estimated using a USDA layer representing historical woodland density of the conterminous US in 1873, a digital representation of the William H. Brewers Map from the 9th US census [**Liknes et al., 2020**].

3. RESULTS and DISCUSSION

3.1. Section 1: Is it theoretically possible? – *Do plant-associated variables that regulate evapotranspiration differ significantly by CSR functional type?*

TLP, IWS, and stomatal conductance were all observed to significantly differ among plants with different CSR functional types (**Fig. 2**). This indicates that it is theoretically possible to manipulate plant water use (and therefore evapotranspiration) in engineered systems such as BRCs through manipulating the CSR type of landscape vegetation. The best CART model for TLP explained 40% of observed data variance (mean squared error upon leave one out cross validation of 0.34). The first split (i.e, the variable that best distinguished plants with high vs low TLP), was stress tolerance (% S); plants that were ≥ 62% S had significantly lower (more negative) TLPs than those that were less stress tolerant (**Fig. 2a,b**). Stem type (woody vs herbaceous – 2nd split) and plant competitiveness (%C – 3rd and 4th splits) were also significantly associated with TLP, whereas growth form and ruderal type strategy were not. The lowest TLPs (average of -2.6 MPa, significantly below other groups – see yellow pdf, **Fig. 2b**) was observed for plants that were ≥ 62% S and < 30% C (i.e., plants with a principally S type functional strategy). The highest TLPs (average of -1.1 MPa, significantly above other groups – see dark red pdf, **Fig. 2b**) was observed for plants that were < 62% S, ≥ 24% C and herbaceous (i.e., graminoids and forbs with CS to C type strategies). Other plant types (high S with some C - light orange symbols, **Fig. 2ab**; lower S, but woody - orange symbols, **Fig. 2ab**; and lower S and C, herbaceous - red symbols, **Fig. 2ab**) had statistically comparable, intermediate, TLPs of ~2MPa.

The above-noted association between stress tolerance and negative TLP is broadly consistent with the drought tolerance literature, where it has been shown that LDMC (a principal leaf trait associated with stress tolerance; Pierce et al., **2017**) significantly covaries with TLP for both herbaceous and woody plant species [**Griffin-Nolan et al., 2019**, **Majekova et al., 2020, Bartlett et al., 2012a, Petruzzellis et al., 2019**]. This association could reflect a more fundamental relationship between TLP and osmotic potential at full hydration [**Bartlett et al., 2012b**, **Marechaux et al., 2015**]; plants with lower TLP tend to have more negative osmotic potentials, reflecting a higher concentration of osmolytes such as non-structural carbohydrates, which contribute to LDMC [**Griffin-Nolan et al., 2019**]. However, vulnerability to cavitation (i.e., the ability a plant to continue transpiring at low water potentials -low TLP- without risking xylem failure) is also often negatively correlated with LDMC, reflecting high cell investment in structural carbohydrates. Such investment tends to coincide with other traits that decrease tissue vulnerability such as wood density [**Markesteijn et al., 2010**]. This appears consistent with the second principal split in our CART analysis (about stem type), where lower TLP was observed for woody than herbaceous species on average (-1.9 MPa vs -1.4 MPa; **Fig. 2a**). However, the TLP range for herbaceous species was large, with some (~30% of evaluated species) exhibiting TLPs as low as their woody counterparts (red pdf, **Fig. 2b**). This suggests that while woody tissue is associated with lower TLPs, its absence does not preclude them, consistent with the host of alternative strategies herbaceous plants have for withstanding low water potentials [**Touchette et al. 2007, Rafi et al. 2019**]).

Like TLP, IWS (**Fig. 2c,d**) and stomatal conductance (**Fig. 2e,f**) varied significantly among plants with differing CSR strategies, particularly along the S to C continuum (note significant splits on %S and %C; **Fig. 2c-f**). The best CART model for IWS explained 34% of observed data variance (mean squared error upon leave one out cross validation of 0.13). The best fit CART model for maximum stomatal conductance explained significantly less variance (~16%; mean squared error upon leave one out cross validation of 0.05). Growth form, stem type, percent R-type strategy, and measurement method (porometery vs infra-red gas analysis) were not significant drivers of either water use trait (note the absence of significant CART splits on these plant variables in **Fig, 2c-f**). However, study age (included in our models as a proxy for increased atmospheric CO_2 over the 25-year period our meta-analysis spans) did explain variability in IWS, with lower IWS reported in older studies (e.g., those conducted prior to 2002; **Fig. 2c**). This finding likely reflects stomatal sensitivity to CO_2, with today's higher CO_2 levels triggering early closure (across a broader range of soil water potentials) than CO_2 levels prior to 2002 [**Engineer et al., 2016, Murray et al., 2019**]. Unlike IWS, maximum stomatal conductance was not sensitive to study age, suggesting that stomatal responsiveness (e.g., timing of closure) may be more sensitive to changes in CO_2 than absolute conductance, for the studies evaluated here (**Fig. 2e**). Given the above-noted association between study age and IWS, care should be taken when pooling studies across decades to make inferences about stomatal water-use traits and their drivers [**Murray et al., 2019**]. Subsequent discussion of CSR effects on IWS considers only more recent studies between 2002 and 2017 (significant split at 73% S in **Fig. 2c,d**). Because stomatal conductance was age-insensitive, CSR effects across the full study range (1991-2017) are interpreted.

For studies conducted post 2002, IWS was more negative for plants possessing an S-type strategy ($\geq$ 73% S) than for plants that did not (average of -0.6 MPa and -0.23 MPa, respectively

– significant at a $p < 0.05$ level); **Fig. 2c,d**). This is consistent with the above-noted link between S-type strategy and lower TLP, and suggests that both wilting and stomatal closure begin at lower water potentials for stress tolerant species (e.g., S-type plants appear to be drought tolerators rather than drought avoiders; **Du et al., 2019**). Stomatal conductance, in contrast, was significantly lower in plants that were more stress tolerant (≥ 50% S) or less competitive (< 36% C) (211 mm H_2O $m^{-2}s^{-1}$ and 330 mm H_2O $m^{-2}s^{-1}$, respectively; $p < 0.05$ level, **Fig. 2 d,e**). These two splits were statistically indistinguishable, reflecting a strong inverse relationship between stomatal conductance and competitive or stress tolerant plant strategies (note significant linear relationship between log transformed stomatal conductance and %C (positive) or %S (negative) in **Fig. S2a,b**). The trade-off we observe between maximum stomatal conductance and the ability to maintain it at low water potentials has been coined the stomatal safety-efficiency trade-off [**Henry et al., 2019**], a concept that resonates conceptually with the fast-slow plant economic spectrum proposed by Reich [**2014**]. The idea is that plants can either be "safe" (i.e., capable of withstanding drought by maintaining stable, low conductance's at negative water potentials – our slow, S-type strategy) or "efficient" (i.e., capable of rapid conductance and growth when conditions are favorable, but incapable of maintaining them long term – our fast, C type strategy) [**Henry et al., 2019**]. One consequence of this tradeoff for plant water use (applicable to BRCs as well as other planted systems) is that plants exhibiting the most extreme trait scenarios (for instance, the ultimate water waster; -2.6 TLP, -0.6 IWS, and max conductance of 300 mm H_2O $m^{-2}s^{-1}$, **Fig. 2**) don't exist in practice because physiological constraints prevent it. This limits the range of potential plant water use scenarios that need to be explored in BRCs.

Based on the results above, we developed 6 plant scenarios featuring different, physiologically realistic, combinations of water use traits to evaluate the capacity of plants with different CSR types to influence BRC water balance (**Table 1**). Each scenario was guided by the significant decision points identified in our CART analyses, including splits along the C to S functional type continuum (all water use traits) and stem type (TLP only). The first set of scenarios was for S-type woody and S-type herbaceous plants (S1w and S1h). Both scenarios had the same TLP, IWS, and maximum stomatal conductance (-2.6 MPa, -0.6 MPa, and 211 H_2O $m^{-2}s^{-1}$, respectively; **Fig. 2, Table 1**), but differed in stem type, which influences average plant height (5 m for woody, 0.5 m for herbaceous), LAI (max of 3 for woody, 2 for herbaceous) and albedo (0.165 for woody, 0.25 for herbaceous), as described in **section 2.3.1**. The second set of scenarios (S2w; woody and S2h; herbaceous) was for plants that were predominantly S, but also C or R (for instance, CS with high S or SR functional types). S2 plants had lower conductance, but higher IWS and TLP, than S1 plants (211 H_2O $m^{-2}s^{-1}$, -0.23 MPa and ~ -2.0 MPa, respectively; **Fig. 2, Table 1**). Plant height, LAI, and albedo varied by stem type, as described above. The final set of scenarios (S3) was for plants that were more competitive than stress tolerant (for instance CS with high C, CR, or CSR functional types). Both woody and herbaceous S3 plants had elevated stomatal conductance and IWS (211 H_2O $m^{-2}s^{-1}$ and -0.23 MPa, respectively), with TLP (-1.9 MPa for woody, -1.1 MPa for herbaceous), plant height, LAI, and albedo all varying by stem type (**Fig. 2, Table 1**).

The capacity of each water use scenario to meaningfully impact evapotranspiration and I:H ratios in BRCs is presented in **section 3.3**. First, however, we discuss whether recommended BRC plants in different US climate zones actually exhibit the CSR types characteristic of each water use strategy. This will determine if manipulating BRC water balance using CSR type is not only possible, but practically feasible (**section 3.2**, below).

3.2. Are the tools available? – *Do BRC plants in different US climate zones span the range of CSR types necessary to make manipulating water use traits through CSR, feasible?*

BRC plants consistent with each principal water use scenario (S1-S3) were identified across all 8 climate zones (i.e., the range of CSR types necessary to manipulate green infrastructure water balance via these scenarios, appears available; **Fig. 3**). Although we were only able to classify a subset of each zone's BRC plant list to CSR type, these subsets had comparable growth form compositions to respective full plant lists (compare solid and dashed lines for % forbs, graminoids, shrubs and trees in each climate zone; **Fig. S3**). While this does not preclude bias in our CSR subsamples, it does suggest a degree of representativeness, as obvious biases due to over or under-representation of specific plant morphologies appear unlikely.

Forbs were found to be significantly more abundant in recommended BRC lists (subsample and full) from eastern US climate zones (Cfa, Dfa, and Dfb; 38-50% of species) than western US zones (Csb, Csa, and Dsb; 10-21% of species), whereas shrubs were significantly more abundant in plant lists from Bwh (hot desert climate; 57% of species) (**Fig. S3**). Graminoid and tree abundance was more stable across zones, with all 8 exhibiting good representation of both herbaceous and woody species, making water use scenarios keyed to either stem type equally plausible.

Although each climate zone had recommended BRC plants with CSR types consistent with S1-S3, not all types were equally prevalent. Across all biomes, BRC plants were significantly more stress tolerant than competitive or ruderal (**Fig. 3**, **Fig. S4**), which likely reflects pre-selection of BRC plant communities by landscape planners to survive common stressors such as high pollutant loads and transient inundation [**Fletcher et al. 2007, Gong 2019, Hunt 2015**]. The geometric median for each biome was between 42 and 79 %S (18-34 %C), with Bwh and Csa (the two hottest and driest biomes; **Fig. 4a,e**) clustering in S1 and S2, respectively, and all other biomes falling between S2 and S3 (**Fig. 3**). Most biomes exhibited significantly more plants with stress-tolerant S1 and S2 water-use strategies than expected due to chance (exceptions being Bwh for S2 and Dfb for S1; **Fig. S5**). Four climate zones (Cfa, Dfa, Dfb, and Dsb) also exhibited more plants with S3 water-use strategies than expected due to chance. This tendency towards over-representation of all 3 S to C type scenarios reflects systemic under-representation of predominantly ruderal plant functional types in BRC plant lists across biomes (note the limited number of plants in the lower right hand corner of **Fig. 3**). Low representation of ruderals likely reflects their tendency to avoid rather than tolerate stress, which influences their life history (many are annuals or biennials that complete their life cycle in 1-2 years) [**Lososova et al. 2006**]. This makes them less likely to be favored for use in BRCs, where the goal tends to be long term plant community establishment [**Beaupre et al. (2016)**].

In short, our results suggest that the variability in CSR strategy (C to S) within each US climate zone is sufficient to make manipulating evapotranspiration and the I:H ratio in BRCs using CSR type feasible. However, we expect that doing so will be more challenging in hotter and drier climate zones such as Bwh and Csa where the range of CSR types is skewed towards stress tolerant plants with conservative S1 and S2 water use strategies (**Fig. 3**). In section 3.3 (below) we determine whether such manipulations are likely to significantly impact BRC water balance in each US climate zone, progressing from ‘is it feasible?’ to ‘is the effect meaningful?’.

3.3. Is the effect meaningful?: *Does manipulating ET traits through changing CSR functional type significantly alter evapotranspirative harvest and or I:H ratios in simulated BRCs?*

Across all 8 climate zones, evapotranspirative harvest and I:H ratios differed significantly in BRC simulations with different plant water use scenarios, suggesting that manipulating ET traits through CSR functional type has the potential to meaningfully impact BRC water balance (**Figs. 5, 6**). This said, no BRC (irrespective of plant water use scenario) was capable of reproducing pre-urban I:H ratios in any climate zone (**Fig. 7**). This suggests that there are practical limits to the effectiveness of restoring pre-urban hydrology using this approach. These results and their implications for urban water management are addressed in detail below: section 3.3.1 (ET and I:H ratios) and section 3.3.2 (pre-urban I:H targets).

3.3.1 Variability in ET and I:H ratio by scenario and climate zone

In all but the wettest climates (Dfa, Cfa, and Dfb; **Fig. 4**), BRCs effectively ran out of water in one or more plant water use scenarios, with soil water potentials falling below the TLP sometime within the first three years (dates noted along the lower edge of **Fig. 5**). This problem was most marked for Bwh and Bsk (hot desert and arid steppe) where TLP was reached for all scenarios, typically within the first 3-8 months. The water-related challenges BRCs in arid regions face are well recognized (and reflected in local BRC design guidelines) with supplemental irrigation often recommended to sustain plant communities in drier months [**Houdeshel et al. 2015**].

What exactly happens when soil water potential falls below the TLP? The first thing to recognize is that BRC vegetation doesn't necessarily die. Wilting occurs, and xylem embolism becomes more likely, but if low water potentials are transient, many plants will eventually recover [**Bartlett et al., 2016**]. Long dry periods below the TLP, however, (see for instance, Bwh, where the TLP was reached between March and June; **Fig. 5**, but the dry period extended through August; **Fig. 4)**, are less likely to be survivable without specialized plant adaptations (e.g., succulence or dormancy, neither of which were simulated here) or application of supplemental irrigation water [**Houdeshel et al. 2015, Lizarraga-Mendiola et al. 2017**]. Given the severe water stress present in at least a subset of our simulations, a second set of "irrigation scenarios" were performed. These scenarios were identical to the original 6 save that BRC drainage water was routed to an underground 1m deep storage tank for later use as irrigation water (see Edinburgh Gardens for a real world example of such a system; **GHD, 2012**). Each BRC was irrigated to field capacity whenever soil water potential (averaged across the filter media depth) fell below the TLP. This practice of irrigating BRCs with their own drainage can be thought of as a form of additional harvest [**Askarizadeh et al., 2015**], because inflow water has more than one opportunity to be evapotranspired, reducing the I:H ratio of the overall system.

For all climate zones, patterns in ET and I:H ratios across scenarios were similar, with overall ET being higher (and I:H ratios lower) when BRCs were irrigated (compare left and right oriented pdfs in **Figs. 5 and 6**). On average, ~0.45 mm (0.09 - 1.40 mm) of evapotranspirative harvest was gained per 1 mm of supplemental irrigation water applied (i.e., approximately half of applied irrigation water was typically evapotranspired, with irrigation actually stimulating ET in excess of irrigation volumes in some climate zones; **see Bsk, Table S5**). Differences between irrigated and nonirrigated scenarios were largest for competitive woody plants (scenario S3w), which required the most supplemental irrigation to keep from wilting (70-700 mm/y depending on the climate; **Fig. 5**). Climate zones where precipitation and relative humidity was low and solar radiation was high required the most supplemental irrigation (Bwh > Bsk > Dsb > Csa > Csb > Cfa, Dfa & Dfb; **Figs 4 & 5**). They were also the zones capable of the highest evapotranspiration

(**Fig. 5**), reflecting the fact that a higher fraction of total precipitation becomes evapotranspiration in arid regions because low humidity facilitates diffusional loss of water from plant leaves, provided water is available [**Taiz et al., 2015**].

Competitive woody plants (S3w) had higher annual evapotranspiration and lower I:H ratios than all other BRC plants. The inverse was true for stress tolerant herbaceous plants (S1h and S2h), which had consistently lower evapotranspiration and higher I:H ratios (**Figs. 5, 6**). Results for S1 and S2 were always statistically comparable within a stem type (i.e., S1h and S2h grouped together and S1w and S2w grouped together; **Figs. 5, 6**), suggesting that the differences in TLP and IWS that distinguish these scenarios have minimal effect on overall BRC water balance at an annual scale. This likely reflects the limited residual water in BRC filter media at low TLPs; the difference in volumetric water content between the TLP for S2 (-1.9 MPa) and S1 (-2.6 MPa) was only 2.6 mm. Relative to the total volumetric water content in each BRC at saturation (390 mm), this equates to a < 1% difference in plant available water. Because BRCs in our simulations either reached the TLP over the course of a year (e.g., Bwh; **Fig. S6)** or did not drop below the IWS (e.g., Cfa; **Fig. S6**), the "timing" of reduced transpiration (IWS) was also relatively unimportant; either most water that could be transpired eventually was or differences in the onset of reduced transpiration were never felt.

The remaining plant water use scenarios evaluated (S3h, S1w, and S2w) had intermediate ET and I:H ratios (always significantly below S3w and above S1h/S2h; **Figs. 5, 6**). Their relative contribution to evapotranspiration (and I:H ratios) varied by climate zone, such that in three zones (Bwh, Dsb, and Bsk) evapotranspiration was always significantly higher (and I:H ratios, lower) in woody plant scenarios than herbaceous ones; S3w > S1,S2w > S3h > S1,S2h for evapotranspiration (opposite order for I:H ratio), and in two zones (Cfa and Dfa) evapotranspiration was significantly higher (and I:H ratios, lower) in competitive plant scenarios than stress tolerant ones; S3w > S3h > S1,S2w > S1,S2h for evapotranspiration (opposite order for I:H ratios). In the remaining three climate zones (Csa, Csb, and Dfb) there was no significant difference among intermediate scenarios (**Figs. 5, 6**).

This result begs the question, why might stem type (woody vs herbaceous) be a primary determinant of high vs low plant water use in some climate zones and CSR (competitive vs stress tolerant) in others? One likely explanation concerns the relative availability of solar radiation and precipitation in these different zones. Both factors emerged as significant drivers of pattern in plant evapotranspiration across scenarios and climate zones (see principal component analysis with factor projection in **Fig. 8**), and have the capacity to impact evapotranspiration in different ways. When solar radiation is abundant, more energy is available for both transpiration and evaporation. Because woody plants have lower albedo on average than herbaceous species in our simulations (0.165 vs 0.25; **McEvoy et al. 2003, Barry and Chambers 1966, and Brovkin et al. 2013**), they reflect less solar radiation, resulting in higher potential evapotranspiration. In climates where maximum monthly solar radiation is high, and precipitation, low (Bwh, Bsk, and Dsb; **Fig. 4**), this results in elevated evapotranspiration in woody vs herbaceous plant scenarios even if herbaceous species have high maximum stomatal conductance, because limited water resources keep those maxima from being realized (note significant factor loading of max monthly solar radiation along negative principal component 2 of **Fig. 8** towards Bwh, Bsk and Dsb, where evapotranspiration in S1w and S2w exceeds S3h). Other factors that likely contribute to this “woody plant effect” include the elevated LAI of woody plants [**Iida et al. 2020**] and their taller height (lower aerodynamic resistance to evapotranspiration [**Wang et al. 2019, Ochoa-Sanchez et al. 2020**]), both of which tend to increase evapotranspiration overall [**Allen et al., 1998**].

The advantage of high stomatal conductance only becomes fully realized when precipitation is abundant and plants are capable of transpiring at their maximum rate long term (note significant factor loading of precipitation along positive principal component 2 of **Fig. 8** towards Cfa and Dfa, where evapotranspiration in S3h exceeds S1w and S2w) . The magnitude of this effect appears to exceed the "woody plant effect" such that possessing a C-type strategy impacts evapotranspiration more than being woody in climates where sufficient water is available. From the perspective of manipulating plant water use in BRCs, these results suggest that the primacy of CSR as a framework for selecting high vs low water use plants is limited to wetter climates; discriminating woody from herbaceous appears more important in drier ones. This said leveraging the full range of evapotranspiration and I:H ratios simulated here for use in BRC design requires knowledge of both stem type and CSR (**Figs 5, 6**). This makes considering the two together useful for managing BRC water balance in any climate zone.

3.3.2: Failure to meet pre-urban targets

Although the various plant water use scenarios evaluated significantly influenced evapotranspiration (and I:H ratios) in BRCs, no scenario successfully reproduced pre-urban I:H ratios in any climate zone (i.e., no scenarios crossed the 1:1 line in **Fig. 7**). While pre-urban I:H targets ranged between 0.05 and 0.80 (-1.26 to -0.10, log10) across climate zones, and were generally indicative of conditions where more water should be harvested than infiltrated, the I:H ratios actually achieved in our BRC simulations were much higher, being more appropriate for conditions where more water should be infiltrated than harvested; I:H ratios of 1.2 - 75.4 (0.07 – 1.9, log10) for non-irrigated scenarios and 0.8 - 74.6 (-0.08 – 1.9, log10) for irrigation scenarios (**Fig. 7; Table S6**). Because supplemental irrigation stimulated evapotranspiration (**Fig. 5**), irrigated scenarios came closer to pre-urban I:H targets than non-irrigated scenarios (**Fig. 7**). Similarly, because competitive woody plants (S3w) had significantly higher evapotranspiration (and lower I:H ratios) across all climates (**Figs. 5, 6**), BRCs simulated with these species came closer to mimicking pre-urban conditions than those sporting different plants (**Figs. 7**).

The results of our I:H comparisons highlight the difficulty inherent in harvesting more water than is infiltrated when evapotranspiration is the sole form of harvest. Even when extra harvest is stimulated by irrigating BRCs with their own drainage water, the total evapotranspiration achieved under the highest transpiration scenarios (S3w) falls short of that needed to balance urban water budgets (**Fig. 7**). This is not to say that meeting pre-urban I:H ratios using plant-based approaches is not possible, it's just challenging given the spatial constraints in urban areas that limit the evapotranspirative surface of BRC elements such that the typical land area allotted for evapotranspiration is small relative to the size of the catchment it receives runoff from [**Brown and Hunt, 2011**, **Ambrose and Winfrey, 2015**, **Huang et al. 2018, Li et al., 2020**]. One way around this constraint, at least in peri-urban or rural areas with more vegetation cover, is adoption of BRC designs that promote lateral exfiltration, allowing the surrounding landscape to augment BRC evapotranspiration, enhancing harvest [**FAWB, 2009**, **Hamel and Fletcher, 2011, Brown and Hunt, 2011, Parker et al., 2020**]. Work by Hamel and Fletcher [**2011**] suggest that when BRCs are capped by a low permeability underlayer (but unlined at the edges), as much as 70% of infiltrated water can laterally exfiltrate and become available to surrounding vegetation, which could substantially increase harvest.

Harvest might also be increased by manipulating physical characteristics of BRCs beyond their vegetation communities in ways that reduce drainage, allowing more evapotranspiration to take place between storms (i.e., decreasing the catchment ratio or opting for loam or silty loam filter media, both of which have higher field capacity and more plant available water than sandy loam; **Meng et al., 2014**). These solutions have downsides, however. Decreasing the catchment to BRC area ratio is not always feasible in urban areas because land is at a premium and existing imperviousness constrains BRC form (i.e., the spatial constraint noted above; **Li et al., 2020**). Furthermore, because fine sediments tend to have reduced hydraulic conductivity, which increases the magnitude and frequency of BRC overflow events, opting for finer filter media isn't necessarily a wise option either [**Boadu, 2000, FAWB, 2009**]. Even with the sandy loam filter media used in our simulations, overflow was prevalent in some climates, most notably Cfa, Dfa, and Bsk where 23-31% of inflow volume eventually overflowed the BRC (**Fig. 6**); going any finer would only compound the problem. Other means of increasing BRC harvest, for instance collecting treated BRC drainage water and piping it to homes or commercial/recreational facilities for nonpotable uses (e.g., toilet flushing, clothes washing, or outdoor irrigation, among others), might be more beneficial [**Askarizadeh et al., 2015, Hirschman et al., 2008**]. However, the magnitude of harvest achieved using this approach would be highly case specific, depending on the variety of nonpotable end uses available at a given location [**Burns et al, 2010, Askarizadeh et al., 2015**], building occupancy (for in home uses; **Burns et al., 2010**), vegetation type and landscape area (for outdoor irrigation; **WUCOLS III, 2000**), the quality of BRC drainage water [**Clary, 2014, Zhang et al., 2015, NAE, 2016**], and the temporal reliability of its supply [**NAE, 2016**], which determines if BRC drainage water must be combined with other nonpotable sources to be practically useful long-term (note that reliability is expected to be low in dry climates like Bwh and Bsk, where BRCs frequently ran out of water; **Fig. 5**).

Although many options exist that could increase the amount of harvest BRCs perform, bringing their water balance more in line with pre-urban I:H ratios, it's important to recognize that there are alternative paths forward. BRCs don't have to "do it all". The "LID universe" contains a vast array of green infrastructure options with different infiltration and harvest capabilities, allowing BRCs to be used in combination with other technologies to achieve desired I:H ratios [**Eger et al., 2014, 2017, Askarizadeh et al., 2015**]. Given that BRCs tend to be biased towards infiltration, using them in consort with technologies biased towards harvest (e.g., rain tanks and green roofs; **Burns et al., 2011**, **Di Giovanni et al., 2013, Askarizadeh et al., 2015**, **Eger et al., 2017**), offers a flexible approach for meeting per-urban I:H targets. This flexibility comes with an additional management burden, however, as water budgets must be balanced across distributed infrastructure elements, likely operated and maintained by different entities. In this sense, balancing the water budget for individual BRCs is more straightforward. Either way, it's clear that BRCs represent a relatively versatile tool in our LID toolbox, and that our capacity to tune their I:H ratios by manipulating vegetation communities (i.e., stem type and CSR) contributes to this versatility. Further work exploring the relative capacity of different BRC plants (e.g., CSR type and stem type) to regulate I:H ratios, particularly in arid climates where such information is most limited, will be necessary to make plant-based approaches for managing BRC water balance an actionable part of engineering practice.

4. CONCLUSIONS

In this paper we evaluated whether CSR functional type could be used as framework for classifying BRC plants into discrete water use strategies that might be leveraged in practice to balance BRC water budgets; bringing them more in-line with pre-urban infiltration to harvest ratios. CSR type was found to be a significant determinant of three plant water use traits (TLP, IWS, and maximum stomatal conductance), with variability along the competitive to stress tolerant continuum being more important than degree of ruderalness (**Fig. 2**). This finding is consistent with Reich's [**2014**] fast-slow plant economic spectrum, with C-type plants exhibiting a "fast" trait strategy (high growth rate, high stomatal conductance and transpiration, larger leaf area to facilitate photosynthesis), and S-type plants exhibiting a "slow" trait strategy (low turgor loss point and point of incipient water stress, reduced transpiration, high leaf dry matter content). The consistent significant relationships observed between CSR type and plant water use traits (**Fig. 2**; highest variance explained for TLP and lowest for maximum stomatal conductance) illustrate that using CSR as a framework to guide "water wise" selection of BRC plants is theoretically sound; CSR influences key water use traits expected to govern overall plant water use strategy in BRCs. Moreover, the variety of CSR types necessary to make using this theory tractable is evident for BRC plants across eight major climate zones of the coterminous US (**Fig. 3**). In drier climates there is a slight bias towards S-type plants that might make leveraging the full C to S continuum slightly more difficult (and perhaps unwise if some form of supplemental irrigation isn't available), but not impossible; BRC species with C or CS functional types were present even in dry climates. Furthermore, irrigating BRCs with their own drainage water may make dry climate systems more survivable across a broad range of plant water use types (**Fig. 5**); below-ground tanks sized to the same depth as the BRC itself provided sufficient irrigation in our simulations, with BRCs never needing supplemental irrigation when water was not available. No attempt was made to optimize tank size for different climate zones or water use scenarios in this study, however. Such information would be valuable (indeed requisite) if this approach were to be implemented in practice.

Our hydraulic simulations (Hydrus 1D) revealed significant differences in evapotranspirative harvest and I:H ratios across various plant water use scenarios in different climate zones (**Figs. 5, 6**). The highest water use plants (competitive woody species) had 1.7 times more evapotranspiration on average (min: 1.4, max: 2.1) and a 1.8 times lower I:H ratio on average (min: 1.5 max: 2.7) than the lowest water use plants (stress tolerant herbaceous species) across all climate zones. The relative importance of CSR type as a determinant of overall plant water use also varied by climate zone, being most important in wetter climates, where C-type plants could take full advantage of elevated stomatal conductance, resulting in all competitive plant scenarios having higher evapotranspiration and lower I:H ratios than stress tolerant plant scenarios (**Fig. 5, 6**). In drier climates, being competitive was of secondary importance to being woody, illustrating that the best strategies for managing BRC water balance have climate-specific nuance.

Looking across all hydraulic simulations, two things are clear: First, plants with different CSR types and stem types exert meaningful influence over BRC water balance such that CSR principles could be leveraged to help design BRCs <u>for</u> evapotranspirative harvest and manage I:H ratios. However, the amount of harvest provided by our "standard configuration" BRCs (4.5% catchment ratio, 1m deep sandy loam filter media, with or without additional harvest stimulated by irrigation with BRC drainage water) is clearly inadequate to meet pre-urban I:H ratios (**Fig. 7**), where more water needs to be harvested than infiltrated. While this does not mean that individual BRCs cannot be tailored to meet pre-urban I:H ratios (see discussion above), it does suggest that implementing BRCs in consort with technologies biased towards harvest is likely to improve our ability to meet pre-urban water balance targets. This is particularly true in the urban core where opportunities for large biofilter area to catchment area ratios are few [**Li et al., 2020**], the urban form limits the effectiveness of lateral exfiltration in stimulating additional harvest [**McGrane, 2016, Walsh et al., 2016**], and perturbations to urban water balance are most extreme [**King et**

al., 2011, Jacobson, 2011, Askarizadeh et al., 2015, **Li et al., 2018**], which makes siting green infrastructure elements that can address these imbalances all the more important.

REFERENCES

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. (1998): Crop evapotranspiration - Guidelines for computing crop water requirements, Food and Agriculture Organization of the United Nations, 56.

Ambrose, R. F., and Winfrey, B. K. (2015): Comparison of stormwater biofiltration systems in Southeast Australia and Southern California, WIREs Water, 2(2), 131–146.

Anderson, S. et at., 2016. Ultra-Urban Green Infrastructure Guidelines, Appendix C: Plant Lists. Prepared by the City and County of Denver and the Urban Drainage and Flood Control District. https://www.denvergov.org/content/dam/denvergov/Portals/705/documents/guidelines/PWES-013.0-Ultra_Urban_Green_Infrastructure_Guide.pdf Accessed December 2020.

Askarizadeh, A., Rippy, M. A., Fletcher, T. D., Feldman, D. L., Peng, J., Bowler, P., Mehring, A. S., Winfrey, B. K., Vrugt, J. A., AghaKouchak, A., Jiang, S. C., Sanders, B. F., Levin, L. A., Taylor, S., and Grant, S. B. (2015): From Rain Tanks to Catchments: Use of Low-Impact Development To Address Hydrologic Symptoms of the Urban Stream Syndrome, Environmental Science & Technology, 49(19), 11264–11280.

Austin ECM, 2014. Environmental Criteria Manual, Appendix N: City of Austin Preferred Plant List. Prepared by the City of Austin, R161-14.28. https://library.municode.com/tx/austin/codes/environmental_criteria_manual?nodeId=APXNCIAUPRPLLI Accessed December 2020.

Barry, R. G., and Chambers, R. E. (1966): A preliminary map of summer albedo over England and Wales, Quarterly Journal of the Royal Meteorological Society, 92(394), 543–548.

Bartlett, M. K., Scoffoni, C., Ardy, R., Zhang, Y., Sun, S., Cao, K., and Sack, L. (2012): Rapid determination of comparative drought tolerance traits: using an osmometer to predict turgor loss point, Methods in Ecology and Evolution, 3(5), 880–888.

Bartlett, M. K., Scoffoni, C., and Sack, L. (2012): The determinants of leaf turgor loss point and prediction of drought tolerance of species and biomes: a global meta-analysis, Ecology Letters, 15(5), 393–405. https://doi.org/10.1111/j.1461-0248.2012.01751.x

Bartlett, M. K., Zhang, Y., Kreidler, N., Sun, S., Ardy, R., Cao, K., and Sack, L. (2014): Global analysis of plasticity in turgor loss point, a key drought tolerance trait, Ecology Letters, 17(12), 1580–1590.

Beaupre, D. et al. (2016). San Francisco Stormwater Design Guidelines, Appendix D: Vegetation Palette for Bioretention BMPs. Prepared by the City of San Francisco. https://www.sfwater.org/Modules/ShowDocument.aspx?documentID=2775 Accessed December 2020.

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., and Wood, E. F. (2018): Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data, 5(1), 180214.

Bell, C. D., Wolfand, J. M., and Hogue, T. S. (2020): Regionalization of Default Parameters for Urban Stormwater Quality Models, JAWRA Journal of the American Water Resources Association, n/a(n/a).

Boadu Fred Kofi (2000): Hydraulic Conductivity of Soils from Grain-Size Distribution: New Models, Journal of Geotechnical and Geoenvironmental Engineering, 126(8), 739–746.

Brodribb, T. J., Holbrook, N. M., Edwards, E. J., and Gutierrez, M. V. (2003): Relations between stomatal closure, leaf turgor and xylem vulnerability in eight tropical dry forest trees, Plant, Cell & Environment, 26(3), 443–450.

Brovkin, V., Boysen, L., Raddatz, T., Gayler, V., Loew, A., and Claussen, M. (2013): Evaluation of vegetation cover and land-surface albedo in MPI-ESM CMIP5 simulations, Journal of Advances in Modeling Earth Systems, 5(1), 48–57. https://doi.org/10.1029/2012MS000169

Brown, R., Ashley, R., and Farrelly, M. (2011): Political and Professional Agency Entrapment: An Agenda for Urban Water Research, Water Resources Management, 25(15), 4037–4050.

Brown R. A., and Hunt W. F. (2011): Underdrain Configuration to Enhance Bioretention Exfiltration to Reduce Pollutant Loads, Journal of Environmental Engineering, 137(11), 1082–1091.

Burns, M., Fletcher, T., Hatt, B., Ladson, A. R., and Walsh, C. J. (2010): Can allotment-scale rainwater harvesting manage urban flood risk and protect stream health?, Presented at the International Conference on Sustainable Techniques and Strategies in Urban Water Management 2010,Groupe de Recherche Rhone Alpes sur les Infrastructures et l'Eau, Villeurbanne, France, 1–10.

Carlson, W. et al., 2013. Eastern Washington Low Impact Development Guidance Manual, Appendix D: Bioretention Plant List. Prepared by AHBL and HDR. https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Low-Impact-Development-guidance Accessed December 2020.

Central Coast. LID Plant Guidance for Bioretention Low Impact Development, Table 1: Plants for Bioretention Areas. Prepared by the California Stormwater Quality Association. https://www.casqa.org/sites/default/files/downloads/central_coast_bioretention_plant_guidance_print.pdf Accessed December 2020.

Clary, J., Pitt, R., Steets, B. Eds. (2014). Pathogens in urban stormwater systems. Reston, VA: ASCE. 289 pp.

Conner, T. et al., 2019. Greater Phoenix Metro Green Infrastructure Handbook, Appendix C: Additional Plant Lists. Prepared for the City of Scottsdale and the Arizona State University Sustainable Cities Network.

Cornelissen, J. H. C., Lavorel, S., Garnier, E., Díaz, S., Buchmann, N., Gurvich, D. E., Reich, P. B., Steege, H. ter, Morgan, H. D., Heijden, M. G. A. van der, Pausas, J. G., and Poorter, H. (2003): A handbook of protocols for standardised and easy measurement of plant functional traits worldwide, Australian Journal of Botany, 51(4), 335–380.

Costello, L. R., and Jones, K. S.: WUCOLS III. A guide to estimating irrigation water needs of landscape plantings in California, University of California Cooperative Extension. https://cimis.water.ca.gov/Content/PDF/wucols00.pdf Accessed December 2020.

Daly, E., Deletic, A., Hatt, B. E., and Fletcher, T. D. (2012): Modelling of stormwater biofilters under random hydrologic variability: a case study of a car park at Monash University, Victoria (Australia), Hydrological Processes, 26(22), 3416–3424.

DiGiovanni Kimberly, Montalto Franco, Gaffin Stuart, and Rosenzweig Cynthia (2013): Applicability of Classical Predictive Equations for the Estimation of Evapotranspiration from Urban Green Spaces: Green Roof Results, Journal of Hydrologic Engineering, 18(1), 99–107.

DiGiovanni-White, K., Montalto, F., and Gaffin, S. (2018): A comparative analysis of micrometeorological determinants of evapotranspiration rates within a heterogeneous urban environment, Journal of Hydrology, 562, 223–243.

Du, P., Arndt, S. K., and Farrell, C. (2019): Is plant survival on green roofs related to their drought response, water use or climate of origin?, Science of The Total Environment, 667, 25–32.

Dylewski, K. L., Brown, T. R., LeBleu, C. M., Brantley, E. F., 2016. Low Impact Development Handbook Appendix D: Vegetation and Alabama Native Plant List. Prepared by Alabama Department of Environmental Management in cooperation with the Alabama Cooperative Extension System and Auburn University.

Ebrahimian, A., Gulliver, J. S., and Wilson, B. N. (2016): Effective impervious area for runoff in urban watersheds, Hydrological Processes, 30(20), 3717–3729.

Eger, C. G., Chandler, D. G., and Driscoll, C. T. (2017): Hydrologic processes that govern stormwater infrastructure behaviour, Hydrological Processes, 31(25), 4492–4506.

Eger, C. G., Chandler, D. G., Kasaee Roodsari, B., Davidson, C. I., and Driscoll, C. T. (2014): Water Budget Triangle: A New Conceptual Framework for Comparison of Green and Gray Infrastructure, International Conference on Sustainable Infrastructure.

Ellis, K. C. et al., 2014. Low Impact Development in Coastal South Carolina: A Planning and Design Guide, Tables 4.2-4 through 4.2-6. Prepared by ACE Basin and North Inlet–Winyah Bay National Estuarine Research Reserves. https://www.scseagrant.org/wp-content/uploads/LID-in-Coastal-SC-low-res.pdf Accessed December 2020.

Engineer, C. B., Hashimoto-Sugimoto, M., Negi, J., Israelsson-Nordström, M., Azoulay-Shemer, T., Rappel, W.-J., Iba, K., and Schroeder, J. I. (2016): CO2 Sensing and CO2 Regulation of Stomatal Conductance: Advances and Open Questions, Trends in Plant Science, 21(1), 16–30.

FAWB (2009): Guidelines for filter media in biofiltration systems (Version 3.01) June 2009, Facility for Advancing Water Biofiltration.
http://graie.org/SOCOMA/IMG/pdf/FAWB_Filter_media_guidelines_v3_June_2009-2.pdf
Accessed December 2020.

Feddes, R. A., and Zaradny, H. (1978): Model for simulating soil-water content considering evapotranspiration — Comments, Journal of Hydrology, 37(3), 393–397.

Feng, Y., Burian, S., and Pomeroy, C. (2016): Potential of green infrastructure to restore predevelopment water budget of a semi-arid urban catchment, Journal of Hydrology, 542, 744–755.

Fishers SW TSM. City of Fishers Stormwater Technical Standards Manual, Appendix D2: Recommended Plant Lists for Best Management Practices. Prepared by Christopher B. Burke Engineering.

Fletcher, T., Zinger, Y., Bratieres, K., and Deletic, A. (2007): Treatment efficiency of biofilters; Results of a large-scale column study, Rainwater and Urban Design, 266.

GHD Pty Ltd (2012): Edinburgh Gardens Raingarden, Landezine.
http://landezine.com/index.php/2012/10/edinburgh-gardens-raingarden-by-ghd-pty-ltd/ Accessed December 2020.

Guo, H. (2011): A Simple Algorithm for Fitting a Gaussian Function [DSP Tips and Tricks], IEEE Signal Processing Magazine, 28(5), 134–137.

Gong, Y., Hao, Y., Li, J., Li, H., Shen, Z., Wang, W., and Wang, S. (2019): The Effects of Rainfall Runoff Pollutants on Plant Physiology in a Bioretention System Based on Pilot Experiments, Sustainability, 11(22).

Griffin-Nolan, R. J., Blumenthal, D. M., Collins, S. L., Farkas, T. E., Hoffman, A. M., Mueller, K. E., Ocheltree, T. W., Smith, M. D., Whitney, K. D., and Knapp, A. K. (2019): Shifts in plant functional composition following long-term drought in grasslands, Journal of Ecology, 107(5), 2133–2148.

Grime, J. P. (1977): Evidence for the Existence of Three Primary Strategies in Plants and Its Relevance to Ecological and Evolutionary Theory, The American Naturalist, 111(982), 1169–1194.

Hamel, P., Fletcher, T., Walsh, C. J., and Plessis, E. (2011): Quantifying the restoration of evapotranspiration and groundwater recharge by vegetated infiltration systems, Proceedings from the 12th International Conference on Urban Drainage, 10–16.

Hamel, P., Daly, E., and Fletcher, T. D. (2013): Source-control stormwater management for mitigating the impacts of urbanisation on baseflow: A review, Hydrology of Peri-Urban Catchments: Processes and Modelling, 485, 201–211.

Henry, C., John, G. P., Pan, R., Bartlett, M. K., Fletcher, L. R., Scoffoni, C., and Sack, L. (2019): A stomatal safety-efficiency trade-off constrains responses to leaf dehydration, Nature Communications, 10(1), 3398.

Hirschman, D., and Collins, K. (2008): The Runoff Reduction Method, Center for Watershed Protection.

Houdeshel, C. D., Hultine, K. R., Johnson, N. C., and Pomeroy, C. A. (2015): Evaluation of three vegetation treatments in bioretention gardens in a semi-arid climate, Landscape and Urban Planning, 135, 62–72.

Huang, C.-L., Hsu, N.-S., Liu, H.-J., and Huang, Y.-H. (2018): Optimization of low impact development layout designs for megacity flood mitigation, Journal of Hydrology, 564, 542–558.

Hunt, W. F., Lord, B., Loh, B., and Sia, A. (2015): Plant Selection for Bioretention Systems and Stormwater Treatment Practices, Springer Open.

Iida, S., Shimizu, T., Tamai, K., Kabeya, N., Shimizu, A., Ito, E., Ohnuki, Y., Chann, S., and Levia, D. F. (2020): Evapotranspiration from the understory of a tropical dry deciduous forest in Cambodia, Agricultural and Forest Meteorology, 295, 108170.

Jacobson, C. R. (2011). Identification and quantification of the hydrological impacts of imperviousness in urban catchments: A review. J. Environ. Manage. 92 (6), 1438−1448.

Jefferson, A. J., Bhaskar, A. S., Hopkins, K. G., Fanelli, R., Avellaneda, P. M., and McMillan, S. K. (2017): Stormwater management network effectiveness and implications for urban watershed function: A critical review, Hydrological Processes, 31(23), 4056–4080.

Jin, Y., Schaaf, C. B., Gao, F., Li, X., Strahler, A. H., Zeng, X., and Dickinson, R. E. (2002): How does snow impact the albedo of vegetated land surfaces as analyzed with MODIS data?, Geophysical Research Letters, 29(10), 12–1.

King, R. S.; Baker, M. E.; Kazyak, P. F.; Weller, D. E. (2011) How novel is too novel? Stream community thresholds at exceptionally low levels of catchment urbanization. Ecological Applications, 21 (5), 1659−1678.

Laio, F., Porporato, A., Ridolfi, L., and Rodriguez-Iturbe, I. (2001): Plants in water-controlled ecosystems: active role in hydrologic processes and response to water stress: II. Probabilistic soil moisture dynamics, Advances in Water Resources, 24(7), 707–723.

Li, C., Liu, M., Hu, Y., Shi. T., Zong, M., Wlater, M.T. (2018): Assessing the impact of urbanization on direct runoff using improved composite CN method in a large urban area. Int J Environ Res Public Health. 15(4):776 doi: 10.3390/ijerph15040775.

Li, Y., Huang, J. J., Hu, M., Yang, H., and Tanaka, K. (2020): Design of low impact development in the urban context considering hydrological performance and life-cycle cost, Journal of Flood Risk Management, 13(3), e12625.

Li, H., Sharkey, L. J., Hunt, W. F., Davis, A. P. (2009): Mitigation of impervious surface hydrology using bioretention in North Carolina and Maryland. J. Hydrol. Eng. 14 (4), 407−415.

Liknes, G. C., Nelson, M. D., and Kaisershot, D. J. (2020): Historical woodland density of the conterminous United States, 1873, USDA Forest Service, Northern Research Station.

Lizárraga-Mendiola, L., Vázquez-Rodríguez, G., Lucho-Constantino, C. A., Bigurra-Alzati, C. A., Beltrán-Hernández, R. O., Ortiz-Hernández, J. E., and López-León, L. D. (2017): Hydrological Design of Two Low-Impact Development Techniques in a Semi-Arid Climate Zone of Central Mexico, Water, 9(561).

Lososová, Z., Chytrý, M., Kühn, I., Hájek, O., Horáková, V., Pyšek, P., and Tichý, L. (2006): Patterns of plant traits in annual vegetation of man-made habitats in central Europe, Perspectives in Plant Ecology, Evolution and Systematics, 8(2), 69–81.

Lundholm, J. T. (2015): Green roof plant species diversity improves ecosystem multifunctionality, Journal of Applied Ecology, 52(3), 726–734.

Majekova, M., Hajek, T., Albert, A., de Bello, F., Dolezal, J., Götzenberger, L., Janeček, Š., Leps, J., and Mudrak, O. (2020): From functional to mechanistic: coordination between turgor loss point and traits related to drought tolerance in herbaceous plants, Authorea Preprints.
Mao, J., and Yan, B. (2019): Global Monthly Mean Leaf Area Index Climatology, 1981-2015, ORNL DAAC.

Manly, B. F. J. Randomization, Bootstrap, and Monte Carlo Methods in Biology (3rd ed.), London: Chapman & Hall, 2007.

Manzoni, S., Vico, G., Katul. G., Palmroth, S., Porporato, A. (2014): Optimal plant water-use strategies under stochastic rainfall. Water Resources Research. 50, doi:10.1002/2014WR015375.

Maréchaux, I., Bartlett, M. K., Sack, L., Baraloto, C., Engel, J., Joetzjer, E., and Chave, J. (2015): Drought tolerance as predicted by leaf water potential at turgor loss point varies strongly across species within an Amazonian forest, Functional Ecology, 29(10), 1268–1277.

Markesteijn, L., Iraipi, J., Bongers, F., and Poorter, L. (2010): Seasonal variation in soil and plant water potentials in a Bolivian tropical moist and dry forest, Journal of Tropical Ecology, retrieved from JSTOR., 26(5), 497–508.

McEvoy, A., Markvart, T., Castañer, L., Markvart, T., and Castaner, L. (2003): Practical handbook of photovoltaics: fundamentals and applications, Elsevier.

McGrane, S. J. (2016): Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review, Hydrological Sciences Journal, 61(13), 2295–2311.

McPhillips, L., and Matsler, M. (2018): Temporal Evolution of Green Stormwater Infrastructure Strategies in Three US Cities, Frontiers in Built Environment, 4.

Meng, Y., Wang, H., Chen, J., and Zhang, S. (2014): Modelling Hydrology of a Single Bioretention System with HYDRUS-1D, The Scientific World Journal, 2014, 521047.

Michigan LID, 2008. Low Impact Development Manual for Michigan: A design Guide for Implementers and Reviewers, Appendix C: Recommended Plant Lists for Best Management Practices. Prepared by the Southeast Michigan Council of Governments. https://semcog.org/desktopmodules/SEMCOG.Publications/GetFile.ashx?filename=LowImpactDevelopmentManualforMichiganSeptember2008.pdf Accessed December 2020.

Missouri GI, 2012. Missouri Guide to Green Infrastructure Chapter 6, Section 7: Plant List. Prepared by Shockey Consulting Services, LLC., Black & Veatch Corporation, and Williams-Creek Consulting Inc.

MSDM, 2000. The 2000 Maryland stormwater design manual volumes 1 and 2, Appendix B.3: Construction Spec's for Bioretention, Filters, and Open Channels. Prepared by the Center for Watershed Protection, Elliot City, Maryland and the Maryland Department of the Environment Water Management Administration.

MSM Wiki, 2003. Minnesota plant lists. Prepared by the Minnesota Stormwater Design Team with information from the Annotated Checklist of the Flora of Minnesota from the University of Minnesota. https://stormwater.pca.state.mn.us/index.php?title=Minnesota_plant_lists Accessed December 2020.

Murray, M., Soh, W. K., Yiotis, C., Batke, S., Parnell, A. C., Spicer, R. A., Lawson, T., Caballero, R., Wright, I. J., Purcell, C., and McElwain, J. C. (2019): Convergence in Maximum Stomatal Conductance of C3 Woody Angiosperms in Natural Ecosystems Across Bioclimatic Zones, Frontiers in Plant Science, 10, 558.

National Academies of Sciences, Engineering, and Medicine (NAE), (2016): Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits. Washington, DC: The National Academies Press. https://doi.org/10.17226/21866.

Nicklow, J. W., and Hellman, A. P. (2004): Optimal design of storm water inlets for highway drainage, Journal of Hydroinformatics, 6(4), 245–257.

Nicklow, J. W., Boulbos, P. F., and Muleta, M. K. (2006). Nicklow, John W., Paul F. Boulos, and Misgana K. Muleta. Comprehensive urban hydrologic modeling handbook for engineers and planners. MHW Soft, Incorporated.

Nocco, M. A., Rouse, S. E., and Balster, N. J. (2016): Vegetation type alters water and nitrogen budgets in a controlled, replicated experiment on residential-sized rain gardens planted with prairie, shrub, and turfgrass, Urban Ecosystems, retrieved from ABI/INFORM Global; SciTech Premium Collection. (1849312524), 19(4), 1665–1691.

O'Donnell, M. S., and Ignizio, D. A. (2012): Bioclimatic predictors for supporting ecological applications in the conterminous United States, US Geological Survey Data Series, 169(10).

Ochoa-Sánchez, A. E., Crespo, P., Carrillo-Rojas, G., Marín, F., and Célleri, R. (2020): Unravelling evapotranspiration controls and components in tropical Andean tussock grasslands, Hydrological Processes, 34(9), 2117–2127.

Ogle, D. G. and Hoag, C. J., 2000. StormWater Plant Materials, Appendix C: Plant Lists. Prepared by the USDA-Natural Resources Conservation Service. https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/idpmcar2261.pdf Accessed December 2020.

Olympia BMPs, 2016. Drainage Design and Erosion Control Manual Volume V, Appendix V-E: Recommended Newly Planted Tree Species for Flow Control Credit. Prepared by the City of Olympia Public Works. http://olympiawa.gov/city-utilities/storm-and-surface-water/policies-and-regulations/policies-and-regulations-2009-drainage-manual.aspx Accessed December 2020.

PA BMP, 2006. Pennsylvania Stormwater BMP Manual, Appendix B: BMP Plant List. Prepared by the Pennsylvania Department of Environmental Protection. https://pecpa.org/wp-content/uploads/Stormwater-BMP-Manual.pdf Accessed December 2020.

Pan, W., Huang, Q., Zhenghe. X., Pang, G. (2020) Experimental investigation and simulation of nitrogen transport in a subsurface infiltration system under saturated and unsaturated conditions. Journal of Contaminant Hydrology. 231, https://doi.org/10.1016/j.jconhyd.2020.103621

Parker, E.A., Grant, S.B., Cao, Y., Rippy, M.A., McGuire, K.J., Holden, P.A., Feraud, M., Avasarala, S., Liu, H., Hung, W.C., Rugh, M., Jay, J., Peng, J., Shao, S., Li, D. (2020): Predicting unsteady solute transport through treen infrastructure with transit time distribution theory. *Under Review by Water Resources Research*

Payne, E. G. I., Pham, T., Deletic, A., Hatt, B. E., Cook, P. L. M., and Fletcher, T. D. (2018): Which species? A decision-support tool to guide plant selection in stormwater biofilters, Advances in Water Resources, 113, 86–99.

Petruzzellis, F., Savi, T., Bacaro, G., and Nardini, A. (2019): A simplified framework for fast and reliable measurement of leaf turgor loss point, Plant Physiology and Biochemistry, 139, 395–399.

Pierce, S., Brusa, G., Vagge, I., and Cerabolini, B. E. L. (2013): Allocating CSR plant functional types: the use of leaf economics and size traits to classify woody and herbaceous vascular plants, Functional Ecology, 27(4), 1002–1010.

Pierce, S., Negreiros, D., Cerabolini, B. E. L., Kattge, J., Díaz, S., Kleyer, M., Shipley, B., Wright, S. J., Soudzilovskaia, N. A., Onipchenko, V. G., van Bodegom, P. M., Frenette-Dussault, C., Weiher, E., Pinho, B. X., Cornelissen, J. H. C., Grime, J. P., Thompson, K., Hunt, R., Wilson, P. J., Buffa, G., Nyakunga, O. C., Reich, P. B., Caccianiga, M., Mangili, F., Ceriani, R. M., Luzzaro, A., Brusa, G., Siefert, A., Barbosa, N. P. U., Chapin III, F. S., Cornwell, W. K., Fang, J., Fernandes, G. W., Garnier, E., Le Stradic, S., Peñuelas, J., Melo, F. P. L., Slaviero, A., Tabarelli, M., and Tampucci, D. (2017): A global method for calculating plant CSR ecological strategies applied across biomes world-wide, Functional Ecology, 31(2), 444–457.

Rafi, Z. N., Kazemi, F., and Tehranifar, A. (2018): Morpho-physiological and biochemical responses of four ornamental herbaceous species to water stress, Acta Physiologiae Plantarum, 41(1), 7.

Rechid, D., Raddatz, T. J., and Jacob, D. (2009): Parameterization of snow-free land surface albedo as a function of vegetation phenology based on MODIS data and applied in climate modelling, Theoretical and Applied Climatology, 95(3), 245–255.

Reich, P. B. (2014): The world-wide 'fast–slow' plant economics spectrum: a traits manifesto, Journal of Ecology, 102(2), 275–301.

Reich, P. B., Ellsworth, D. S., Walters, M. B., Vose, J. M., Gresham, C., Volin, J. C., and Bowman, W. D. (1999): Generality of leaf trait relationships: a test across six biomes, Ecology, 80(6), 1955–1969.

Roy, A. H.; Rhea, L. K.; Mayer, A. L.; Shuster, W. D.; Beaulieu, J. J.; Hopton, M. E.; Morrison, M. A.; Amand, A. S. (2014) How Much Is Enough? Minimal Responses of Water Quality and Stream Biota to Partial Retrofit Storm water Management in a Suburban Neighborhood. PLoS One, 9 (1), e85011.

SDDM, 2016. County of San Diego BMP Design Manual, Appendix E.26: PL Plant List for Bioretention Facilities. Prepared by the County of San Diego, California. https://www.sandiegocounty.gov/content/sdc/dpw/watersheds/DevelopmentandConstruction/BMP_Design_Manual.html Accessed December 2020.

Shuster, W.; Rhea, L. (2013) Catchment-scale hydrologic implications of parcel-level storm water management (Ohio USA). J. Hydrol. 485, 177−187.

Šimůnek, J., and Hopmans, J. W. (2009): Modeling compensated root water and nutrient uptake, Ecological Modelling, 220(4), 505–521.

Šimunek, J., Jacques, D., Langergraber, G., Bradford, S. A., Šejna, M., and van Genuchten, M. Th. (2013): Numerical Modeling of Contaminant Transport Using HYDRUS and its Specialized Modules, Journal of the Indian Institute of Science, 93(2), 265–284.

SoCal LID, 2010. Low Impact Development Manual for Southern California: Technical Guidance and Site Planning Strategies, Appendix A: Lists of Plants Suitable for Southern California. Prepared for the Southern California Stormwater Monitoring Coalition, in cooperation with the State Water Resources Control Board, by the Low Impact Development Center, Inc. https://www.casqa.org/sites/default/files/downloads/socallid-manual-final-040910.pdf Accessed December 2020.

SWMM, 2016. City of Portland Stormwater Management Manual, Public Stormwater Facility Plant List. Prepared by the City of Portland, Oregon. https://www.portlandoregon.gov/bes/64040 Accessed December 2020.

Tabassum, R. et al., 2012. West Virginia Stormwater Management and Design Guidance Manual, Appendix F: BMP Landscaping and Plant Lists. Prepared by the West Virgnia Department of Environmental Protection. https://dep.wv.gov/WWE/Programs/stormwater/MS4/Pages/StormwaterManagementDesignandGuidanceManual.aspx Accessed December 2020.

Tahoe BMP, 2014. Best Management Practices Handbook, Chapter 5.3: Vegetation. Prepared by the Tahoe Regional Planning Agency. https://tahoebmp.org/Documents/BMPHandbook/Ch5_SoilandVegetationManagement.pdf Accessed December 2020.

Taiz, L., Møller, I. M., and Murphy, A. (2015): Plant physiology and development, Sinauer Associates Inc., Sunderland.

Tavakol-Davani, H. E., Tavakol-Davani, H., Burian, S. J., McPherson, B. J., and Barber, M. E. (2019): Green infrastructure optimization to achieve pre-development conditions of a semiarid urban catchment, Environmental Science: Water Research & Technology, 5(6), 1157–1171.

Therneau, T., Atkinson, B., and Ripley, B. (2019): Package “rpart.” https://cran.r-project.org/web/packages/rpart/rpart.pdf Accessed December 2020.

Touchette, B. W., Iannacone, L. R., Turner, G. E., and Frank, A. R. (2007): Drought tolerance versus drought avoidance: A comparison of plant-water relations in herbaceous wetland plants subjected to water withdrawal and repletion, Wetlands, 27(3), 656–667.

Tucson LID, 2015. Low Impact Development and Green Infrastructure Guidance Manual, Appendix G: Plant List. Prepared by Pima County, the City of Tucson, and Pima Association of Governments.

Utah LID, 2018. A Guide to Low Impact Development within Utah, Vegetation Selection. Prepared by Michael Baker International and Environmental Planning Group LLC.

Vermont RGM, 2011. The Vermont Rain Garden Manual Table 1: The Vermont Rain Garden Plant List. Prepared by Winooski Natural Resources Conservation District, University of Vermont, and Lake Champion Sea Grant.

Volaire, F. (2018): A unified framework of plant adaptive strategies to drought: Crossing scales and disciplines, Global Change Biology, 24(7), 2929–2938.

Wadzuk, B., Hickman J., Traver, R. (2015): Understanding the role of evapotranspiration in bioretention: Mesocosm study. J. Sustain. Water Built Environ., 1(2), doi: 04014002

Waickowski, S. et al., 2018. NCDEQ Stormwater Design Manual part C-2: Bioretention Cell. Prepared by the North Carolina Department of Environmental Quality.

Waller, L. J., Evanylo, G. K., Krometis, L.-A. H., Strickland, M. S., Wynn-Thompson, T., and Badgley, B. D. (2018): Engineered and Environmental Controls of Microbial Denitrification in Established Bioretention Cells, Environmental Science & Technology, 52(9), 5358–5366.

Walsh, C. J., Booth, D. B., Burns, M. J., Fletcher, T. D., Hale, R. L., Hoang, L. N., Livingston, G., Rippy, M. A., Roy, A. H., Scoggins, M., and Wallace, A. (2016): Principles for urban stormwater management to protect stream ecosystems, Freshwater Science, 35(1), 398–411.

Walsh, C. J., Fletcher, T. D., and Ladson, A. R. (2005): Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream, Journal of the North American Benthological Society, 24(3), 690–705.

Wang, Z., Li, Y., Su, X., Tao, S., Feng, X., Wang, Q., Xu, X., Liu, Y., Michaletz, S. T., Shrestha, N., Larjavaara, M., and Enquist, B. J. (2019): Patterns and ecological determinants of woody plant height in eastern Eurasia and its relation to primary productivity, Journal of Plant Ecology, 12(5), 791–803.

Ward, A. and Banhunyadi, R., 2019. Low Impact Development Technical Manual volumes 1-3, Appendix A: Approved Plants. Prepared by the Walton County LDC.

Westfall, P. H. (2011): On Using the Bootstrap for Multiple Comparisons, Journal of Biopharmaceutical Statistics, 21(6), 1187–1205.

Zhang, K., Randelovic, A., Aguiar, L. M., Page, D., McCarthy, D. T., & Deletic, A. (2015). Methodologies for pre-validation of biofilters and wetlands for stormwater treatment. *PloS one*, *10*(5), e0125979. https://doi.org/10.1371/journal.pone.0125979

MANUSCRIPT FIGURES:

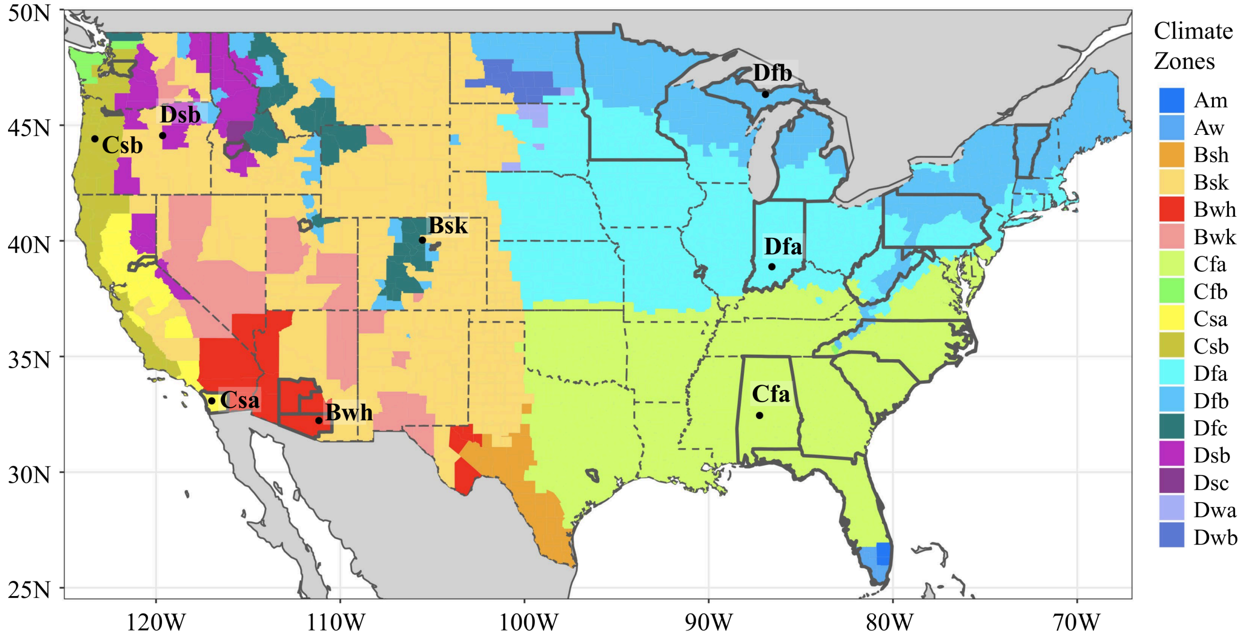

Figure 1: Map of Koppen-Geiger climate zones of the coterminous US. Grey lines indicate regions (counties or states) where bioretention plant lists were sourced. Black dots indicate the location of USCRN stations where meteorological data were sourced for each of the 8 climate zones evaluated in this study: Bwh (USCRN 1011), Bsk (USCRN 1507), Cfa (USCRN 1122), Csa (USCRN 1528), Csb (USCRN 1234), Dfa (USCRN 1510), Dfb (USCRN 1113), Dsb (USCRN 1145).

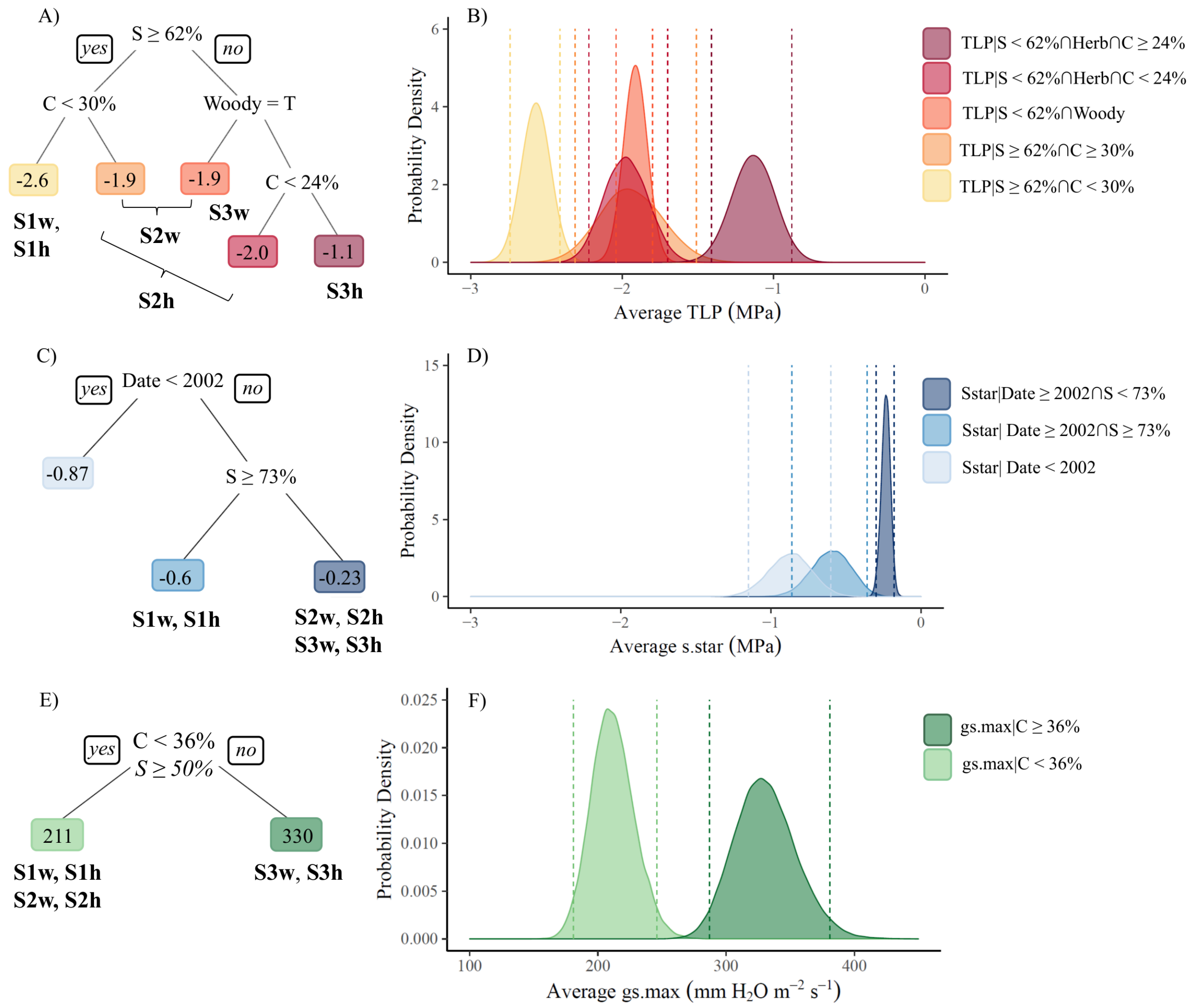

Figure 2: Classification and regression tree (CART) models for turgor loss point (**A:** TLP, red tones), the point of incipient water stress (**C:** IWS, blue tones), and maximum stomatal conductance (**E:** gs.max, green tones) are shown along with the probability distributions for each terminal CART node (**B:** TLP, **D:** IWS, **F:** gs.max). Probability distributions are color coded to match terminal nodes. 95% confidence bounds about each probability distribution are shown using dashed lines of corresponding color. CART models are read by evaluating the equality at each branch point and moving to the left if the equality is not satisfied and to the right if the equality is satisfied. S stands for stress tolerance, C stands for competitiveness, and Woody stands for woody stem type. Each terminal node is defined as the union of the conditions satisfied at each junction (for instance, a TLP of -2.6 (pale yellow color) occurs at S ≥ 62%∩C < 30%). The names of our six plant water use scenarios are listed below the terminal nodes with the characteristics they reflect. Note that degree of stress tolerance is a key determinant in all three models, providing connective tissue between them and the foundation for our multi-trait scenarios.

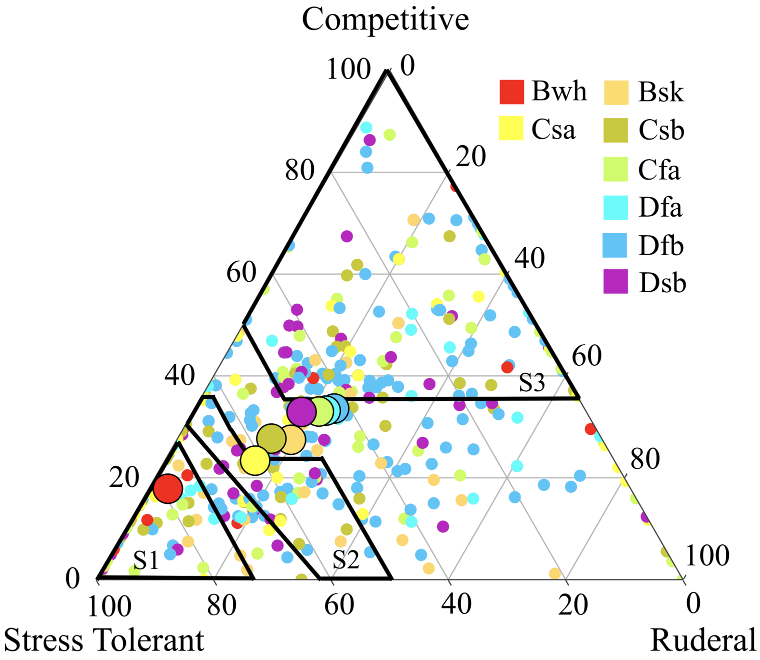

Figure 3: Ternary diagram of CSR type of bioretention plants by climate zone (top corner: 100% competitive, lower left corner: 100% stress tolerant, and lower right corner: 100% ruderal). Plants sourced from design guidelines for different climate zones are indicated using climate specific colors and small circles (red: Bwh, orange: Bsk, yellow: Csa, olive: Csb, lime: Cfa, cyan: Dfa, blue: Dfb, purple: Dsb). The geometric median CSR type of each climate zone is indicated using large circles of corresponding color. The range of possible CSR types for each water use scenarios defined in Fig. 2 are delineated by solid black lines: S1 woody and herbaceous (highly stress tolerant CSR zone), S2 woody and herbaceous (moderate-highly stress tolerant CSR zone), and S3 woody and herbaceous (moderate-highly competitive CSR zone). Fewer BRC plants were ruderal than any other plant type (see bare lower right corner).

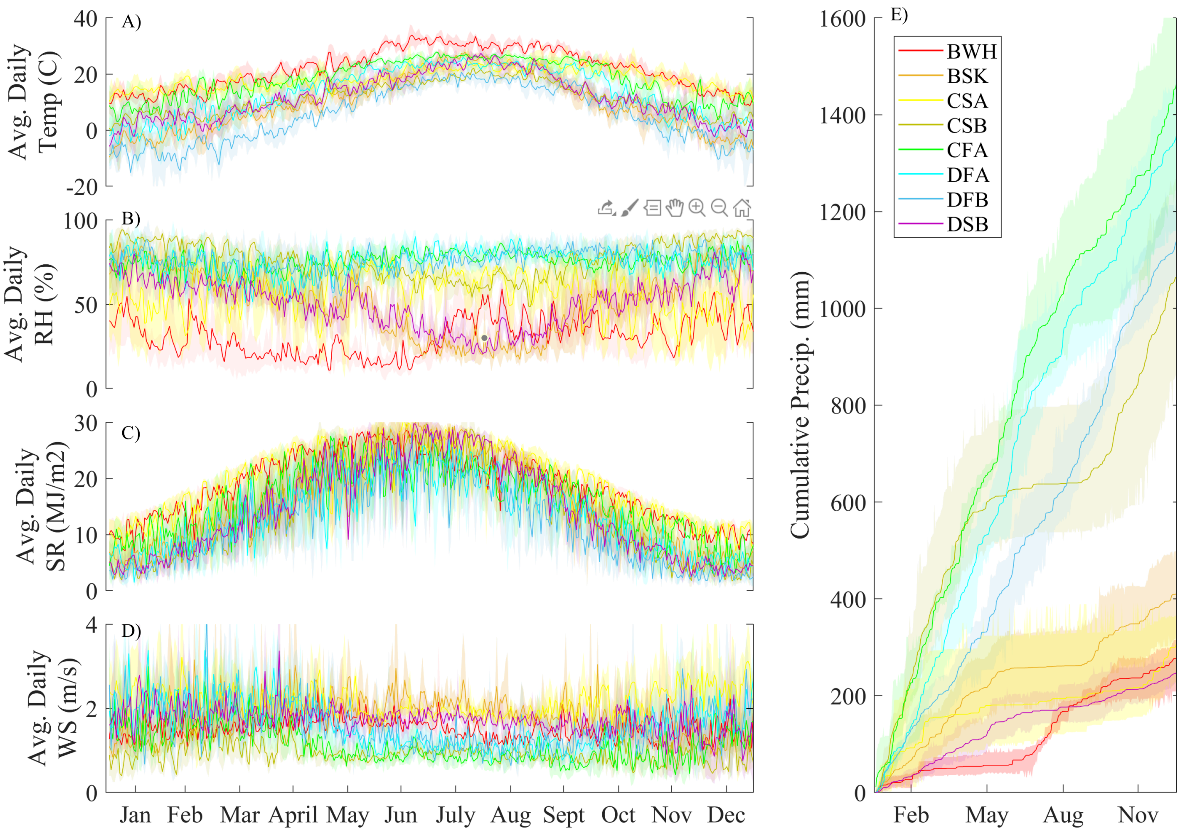

Figure 4: Average daily timeseries (estimated using 4 years of continuous data; solid lines) for **A:** temperature (Temp; C), **B:** relative humidity (RH; %), **C:** solar radiation (SR; MJ/m^2), **D:** wind speed (WS; m/s), and **E:** cumulative precipitation (Precip; mm) from eight USCERN meteorological stations, one in each climate zone. Climate zones are indicated by color (red: Bwh, orange: Bsk, yellow: Csa, olive: Csb, lime: Cfa, cyan: Dfa, blue: Dfb, purple: Dsb). Shaded regions are 95% confidence bounds about each average.

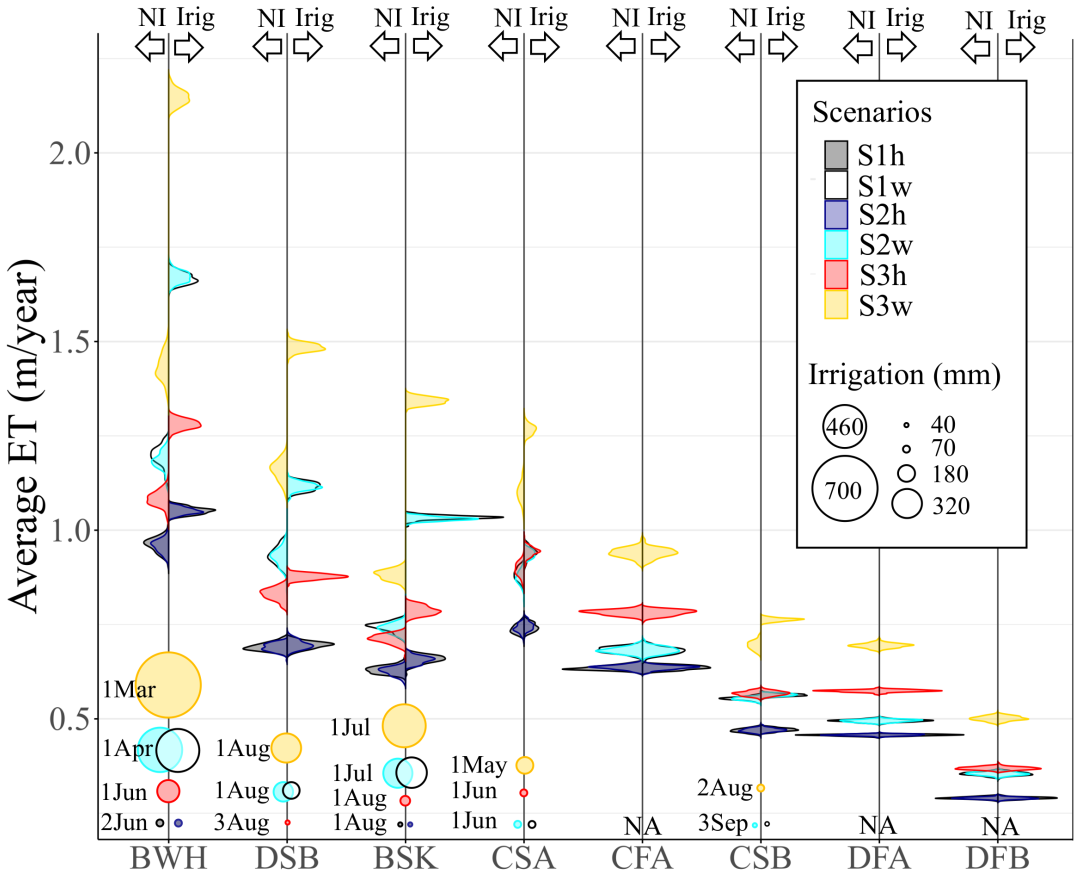

Figure 5: Probability distributions of average annual evapotranspiration (ET, m/year; y-axis) by climate zone (x-axis) and plant water-use scenario (S1h: black, S1w: white, S2h: dark blue, S2w: cyan, S3h: red, S3w: yellow). Distributions pointing left are for simulated BRCs with no supplemental irrigation. Distributions pointing right are for simulated BRCs that received supplemental irrigation whenever the soil water potential fell below the turgor loss point (TLP; see **Table 1** for scenario-specific TLPs). The total amount of supplemental irrigation applied for each scenario in each climate is indicated by circle size (bottom of plot). The year and month when irrigation was first applied is noted on the left hand side of each irrigation circle (notation - 1Mar: required irrigation in year 1 during the month of March). NA is reported for climate zones where no supplemental irrigation was required. The degree of overlap of each ET distribution is a visual indicator of differences in annual ET among scenarios (see **Table S8** for formal significance thresholds).

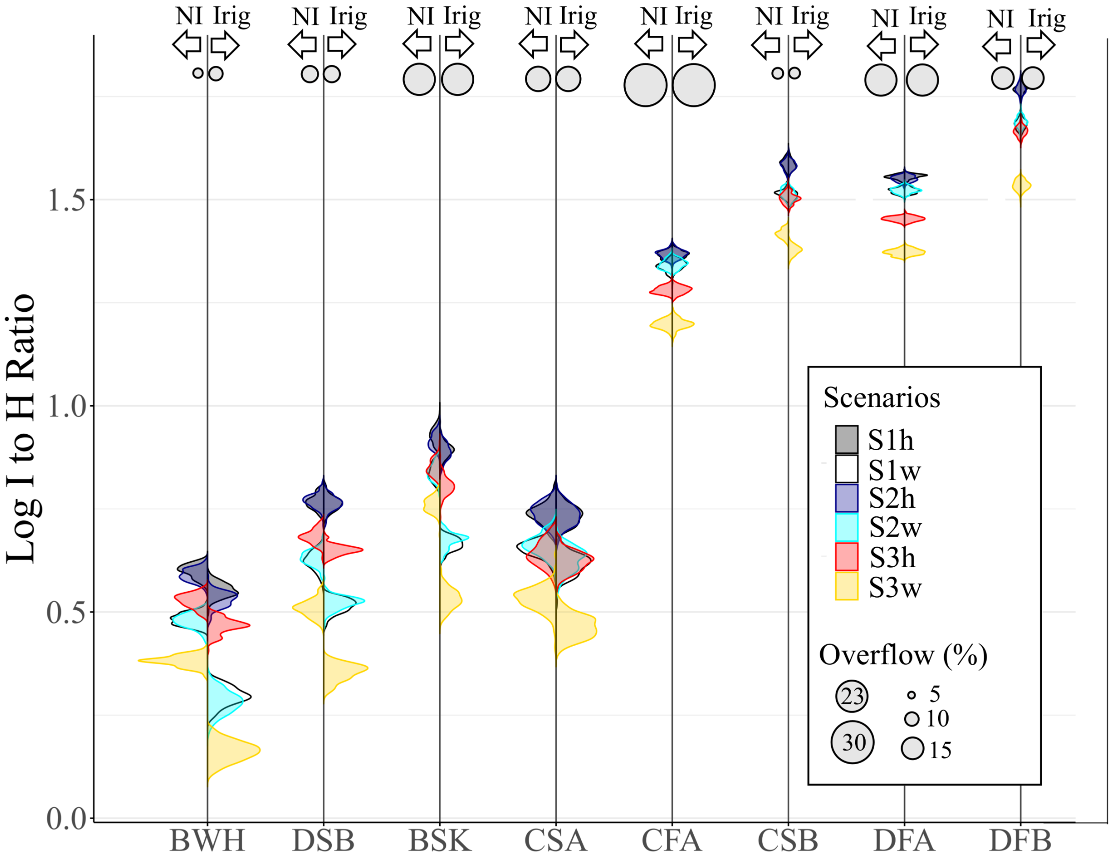

Figure 6: Probability distributions of average annual infiltration to harvest ratios (log10 I:H; y-axis) by climate zone (x-axis) and plant water-use scenario. Scenario color and the orientation of each probability distribution (left for non-irrigated right for irrigated) is the same as **Fig. 5.** The percentage of overall inflow that becomes overflow on an annual basis is shown using grey circles (circle size scales with overflow amount; left = non-irrigated scenarios and right = irrigated scenarios). The degree of overlap of each I:H ratio distribution is a visual indicator of differences in I:H ratio's among scenarios (see **Table S8** for formal significance thresholds).

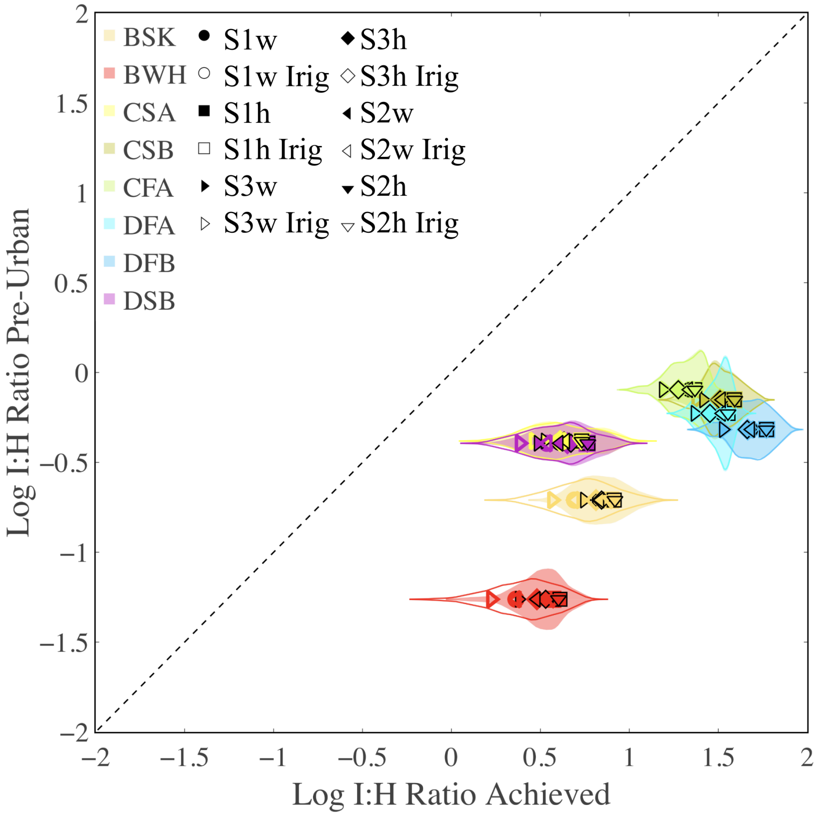

Figure 7: A one to one plot of the log10 infiltration to harvest (I:H) ratio achieved in our BRC simulations and the pre-urban expectation in each climate zone. All simulated I:H ratios are biased high (i.e., simulated BRCs infiltrate more than expected under pre-urban conditions). Climate zones are indicated using color (red: Bwh, orange: Bsk, yellow: Csa, olive: Csb, lime: Cfa, cyan: Dfa, blue: Dfb, purple: Dsb). Average log10 I:H ratios for each scenario are shown using symbols (solid for non-irrigated and open for irrigated). The full range and shape of the distribution of simulated log10 I:H ratios in each climate zone is indicated using violins (shaded for non-irrigated, open for irrigated).

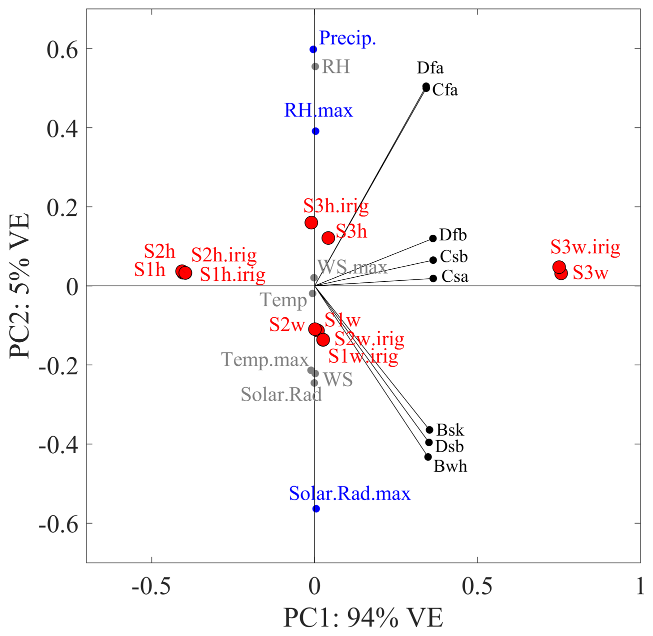

Figure 8: Biplot of dominant patterns in evapotranspiration (ET) across scenarios and climate zones. Irrigated and non-irrigated simulations were de-meaned separately prior to analysis so that differences in their respective ET magnitudes would not drive observed patterns. Principal component 1 (PC1) is on the x-axis and explains 94% of observed variance across scenarios. Positive PC1 scenarios have higher ET in all climates whereas negative PC1 scenarios have lower ET in all climates. PC2 explains an additional 5% of the variance across scenarios with Bwh, Bsk and Dsb, loading towards S2w and S1w and away from S3h, and Dfa and Cfa doing the reverse. Csa, Csb, and Dfb did not contribute significantly to PC2. Factor projection with meteorological variables (blue = significant and grey = insignificant factor loadings; $p < 0.05$ level) illustrates that maximum monthly solar radiation clusters with Bsk, Dsb, and Bwh (more ET from woody than competitive plant scenarios), whereas precipitation, and to a lesser extent maximum monthly relative humidity, loads with Dfa and Cfa (more ET with competitive than woody plant scenarios).

Table 1: Plant Water Use Scenarios

Scenario	%S	%C	Stem Type	ET traits
S1w (S-type; Woody)	> 73%	< 30%	W	gs_{max}: 211 mm H_2O $m^{-2}s^{-1}$ TLP: -2.6 MPa IWS: -0.6 MPa Avg. plant height: 5m albedo: 0.165 max LAI: 3
S1h (S-type; Herb)	> 73%	< 30%	H	gs_{max}: 211 mm H_2O $m^{-2}s^{-1}$ TLP: -2.6 MPa IWS: -0.6 MPa Avg. plant height: 0.5m albedo: 0.25 max LAI: 2
S2w (CS-type; Woody ***OR*** SR-type Woody)	62 - 73% ***OR*** 50 - 62%	30 - 36% ***OR*** < 24%	W	gs_{max}: 211 mm H_2O $m^{-2}s^{-1}$ TLP: -1.9 MPa IWS: -0.23 MPa Avg. plant height: 5m albedo: 0.165 max LAI: 3
S2h (CS-type; Herb ***OR*** SR-type Herb)	62 - 73% ***OR*** 50 - 62%	30 - 36% ***OR*** < 24%	H	gs_{max}: 211 mm H_2O $m^{-2}s^{-1}$ TLP: -2.0 MPa IWS: -0.23 MPa Avg. plant height: 0.5m albedo: 0.25 max LAI: 2
S3w (C, CR, CS, or CSR type; Woody)	< 50%	> 36%	W	gs_{max}: 330 mm H_2O $m^{-2}s^{-1}$ TLP: -1.9 MPa IWS: -0.23 MPa Avg. plant height: 5m albedo: 0.165 max LAI: 3
S3h (C, CR, CS, or CSR type; Herb)	< 50%	> 36%	H	gs_{max}: 330 mm H_2O $m^{-2}s^{-1}$ TLP: -1.1 MPa IWS: -0.23 MPa Avg. plant height: 0.5m albedo: 0.25 max LAI: 2

Balancing the Water Budget: the effect of plant functional type on infiltration to harvest ratios in stormwater bioretention cells

Lauren Krauss

Supplemental Material File

Table of Contents:

Supplemental Figures:

Supplemental Tables:

SUPPLEMENTAL FIGURES

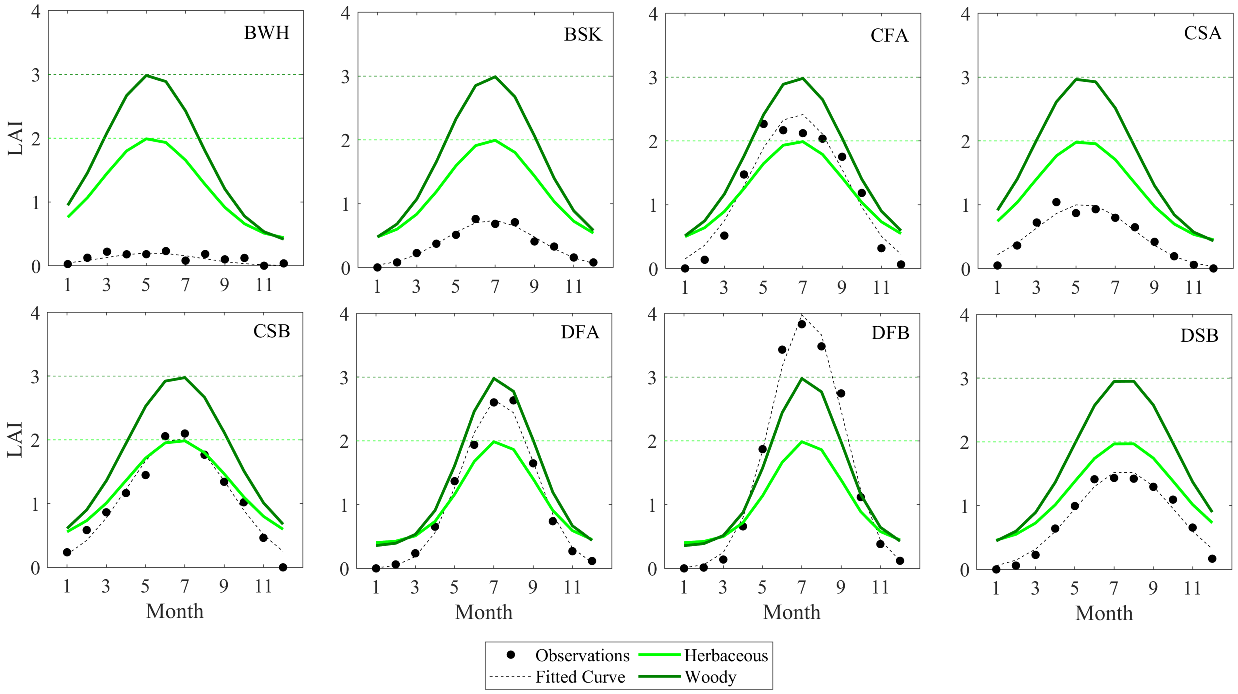

Figure S1: Leaf Area Index by climate zone and stem type (woody: dark green, herbaceous: light green). Data observations (black circles) represent average monthly LAI values estimated for each climate zone using ArcGIS Pro and the Global Monthly Mean Leaf Area Index layer by ORNL DAAC (1981 – 2015). Observations were fit with Gaussian curves (black dashed lines) and these fits were scaled to a max LAI of 2 for herbaceous and 3 for woody plant types across all climates. These maxima are considered representative values for these two plant types [**Mao and Yan, 2019**]; maxima for each respective climate zone were not retained for use in our simulations because bioretention cells are expected to be more densely vegetated than the average landscape in dry desert biomes like Bwh and less densely vegetated than the average landscape in wetter regions like Dfb, making zone-specific LAI maxima inappropriate.

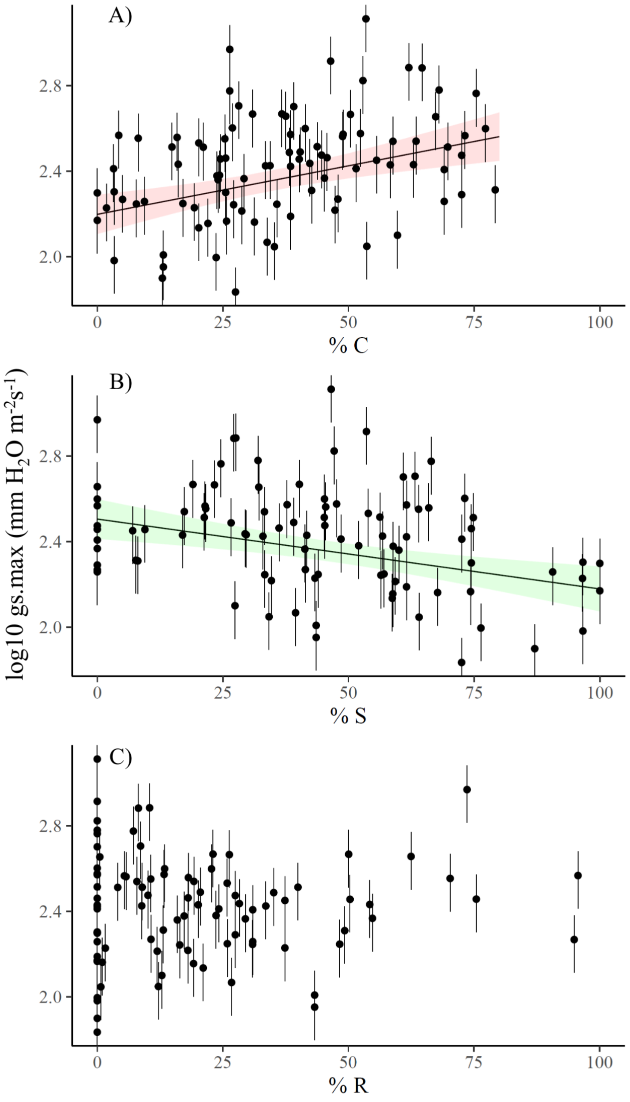

Figure S2: Variability in $\log_{10}$ maximum stomatal conductance (gs.max; y-axis) by degree of plant competitiveness (%C; panel A), stress tolerance (%S; panel B), and ruderalness (%R; panel C). Data are from the meta-analysis for maximum stomatal conductance reported in Table S2. Confidence bounds about individual points are standard error assuming a coefficient of variation of 0.3 (30%). Fitted lines are shown for significant relationships ($p < 0.05$ level) between degree of expression of a particular functional type and $\log_{10}$ gs.max. Shaded regions about each fit (red for %C and green for %S) reflect 95% confidence bounds about the slope of each line.

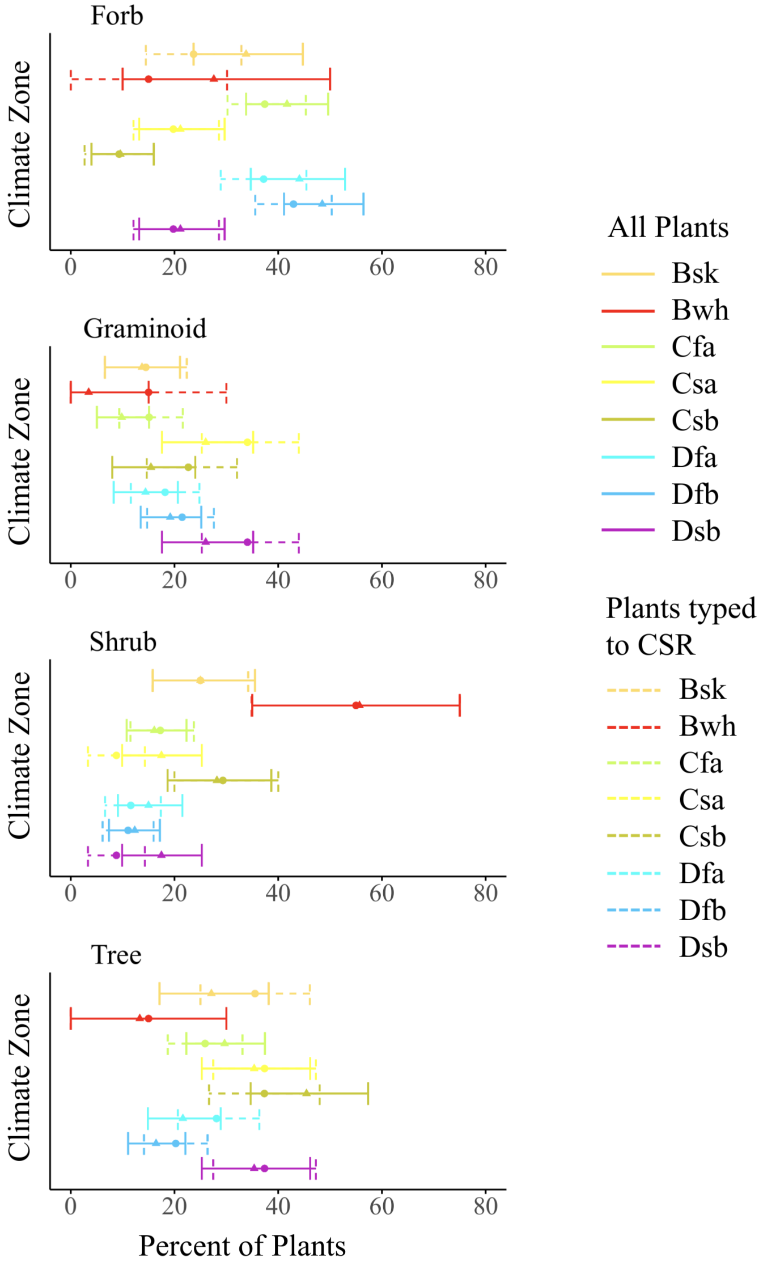

Figure S3: Percent of BRC plants in each climate zone (colors) that have each of the following growth forms (forbs: top panel, graminoids: second panel, shrubs: third panel, trees: fourth panel). Solid lines (average denoted using triangles) are for full BRC plant lists. Dashed lines (average denoted using circles) are for the subset of BRC plants that could be classified to CSR type. Confidence bounds (note high degree of overlap between solid and dashed) are reported at a 95% confidence level.

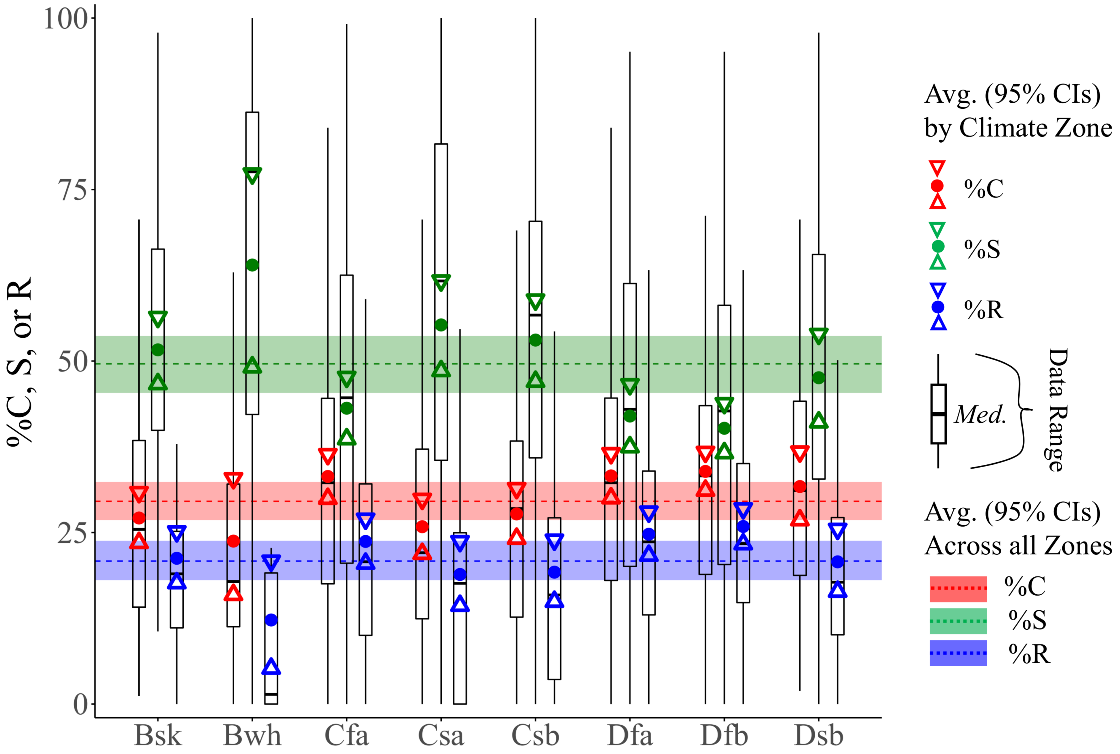

Figure S4: Distribution of the degree of BRC plant competitiveness (%C), stress tolerance (%S), and ruderalness (%R) by climate zone. Mean %C, S and R (circles) and 95% confidence bounds (triangles) are illustrated in color: red for %C, green for %S, and blue for %R. Box and whisker plots depict 25th and 75th quantile (box edges), minimum and maximum (whiskers) and median (bar) values of %C, S, and R in each zone. Dashed lines with shaded bands depict the average %C, S, and R of BRC plants across all climate zones, with stress tolerance exceeding competitiveness, which exceeded ruderalness.

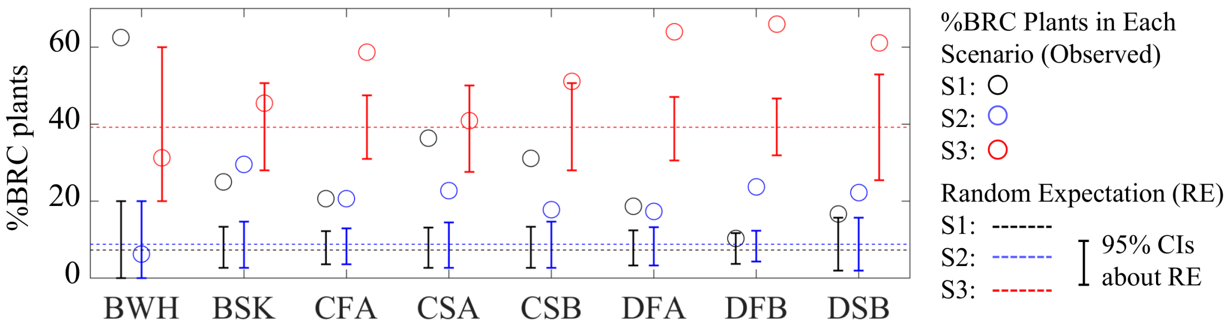

Figure S5: Percent of BRC plants that have a CSR type consistent with each scenario. Observations are shown using open circles: black for S1w and S1h, blue for S2w and S2h, and red for S3w and S3h. The percent of BRC plants expected to belong to each scenario if plants were randomly distributed by CSR type in each climate zone, are shown using dashed lines of corresponding color. Statistical confidence about this random expectation was determined by 1) randomly assigning *n* plants (the number classified in each climate zone) a CSR type, 2) estimating the percent that fell within each scenario, and 3) repeating the process 10,000 times, creating a probability distribution about the random expectation for each scenario and climate zone. Percentile 95% confidence bounds were estimated for each probability distribution and are shown using vertical error bars. When open circles lie above the 95% bounds for a given scenario, it indicates that more BRC plants had a CSR type consistent with that scenario than expected due to chance.

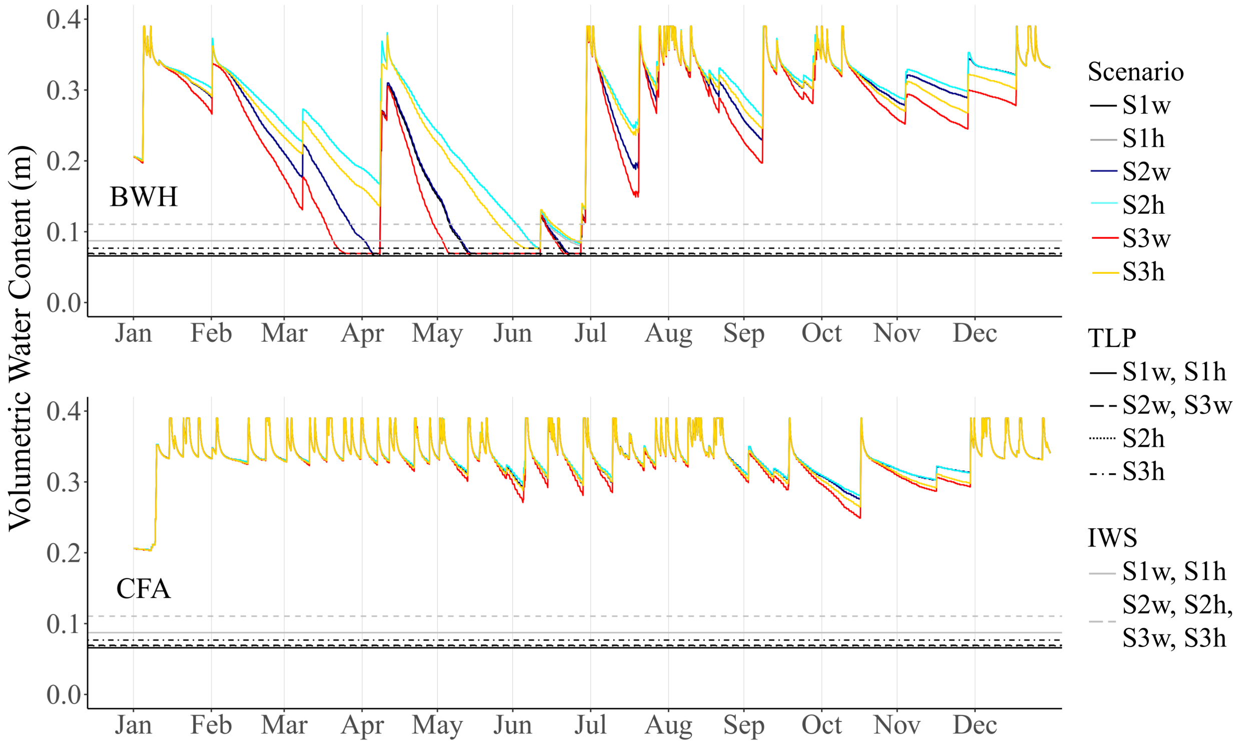

Figure S6: Changes in volumetric water content (m) in the driest (Bwh) and wettest (Cfa) climate zones for each plant water use scenario (colored lines) over time. The turgor loss point (TLP) and point of incipient water stress (IWS) are illustrated using black and grey horizontal lines, respectively, with line type (solid, dashed, dot, or dash and dot) being used to indicate which TLP's and IWS's are associated with each water use scenario. Water levels frequently fall below the IWS and TLP in Bwh, but not Cfa.

SUPPLEMENTAL TABLES

Table S1: Turgor Loss Point (TLP) Meta-analysis

Plant Species	BRC Plant (Y/N)	Climate Zone^1	Stem Type	Growth Form	TLP (MPa)	%C	%S	%R	CSR type	Reference for TLP	Reference for CSR
Acer campestre	Y	Csb	W	tree	-1.90	42.29	29.41	28.30	CSR	Bartlett et al., 2016	Pierce et al., 2017
Acer monspessulanum			W	tree	-2.20	23.49	68.83	7.69	S	Bartlett et al., 2016	Pierce et al., 2017
Acer negundo	Y	Bsk; Cfa; Dfa	W	tree	-2.05	50.38	23.31	26.31	C	Bartlett et al., 2014	Pierce et al., 2017
Acer pseudoplatanus	Y	Csb	W	tree	-1.40	37.51	54.93	7.55	CS	Bartlett et al., 2016	Pierce et al., 2017
Acer rubrum	Y	Bsk; Cfa; Csb; Dfa; Dfb	W	tree	-1.98	32.75	59.41	7.85	CS	Bartlett et al., 2014	*this study*
Acer saccharum	Y	Cfa; Csb; Dfa	W	tree	-2.78	27.13	56.44	16.43	S	Bartlett et al., 2016	Pierce et al., 2017
Agropyron desertorum	Y	Dsb	H	graminoid	-2.70	12.12	87.88	0.00	S	Frank et al., 1984	Pierce et al., 2017
Anacardium excelsum			W	tree	-1.13	55.47	34.61	9.92	CS	Bartlett et al., 2016	Pierce et al., 2017
Andropogon gerardii	Y	Cfa; Dfa; Dfb	H	graminoid	-1.42	24.33	52.02	23.66	S	Bartlett et al., 2014	Pierce et al., 2017
Aporosa globifera			W	tree	-1.48	39.61	45.70	14.69	CS	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Aporosa microstachya			W	tree	-1.69	38.62	50.54	10.84	CS	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Arbutus unedo	Y	Csb	W	tree	-1.33	22.74	69.84	7.42	S	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Artemisia frigida			H	forb	-1.50	3.26	53.56	43.18	SR	Griffin-Nolan et al., 2019	Liancourt et al., 2015
Astronium graveolens			W	tree	-2.07	53.64	34.18	12.18	CS	Bartlett et al., 2012	Pierce et al., 2017
Bouteloua curtipendula	Y	Bwh; Cfa; Csa	H	graminoid	-2.50	15.21	66.01	18.78	S	Griffin-Nolan et al., 2019	Pierce et al., 2017
Bouteloua gracilis	Y	Bsk; Cfa	H	graminoid	-2.30	4.74	73.10	22.16	S	Griffin-Nolan et al., 2019	Pierce et al., 2017
Byrsonima sericea			W	tree	-2.12	35.65	62.79	1.56	S	Bartlett et al., 2014	Pierce et al., 2017
Carex duriuscula			H	graminoid	-3.20	15.84	79.52	4.64	S	Griffin-Nolan et al., 2019	Griffin-Nolan et al., 2019; Li et al., 2017
Carpinus betulus	Y	Csb	W	tree	-2.33	35.74	33.33	30.93	CSR	Li et al., 2016	Pierce et al., 2017
Casearia sylvestris			W	tree	-2.96	30.59	50.85	18.57	S	Bartlett et al., 2014	Pierce et al., 2017
Celtis australis			W	tree	-2.01	41.04	37.99	20.97	CS	Bartlett et al., 2012	Pierce et al., 2017
Coffea arabica			W	shrub	-1.95	18.28	60.53	21.19	S	Bartlett et al., 2014	Pierce et al., 2017

Table S1 Continued

Plant Species	BRC Plant (Y/N)	Climate Zone[1]	Stem Type	Growth Form	TLP (MPa)	%C	%S	%R	CSR type	Reference for TLP	Reference for CSR
Cordia lasiocalyx			W	tree	-1.63	37.38	47.29	15.33	CS	Bartlett et al., 2016	Pierce et al., 2017
Corylus avellana			W	tree	-1.85	28.75	59.30	11.95	S	Li et al., 2016	Pierce et al., 2017
Curatella americana			W	tree	-1.91	63.18	36.82	0.00	C	Bartlett et al., 2016	Pierce et al., 2017
Dianella revoluta			H	forb	-1.04	38.9	61.1	0	CS	Farrell et al., 2017	*this study*
Fagus sylvatica	Y	Csb	W	tree	-2.07	22.77	63.59	13.63	S	Bartlett et al., 2014	Pierce et al., 2017
Festuca arundinacea	Y	Bsk	H	graminoid	-2.38	38.40	24.01	37.59	CR	Bartlett et al., 2014	Pierce et al., 2017
Ficinia nodosa			H	graminoid	-0.82	32.4	67.6	0	S	Farrell et al., 2017	*this study*
Ficus auriculata			W	tree	-0.86	68.02	31.98	0.00	C	Bartlett et al., 2016	Hao et al., 2010
Ficus benjamina			W	tree	-1.65	20.20	53.92	25.87	S	Bartlett et al., 2016	Pierce et al., 2017
Ficus concinna			W	tree	-2.23	25.72	74.28	0.00	S	Bartlett et al., 2016	Hao et al., 2010
Ficus curtipes			W	tree	-1.47	34.37	56.76	8.86	CS	Bartlett et al., 2016	Hao et al., 2010
Ficus esquiroliana			W	shrub	-1.15	75.40	24.60	0.00	C	Bartlett et al., 2016	Hao et al., 2010
Ficus hispida			W	tree	-1.23	52.37	47.63	0.00	CS	Bartlett et al., 2016	Hao et al., 2010
Ficus racemosa			W	tree	-1.44	46.44	53.56	0.00	CS	Bartlett et al., 2016	Hao et al., 2010
Ficus religosa			W	tree	-1.69	58.31	41.69	0.00	CS	Bartlett et al., 2016	Hao et al., 2010
Ficus semicordata			W	tree	-1.52	53.46	46.54	0.00	CS	Bartlett et al., 2016	Hao et al., 2010
Ficus tinctoria			W	tree	-1.82	43.76	56.24	0.00	CS	Bartlett et al., 2016	Hao et al., 2010
Fraxinus americana	Y	Cfa; Csb; Dfa	W	tree	-1.19	27.10	53.19	19.71	S	Bartlett et al., 2014	Pierce et al., 2017
Fraxinus excelsior			W	tree	-2.08	62.00	27.57	10.43	C	Li et al., 2016	Pierce et al., 2017
Fraxinus ornus			W	tree	-2.84	45.48	38.93	15.59	CS	Bartlett et al., 2016	Pierce et al., 2017
Fraxinus pennsylvanica	Y	Bsk; Cfa; Csb; Dfa; Dfb	W	tree	-2.36	45.7	44.6	9.7	CS	Bartlett et al., 2012	Loranger and Shipley, 2010
Genipa americana			W	tree	-2.55	69.76	21.28	8.96	C	Bartlett et al., 2016	Pierce et al., 2017
Ginkgo biloba	Y	Bsk; Csb	W	tree	-2.22	33.59	15.45	50.96	CR	Bartlett et al., 2016	Pierce et al., 2017
Hedera helix			W	liana	-2.30	36.08	13.00	50.93	CR	Bartlett et al., 2012	Pierce et al., 2017
Helianthus annuus	Y	Bwh	H	forb	-1.20	77.25	0.00	22.75	C	Bartlett et al., 2014	Pierce et al., 2017

Table S1 Continued

Plant Species	BRC Plant (Y/N)	Climate Zone[1]	Stem Type	Growth Form	TLP (MPa)	%C	%S	%R	CSR type	Reference for TLP	Reference for CSR
Hesperostipa comata			H	graminoid	-2.70	4.78	95.22	0.00	S	Griffin-Nolan et al., 2019	Pierce et al., 2017
Heteranthera limosa			H	forb	-0.30	28.52	0.00	71.48	R	Touchette et al., 2014	Pierce et al., 2017
Hybanthus prunifolius			W	shrub	-1.74	38.38	44.48	17.13	CS	Bartlett et al., 2016	Pierce et al., 2017
Hymenaea courbaril			W	tree	-2.17	48.91	37.78	13.31	CS	Bartlett et al., 2016	Pierce et al., 2017
Ilex aquifolium			W	tree	-2.45	45.10	54.90	0.00	CS	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Juglans regia			W	tree	-1.53	73.16	21.45	5.40	C	Bartlett et al., 2016	Pierce et al., 2017
Juncus effusus	Y	Bsk; Cfa; Csb; Dfa; Dfb; Dsb	H	graminoid	-0.60	38.48	61.52	0.00	CS	Touchette et al., 2014	Pierce et al., 2017
Juniperus communis			W	shrub	-3.54	0.00	86.61	13.39	S	Bartlett et al., 2016	Pierce et al., 2017
Juniperus virginiana	Y	Bsk; Cfa; Dfa; Dfb	W	tree	-2.47	4.92	95.08	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Lantana camara			W	shrub	-1.37	34.54	46.42	19.04	CS	Bartlett et al., 2016	Pierce et al., 2017
Larix decidua			W	tree	-2.26	0.00	99.16	0.84	S	Bartlett et al., 2016	Pierce et al., 2017
Linaria dalmatica			H	forb	-1.30	28.28	39.52	32.20	CSR	Griffin-Nolan et al., 2019	Pierce et al., 2017
Lolium perenne			H	forb	-2.25	21.68	0.00	78.32	R	Holloway-Phillips and Brodribb, 2011	Pierce et al., 2017
Lupinus albus			H	forb	-0.90	69.10	0.00	30.90	C	Bartlett et al., 2012	Pierce et al., 2017
Mallotus penangensis			W	tree	-1.17	62.57	33.94	3.49	C	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Medicago sativa			H	forb	-1.60	14.87	45.17	39.97	SR	Brown and Tanner, 1983	Pierce et al., 2017
Miconia albicans			W	tree	-2.48	48.01	51.99	0.00	CS	Bartlett et al., 2012	Pierce et al., 2017
Neoscortechinia kingii			W	tree	-1.72	33.62	66.38	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Ochroma pyramidale			W	tree	-1.60	79.04	18.78	2.18	C	Bartlett et al., 2016	Pierce et al., 2017
Oryza sativa			H	graminoid	-1.41	37.88	37.13	24.99	CS	Bartlett et al., 2012	Pierce et al., 2017
Ouratea hexasperma			W	tree	-2.34	34.62	65.38	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Ouratea lucens			W	tree	-1.87	42.13	56.31	1.56	CS	Bartlett et al., 2016	Pierce et al., 2017

Table S1 Continued

Plant Species	BRC Plant (Y/N)	Climate Zone[1]	Stem Type	Growth Form	TLP (MPa)	%C	%S	%R	CSR type	Reference for TLP	Reference for CSR
Panicum virgatum	Y	Bsk; Cfa; Dfa; Dfb	H	graminoid	-2.24	17.04	57.06	25.90	S	Bartlett et al., 2014	Pierce et al., 2017
Pascopyrum smithii			H	graminoid	-3.50	22.27	67.23	10.50	S	Dong et al., 2011	Pierce et al., 2017
Phillyrea angustifolia			W	shrub	-2.91	12.43	87.57	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Phillyrea latifolia			W	shrub	-2.55	30.68	69.32	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Picea abies			W	tree	-2.51	0.00	100.00	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Pinus cembra			W	tree	-2.34	4.26	95.74	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Pinus halepensis			W	tree	-2.42	2.37	97.63	0.00	S	Villar-Salvador et al., 1999	Pierce et al., 2017
Pinus ponderosa			W	tree	-2.57	9.00	91.00	0.00	S	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Pistacia lentiscus			W	tree	-2.70	29.43	70.57	0.00	S	Alvarez et al., 2018	Pierce et al., 2017
Pistacia terebinthus			W	tree	-2.73	53.15	31.85	15.01	C	Bartlett et al., 2016	Pierce et al., 2017
Poa pratensis			H	graminoid	-2.42	12.36	0.00	87.64	R	Dong et al., 2011	Pierce et al., 2017
Poa secunda			H	graminoid	-2.10	0.0	62.3	37.7	SR	Griffin-Nolan et al., 2019	Griffin-Nolan et al., 2019; James et al., 2010
Polygonum amphibium	Y	Dfb	H	forb	-0.45	43.09	33.51	23.40	CS	Touchette et al., 2014	Pierce et al., 2017
Populus tremuloides	Y	Csb; Dfa; Dfb; Dsb	W	tree	-2.16	25.53	56.76	17.71	S	Bartlett et al., 2014	Pierce et al., 2017
Prionostemma aspera			W	tree	-2.07	50.18	43.67	6.15	CS	Bartlett et al., 2016	Pierce et al., 2017
Protium panamense			W	tree	-2.57	74.46	24.99	0.55	C	Bartlett et al., 2016	Pierce et al., 2017
Prunus mahaleb			W	shrub	-2.62	22.19	54.20	23.62	S	Bartlett et al., 2016	Pierce et al., 2017
Prunus persica			W	tree	-2.81	36.17	53.51	10.31	CS	Bartlett et al., 2014	Pierce et al., 2017
Prunus serotina	Y	Cfa; Dfa	W	tree	-1.42	39.54	49.74	10.71	CS	Bartlett et al., 2012	Pierce et al., 2017
Pseudobombax septenatum			W	tree	-1.28	76.57	12.96	10.46	C	Bartlett et al., 2016	Pierce et al., 2017
Psychotria horizontalis			W	shrub	-1.34	43.14	39.92	16.94	CS	Bartlett et al., 2016	Pierce et al., 2017
Quercus cerris			W	tree	-3.58	28.95	68.02	3.03	S	Bartlett et al., 2012	Pierce et al., 2017
Quercus coccifera			W	shrub	-2.95	9.38	90.62	0.00	S	Bartlett et al., 2012	Pierce et al., 2017
Quercus ilex			W	tree	-3.02	25.39	63.95	10.67	S	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Quercus petraea			W	tree	-2.32	28.14	63.23	8.63	S	Bartlett et al., 2014	Pierce et al., 2017

Table S1 Continued

Plant Species	BRC Plant (Y/N)	Climate Zone^1	Stem Type	Growth Form	TLP (MPa)	%C	%S	%R	CSR type	Reference for TLP	Reference for CSR
Quercus pubescens			W	tree	-2.91	31.28	67.72	1.00	S	Bartlett et al., 2016	Pierce et al., 2017
Quercus robur	Y	Bsk; Csb	W	tree	-2.48	27.15	63.30	9.55	S	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Quercus rubra	Y	Cfa; Csb; Dfa; Dfb	W	tree	-2.52	32.72	57.31	9.97	S	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Quercus suber			W	tree	-3.08	26.35	66.45	7.20	S	Bartlett et al., 2012	Pierce et al., 2017
Quercus velutina	Y	Csb	W	tree	-2.75	40.5	45.9	13.6	CS	Bartlett et al., 2012	Brym et al., 2011
Rinorea anguifera			W	tree	-1.75	35.78	64.22	0.00	S	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Robinia pseudoacacia	Y	Cfa	W	tree	-1.97	47.88	41.41	10.71	CS	Bartlett et al., 2014	Pierce et al., 2017
Shorea lepidota			W	tree	-1.35	40.51	59.49	0.00	CS	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Shorea macroptera			W	tree	-0.96	33.89	66.11	0.00	S	Bartlett et al., 2012 & 2016	Pierce et al., 2017
Sorghastrum nutans	Y	Cfa; Dfa; Dfb	H	graminoid	-1.60	23.81	58.88	17.31	S	Griffin-Nolan et al., 2019	Pierce et al., 2017
Tachigalia versicolor			W	tree	-2.39	68.95	24.97	6.08	C	Bartlett et al., 2016	Pierce et al., 2017
Taxus baccata			W	tree	-2.26	1.70	98.30	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Tocoyena formosa			W	shrub	-2.80	60.21	34.06	5.73	C	Bartlett et al., 2012	Pierce et al., 2017
Triticum aestivum			H	graminoid	-1.53	39.28	22.81	37.91	CR	Bartlett et al., 2014	Pierce et al., 2017
Typha angustifolia	Y	Dfa	H	forb	-0.55	65.68	34.32	0.00	C	Touchette et al., 2014	Pierce et al., 2017
Typha latifolia	Y	Bsk; Dfa; Dfb	H	forb	-0.49	86.30	10.25	3.45	C	Touchette et al., 2014	Pierce et al., 2017
Vaccinium myrtillus			W	shrub	-1.38	13.15	43.56	43.29	SR	Bartlett et al., 2016	Pierce et al., 2017
Vaccinium vitis-idaea			W	shrub	-1.88	3.36	96.64	0.00	S	Bartlett et al., 2016	Pierce et al., 2017
Vatica bella			W	tree	-1.16	30.24	69.76	0.00	S	Bartlett et al., 2012	Pierce et al., 2017
Viburnum tinus			W	tree	-1.93	35.00	47.63	17.37	CS	Bartlett et al., 2016	Pierce et al., 2017
Vitis vinifera			W	liana	-1.56	72.51	0.00	27.49	C	Bartlett et al., 2014	Pierce et al., 2017
Vochysia ferruginea			W	tree	-2.25	43.08	51.90	5.02	CS	Bartlett et al., 2016	Pierce et al., 2017
Vulpia myuros			H	graminoid	-2.20	9.42	42.78	47.80	SR	Ramirez et al., 2015	Pierce et al., 2017
Zea mays			H	graminoid	-1.45	82.97	8.61	8.41	C	Bartlett et al., 2014	Pierce et al., 2017
Ranunculus bulbosus			H	forb	-1.43	41.20	23.73	35.07	CR	Nolf et al., 2016	Pierce et al., 2017
Ranunculus acris			H	forb	-1.68	53.27	5.47	41.27	CR	Nolf et al., 2016	Pierce et al., 2017

Table S1 Continued

Plant Species	BRC Plant (Y/N)	Climate Zone[1]	Stem Type	Growth Form	TLP (MPa)	%C	%S	%R	CSR type	Reference for TLP	Reference for CSR
Alnus rhombifolia	Y	Bsk; Csb	W	tree	-1.62	33.80	39.46	26.75	CSR	John et al., 2018	John et al., 2018
Betula occidentalis	Y	Bsk	W	tree	-1.78	47.30	34.65	18.05	S	John et al., 2018	John et al., 2018
Cercis occidentalis	Y	Csa; Csb; Dfa	W	tree	-2.27	45.72	36.18	18.10	CS	John et al., 2018	John et al., 2018
Cercocarpus betuloides	Y	Csa	W	shrub	-2.74	12.95	87.05	0.00	S	John et al., 2018	John et al., 2018
Cleome isomeris	Y	Bwh	W	shrub	-1.33	29.57	0.92	69.51	R	John et al., 2018	John et al., 2018
Encelia farinosa	Y	Bwh; Csa	W	shrub	-1.50	55.58	7.04	37.38	CR	John et al., 2018	John et al., 2018
Fraxinus dipetala	Y	Csa	W	tree	-1.99	20.20	58.70	21.10	S	John et al., 2018	John et al., 2018
Malosma laurina	Y	Csa	W	tree	-2.62	38.46	61.54	0.00	CS	John et al., 2018	John et al., 2018
Platanus racemosa	Y	Bsk; Csb	W	tree	-1.87	59.73	27.40	12.86	C	John et al., 2018	John et al., 2018
Prunus ilicifolia	Y	Csa	W	tree	-2.12	27.50	72.50	0.00	S	John et al., 2018	John et al., 2018
Quercus agrifolia	Y	Csa; Csb	W	tree	-2.99	23.66	76.34	0.00	S	John et al., 2018	John et al., 2018
Quercus engelmannii	Y	Csa	W	tree	-2.37	16.33	81.77	1.90	S	John et al., 2018	John et al., 2018
Rhus integrifolia	Y	Csa	W	shrub	-2.44	27.48	72.52	0.00	S	John et al., 2018	John et al., 2018
Umbellularia californica	Y	Csa	W	tree	-2.39	35.24	64.03	0.73	S	John et al., 2018	John et al., 2018

[1] : recommended climate zones for use in BRCs; [2] : IWS: incipient water stress point;

Stem Type: W = Woody, H = Herbacous

Table S2: Incipient Water Stress (IWS) and Max Stomatal Conductance (gs.max)

Plant Species	BRC Plant (Y/N)	Climate Zone[1]	Stem Type	Growth Form	gs.max (mm H2O/m2/s)	IWS[2] (leaf) MPa	Plant height (m)[3]	IWS (soil) MPa	%C	%S	%R	CSR Type	gs.max method	Study Year	Reference for gs.max and IWS	Reference for plant height	Reference for CSR
Acer campestre	Y	Csb	W	tree	272.98	-0.28	0.60	0.00	42.29	29.41	28.30	CSR	I	2014	Li et al. 2016	Li et al. 2016	Pierce et al., 2017
Acer negundo	Y	Bsk; Cfa; Dfa	W	tree	462.71	-0.03	3.20	0.00	50.38	23.31	26.31	C	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	Pierce et al., 2017
Acer saccharum	Y	Cfa; Csb; Dfa	W	tree	174.8	-1.32	11.50	-0.79	27.13	56.44	16.43	S	P	1991	Yang et al., 1998	Yang et al., 1998	Pierce et al., 2017
Achillea millefolium	Y	Bsk; Cfa; Csa; Csb; Dsb	H	forb	142.92	-0.29	--	-0.29	22.02	58.81	19.18	S	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Alnus rhombifolia	Y	Bsk; Csb	W	tree	116.56	-0.90	3.20	-0.54	33.80	39.46	26.75	CSR	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018
Amorpha canescens	Y	Bsk	W	shrub	228.82	-0.28	--	-0.28	24.04	60.02	15.95	S	I	2014	O'Keefe & Nippert, 2018	--	Pierce et al., 2017
Amorpha fruticosa			W	shrub	308.6	-0.06	--	-0.06	40.38	39.09	20.53	CS	I	2015	Yan et al., 2017	--	Pierce et al., 2017
Andropogon gerardii	Y	Cfa; Dfa; Dfb	H	graminoid	240.1	-0.06	--	-0.06	24.33	52.02	23.66	S	I	2014	O'Keefe & Nippert, 2018	--	Pierce et al., 2017
Arabidopsis thaliana			H	forb	369.4	-0.05	0.30	0.00	4.27	0.00	95.73	R	P	2015	Scoffoni et al., 2018	eol.org	Pierce et al., 2017
Asclepias syriaca	Y	Dfa; Dfb	H	forb	346.74	-0.18	--	-0.18	63.44	17.32	19.24	C	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Astronium graveolens			W	tree	111.64	-0.77	1.60	-0.44	53.64	34.18	12.18	CS	P	2012	Wolfe et al., 2016	Wolfe et al., 2016	Pierce et al., 2017
Athyrium felix-femina	Y	Cfa; Csb; Dfb	H	fern	255.42	-0.07	0.74	0.00	69.03	0.00	30.97	C	I	2016	Cardoso et al., 2019	eol.org	Pierce et al., 2017
Athyrium felix-femina (Frizelliae)	Y	Cfa; Csb; Dfb	H	fern	181.17	-0.08	0.74	0.00	69.03	0.00	30.97	C	I	2016	Cardoso et al., 2019	eol.org	Pierce et al., 2017
Betula occidentalis	Y	Bsk	W	tree	164.79	-0.39	2.10	-0.05	47.30	34.65	18.05	CS	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018

Table S2 Continued

Plant Species	**BRC Plant (Y/N)**	**Climate Zone[1]**	**Stem Type**	**Growth Form**	**gs.max (mm H2O/m2/s)**	**IWS[2] (leaf) MPa**	**Plant height (m)[3]**	**IWS (soil) MPa**	**%C**	**%S**	**%R**	**CSR Type**	**gs.max method**	**Study Year**	**Reference for gs.max and IWS**	**Reference for plant height**	**Reference for CSR**
Bursera simaruba			W	tree	451.45	-1.02	4.50	-0.63	67.34	32.15	0.51	C	P	2001	Brodribb et al. 2003	Brodibb and Holbrook, 2003	Suresh et al., 2018; Castro-Esau et al., 2006
Calycophyllum candidissimum			W	tree	364.76	-1.14	4.50	-0.75	48.81	45.45	5.73	CS	P	2001	Brodribb et al. 2003	Brodibb and Holbrook, 2003	Werden et al., 2018
Carpinus betulus	Y	Csb	W	tree	175.75	-0.86	0.60	-0.55	35.74	33.33	30.93	CSR	I	2014	Li et al. 2016	Li et al. 2016	Pierce et al., 2017
Cavanillesia platanifolia			W	tree	205.16	-0.13	1.51	0.00	79.19	7.66	13.15	C	P	2012	Wolfe et al., 2016	Wolfe et al., 2016	Pierce et al., 2017
Ceanothus cuneatus			W	shrub	198.5	-0.82	3.70	-0.45	0.00	100.00	0.00	S	P	2006	Jacobson et al., 2008	eol.org	Fletcher et al., 2018
Ceanothus megacarpus	Y	Csa	W	shrub	147.7	-0.75	3.50	-0.38	0.00	100.00	0.00	S	P	2006	Jacobson et al., 2008	eol.org	Fletcher et al., 2018
Ceanothus spinosus			W	shrub	168.8	-1.04	4.60	-0.65	1.83	96.56	1.61	S	P	2006	Jacobson et al., 2008	eol.org	John et al., 2018
Centaurea cyanus			H	forb	285.78	-0.27	--	-0.27	40.19	9.48	50.33	CR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Cerastium tomentosum	Y	Bsk	H	forb	176.2	-0.25	--	-0.25	7.77	43.95	48.28	SR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Cercis occidentalis	Y	Csa; Csb; Dfa	W	tree	290.34	-0.12	2.10	0.00	45.72	36.18	18.10	CS	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018
Cercocarpus betuloides	Y	Csa	W	shrub	79.18	-1.70	2.10	-1.36	12.95	87.05	0.00	S	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018
Cornus drummondii			W	shrub	325.07	-0.25	--	-0.25	21.09	74.83	4.08	S	I	2014	O'Keefe & Nippert, 2018	--	Pierce et al., 2017
Corylus avellana			W	shrub	163.32	-0.84	0.60	-0.53	28.75	59.30	11.95	S	I	2014	Li et al. 2016	Li et al. 2016	Pierce et al., 2017
Daucus carota			H	forb	231.57	-0.19	--	-0.19	29.20	41.31	29.49	CSR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Encelia californica			W	shrub	933.0	-0.11	0.80	0.00	26.36	0.00	73.64	R	P	2006	Jacobson et al., 2008	eol.org	John et al., 2018
Encelia farinosa	Y	Bwh; Csa	W	shrub	282.25	-1.10	0.70	-0.79	55.58	7.04	37.38	CR	P	2016	Henry et al., 2019	eol.org	John et al., 2018

Table S2 Continued

Plant Species	BRC Plant (Y/N)	Climate Zone[1]	Stem Type	Growth Form	gs.max (mm H2O/m2/s)	IWS[2] (leaf) MPa	Plant height (m)[3]	IWS (soil) MPa	%C	%S	%R	CSR Type	gs.max method	Study Year	Reference for gs.max and IWS	Reference for plant height	Reference for CSR
Enterolobium cyclocarpum			W	tree	346.29	-1.29	4.50	-0.90	58.83	33.26	7.90	C	P	2001	Brodribb et al. 2003	Brodibb and Holbrook, 2003	Werden et al., 2018
Epilobium ciliatum subsp. glandulosum	Y	Dsb	H	forb	257.72	-0.29	--	-0.29	3.24	72.54	24.22	S	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Erigeron canadensis			H	forb	169.26	-0.19	--	-0.19	19.31	43.31	37.38	SR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Eupatorium perfoliatum	Y	Cfa; Dfa; Dfb	H	forb	397.4	-0.22	--	-0.22	41.38	45.21	13.42	CS	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Ficus auriculata			W	tree	601.97	-0.17	10.0	0.00	68.02	31.98	0.00	C	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Ficus benjamina			W	shrub	340.17	-0.71	15.2	-0.11	20.20	53.92	25.87	S	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Pierce et al., 2017
Ficus concinna			W	tree	146.44	-1.84	25.0	-1.04	25.72	74.28	0.00	S	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Ficus curtipes			W	tree	266.37	-0.83	10.0	-0.33	34.37	56.76	8.86	CS	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Ficus esquiroliana			W	shrub	580.40	-0.44	8.9	0.00	75.40	24.60	0.00	C	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Ficus hispida			W	tree	376.57	-0.56	10.0	-0.06	52.37	47.63	0.00	CS	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Ficus racemosa			W	tree	821.92	-0.12	30.0	0.00	46.44	53.56	0.00	CS	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Ficus religosa			W	tree	268.7	-1.27	25.0	-0.47	58.31	41.69	0.00	CS	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Ficus semicordata			W	shrub	1297	-0.22	10.6	0.00	53.46	46.54	0.00	CS	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Ficus tinctoria			W	tree	326.92	-1.07	28.0	-0.21	43.76	56.24	0.00	CS	I	2008	Hao et al. 2010	eol.org; Hao et al., 2010	Hao et al., 2010
Fraxinus dipetala	Y	Csa	W	tree	136.28	-0.25	2.10	0.00	20.20	58.70	21.10	S	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018
Fraxinus excelsior			W	tree	766.69	-0.14	0.60	0.00	62.00	27.57	10.43	C	I	2014	Li et al. 2016	Li et al. 2016	Pierce et al., 2017
Genipa americana			W	tree	325.6	-0.11	0.71	0.00	69.76	21.28	8.96	C	P	2012	Wolfe et al., 2016	Wolfe et al., 2016	Pierce et al., 2017
Gliricidia sepium			W	tree	763.91	-1.44	4.50	-1.05	64.63	27.17	8.20	C	P	2001	Brodbribb & Holbrook, 2003	Brodibb and Holbrook, 2003	Werden et al., 2018

Table S2 Continued

Plant Species	**BRC Plant (Y/N)**	**Climate Zone^1**	**Stem Type**	**Growth Form**	**gs.max (mm H2O/m2/s)**	**IWS^2 (leaf) MPa**	**Plant height (m)^3**	**IWS (soil) MPa**	**%C**	**%S**	**%R**	**CSR Type**	**gs.max method**	**Study Year**	**Reference for gs.max and IWS**	**Reference for plant height**	**Reference for CSR**
Helianthus annuus	Y	Bwh	H	forb	397.01	-0.59	1.80	-0.25	77.25	0.00	22.75	C	P	2009	Guyot et al. 2012	eol.org	Pierce et al., 2017
Hymenaea courbaril			W	tree	373.75	-2.07	4.50	-1.68	48.91	37.78	13.31	CS	P	2001	Brodribb et al. 2003	Brodibb and Holbrook, 2003	Pierce et al., 2017
Hypericum perforatum			H	forb	358.04	-0.22	--	-0.22	8.15	21.58	70.27	R	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Juglans regia			W	tree	368.1	-0.10	1.52	0.00	73.16	21.45	5.40	C	P	2000	Cochard et al., 2002	Cochard et al., 2002	Pierce et al., 2017
Lythrum salicaria	Y	Dfb	H	shrub	361.15	-0.24	--	-0.24	15.88	65.97	18.14	S	P	2015	Belluau & Shipley, 2017	--	Pierce et al., 2017
Malosma laurina	Y	Csa	W	tree	154.19	-0.12	3.20	0.00	38.46	61.54	0.00	CS	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018
Malosma laurina	Y	Csa	W	tree	264.3	-0.13	3.90	0.00	38.46	61.54	0.00	CS	P	2006	Jacobson et al., 2008	eol.org	John et al., 2018
Malosma laurina	Y	Csa	W	tree	372.7	-0.12	3.90	0.00	38.46	61.54	0.00	CS	P	2006	Jacobson et al., 2008	eol.org	John et al., 2018
Medicago lupulina			H	forb	270.33	-0.19	--	-0.19	16.11	29.63	54.26	R	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Medicago sativa			H	forb	325.68	-0.31	--	-0.31	14.87	45.17	39.97	SR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Melilotus albus			H	forb	265.94	-0.25	--	-0.25	33.48	32.96	33.57	CSR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Myagrum perfoliatum			H	forb	453.83	-0.15	--	-0.15	37.51	0.00	62.49	CR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Nigella damascena			H	forb	203.9	-0.15	--	-0.15	42.65	8.07	49.28	CR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Panicum virgatum	Y	Bsk; Cfa; Dfa; Dfb	H	graminoid	177.11	-0.34	--	-0.34	17.04	57.06	25.90	S	I	2014	O'Keefe & Nippert, 2018	--	Pierce et al., 2017
Plantago lanceolata			H	forb	307.25	-0.30	--	-0.30	38.22	26.63	35.15	CSR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Platanus racemosa	Y	Bsk; Csb	W	tree	125.8	-1.14	3.20	-0.78	59.73	27.40	12.86	C	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018

Table S2 Continued

Plant Species	**BRC Plant (Y/N)**	**Climate Zone^1**	**Stem Type**	**Growth Form**	**gs.max (mm H2O/m2/s)**	**IWS^2 (leaf) MPa**	**Plant height (m)^3**	**IWS (soil) MPa**	**%C**	**%S**	**%R**	**CSR Type**	**gs.max method**	**Study Year**	**Reference for gs.max and IWS**	**Reference for plant height**	**Reference for CSR**
Prunus ilicifolia	Y	Csa	W	tree	68.22	-0.34	2.10	0.00	27.50	72.50	0.00	S	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018
Quercus agrifolia	Y	Csa; Csb	W	tree	98.91	-1.79	2.10	-1.45	23.66	76.34	0.00	S	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018
Quercus coccifera			W	tree	181.0	-0.29	--	-0.29	9.38	90.62	0.00	S	I	2003	Peguero-Pina et al., 2009	--	Pierce et al., 2017
Quercus ilex			W	shrub	355.8	-0.79	--	-0.79	25.39	63.95	10.67	S	I	2003	Peguero-Pina et al., 2009	--	Pierce et al., 2017
Quercus oleoides			W	tree	400.00	-2.14	4.50	-1.75	26.88	73.12	0.00	S	P	2001	Brodribb et al. 2003	Brodibb and Holbrook, 2003	Derroire et al., 2018
Quercus petraea			W	tree	507.7	-1.82	16.00	-1.20	28.14	63.23	8.63	S	P	1994	Cochard et al., 1996	Cochard et al., 1996	Pierce et al., 2017
Quercus pubescens			W	tree	144.9	-0.20	--	-0.20	31.28	67.72	1.00	S	I	1994	Damesin and Rambal, 1995	--	Pierce et al., 2017
Quercus suber			W	tree	596.42	-0.23	--	-0.23	26.35	66.45	7.20	S	I	2003	Peguero-Pina et al., 2009	Peguaro-Pina et al., 2009; https://selectree.calpoly.edu	Pierce et al., 2017
Rhedera trinervis			W	tree	503.61	-0.96	4.50	-0.57	39.10	60.90	0.00	CS	P	2001	Brodribb et al. 2003	Brodibb and Holbrook, 2003	Werden et al., 2018
Rhus glabara			W	shrub	298.51	-0.95	--	-0.95	44.62	45.27	10.10	CS	I	2014	O'Keefe & Nippert, 2018	--	Pierce et al., 2017
Rhus ovata	Y	Csa	W	shrub	199.5	-0.48	3.20	-0.12	25.55	74.44	0.00	S	P	2006	Jacobson et al., 2008	eol.org	Aparecido et al., 2020
Rhus ovata	Y	Csa	W	shrub	288.8	-0.79	3.20	-0.43	25.55	74.44	0.00	S	P	2014	Pivovaroff et al., 2018	eol.org	Aparecido et al., 2020
Robina pesudoacacia	Y	Cfa	W	tree	185.7	-0.70	--	-0.70	47.88	41.41	10.71	CS	I	2015	Yan et al., 2017	Yan et al., 2017	Pierce et al., 2017
Rumex acetosella			H	forb	286.42	-0.19	--	-0.19	24.52	0.00	75.48	R	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Sambucus nigra	Y	Bsk; Bwh; Cfa; Dsb	W	shrub	269.3	-0.53	5.20	-0.13	62.93	16.97	20.11	C	P	2014	Pivovaroff et al., 2018	eol.org	Pierce et al., 2017
Silene vulgaris			H	forb	232.92	-0.21	--	-0.21	45.20	0.00	54.80	CR	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017

Table S2 Continued

Plant Species	**BRC Plant (Y/N)**	**Climate Zone**[1]	**Stem Type**	**Growth Form**	**gs.max (mm H2O/m2/s)**	**IWS**[2] **(leaf) MPa**	**Plant height (m)**[3]	**IWS (soil) MPa**	**%C**	**%S**	**%R**	**CSR Type**	**gs.max method**	**Study Year**	**Reference for gs.max and IWS**	**Reference for plant height**	**Reference for CSR**
Simarouba glauca			W	tree	666.41	-0.80	4.50	-0.41	52.86	47.14	0.00	CS	P	2001	Brodribb et al. 2003	Brodibb and Holbrook, 2003	Werden et al., 2018
Solidago canadensis	Y	Cfa; Dsb	H	forb	465.32	-0.45	--	-0.45	36.73	40.22	23.05	CS	I	2014	O'Keefe & Nippert, 2018	--	Pierce et al., 2017
Sorghastrum nutans	Y	Cfa; Dfa; Dfb	H	graminoid	238.74	-0.12	--	-0.12	23.81	58.88	17.31	S	I	2014	O'Keefe & Nippert, 2018	--	Pierce et al., 2017
Stellaria media			H	forb	185.15	-0.26	--	-0.26	5.03	0.00	94.97	R	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Sweitenia macrophylla			W	tree	258.01	-1.80	4.50	-1.41	51.50	48.50	0.00	CS	P	2001	Brodribb et al. 2003	Brodibb and Holbrook, 2003	Werden et al., 2018
Trifolium pratense			H	forb	464.71	-0.23	--	-0.23	30.90	19.03	50.07	R	P	2015	Belluau and Shipley, 2017	--	Pierce et al., 2017
Umbellularia californica	Y	Csa	W	tree	111.17	-0.40	1.10	-0.08	35.24	64.03	0.73	S	P	2016	Henry et al., 2019	Henry et al., 2019; https://selectree.calpoly.edu	John et al., 2018
Vaccinium myrtillus			W	shrub	101.74	-0.84	0.26	-0.53	13.15	43.56	43.29	SR	P	2011	Ganthaler & Mayr 2015	eol.org	Pierce et al., 2017
Vaccinium myrtillus			W	shrub	89.36	-1.36	0.26	-1.05	13.15	43.56	43.29	SR	P	2011	Ganthaler & Mayr 2015	eol.org	Pierce et al., 2017
Vaccinium vitis-idaea			W	shrub	201	-0.10	0.2	0.00	3.36	96.64	0.00	S	P	2011	Ganthaler & Mayr 2015	eol.org	Pierce et al., 2017
Vaccinium vitis-idaea			W	shrub	95.75	-1.06	0.2	-0.76	3.36	96.64	0.00	S	P	2011	Ganthaler & Mayr 2015	eol.org	Pierce et al., 2017
Vitis vinifera (M)			W	liana	297.75	-0.59	1.00	-0.27	72.51	0.00	27.49	C	I	2008	Tombesi et al. 2014	missouri botanical garden	Pierce et al., 2017
Vitis vinifera (S)			W	liana	194.96	-0.52	1.00	-0.20	72.51	0.00	27.49	C	I	2008	Tombesi et al. 2014	missouri botanical garden	Pierce et al., 2017

[1] : recommended climate zones for BRC use; [2] : IWS: incipient water stress point; [3] : only provided for plants where conversion from IWS-leaf to IWS-soil was required
Stem Type: W = Woody, H = Herbacous; Method: I = Infrared Gas Analysis, P: Porometry

Table S3: Climate Zone Planting Guides

Climate Zone	Design Manuals	Number [percent] plants classified by CSR type
Bsk	East WA LID, 2013	50 [30.49%]
	Utah LID, 2018	27 [25.23%]
	Denver GI Guidelines, 2016	16 [28.57%]
Bwh	Tucson LID, 2015	7 [14.58%]
	Phoenix GI Handbook, 2019	13 [7.22%]
Cfa	Alabama LID, 2016	88 [23.66%]
	Austin ECM, 2014	32 [22.86%]
	NCDEQ, 2018	39 [28.06%]
	LID SC, 2014	32 [56.14%]
	Walton LID, 2019	11 [20.00%]
	Missouri GI, 2012	16 [51.61%]
Csa	Tahoe BMP, 2014	40 [30.08%]
	SDDM, 2016	10 [37.04%]
	SoCal LID, 2010	31 [21.38%]
Csb	SWMM, 2016	46 [32.39%]
	Olympia BMPs, 2016	20 [26.32%]
	Central Coast TAM	15 [57.69%]
Dfa	Fishers SW TSM	105 [56.45%]
	WVA SWM, 2012	73 [31.06%]
Dfb	Michigan LID, 2008	83 [45.60%]
	Vermont RGM, 2011	68 [45.64%]
	MSM Wiki, 2003	73 [57.03%]
	PA BMP, 2006	62 [56.88%]
Dsb	Boise SW Resource Guide, 2000	52 [43.70%]

Table S4: BRC Plant CSR Data by Climate Zone and Design Manual

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Bsk	East WA LID, 2013	*Prunus virginiana*	52.32	20.86	26.82	S/CSR [1]
		Betula nigra	0.00	40.97	59.03	CR [2]
		Betula occidentalis	34.65	47.30	18.05	CS/CSR [3]
		Amelanchier alnifolia	68.10	21.80	10.10	S/CS [4]
		Berberis thunbergii	88.40	11.60	0.00	S [4]
		Cornus alba	43.40	33.20	23.30	CS/CSR [4]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Fraxinus pennsylvanica	45.70	44.60	9.70	CS [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Quercus macrocarpa	40.88	49.69	9.43	CS [5]
		Alnus incana	35.30	40.12	24.58	CS/CSR [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Cotinus coggygria	57.40	30.97	11.63	S/CSR [6]
		Ginkgo biloba	15.45	33.59	50.96	CR/CSR [6]
		Gleditsia triacanthos var. inermis	24.62	61.82	13.56	C/CSR [6]
		Pinus mugo mugo	97.87	2.13	0.00	S [6]
		Pinus ponderosa	91.00	9.00	0.00	S [6]
		Pinus sylvestris	97.37	2.63	0.00	S [6]
		Populus tremuloides	56.76	25.53	17.71	S/CSR [6]
		Rhus glabra	45.27	44.62	10.10	CS [6]
		Syringa vulgaris	50.83	36.83	12.34	CS/CSR [6]
		Caragana arborescens	52.59	19.66	27.74	S/CSR [6]
		Cotinus coggygria	57.40	30.97	11.63	S/CSR [6]
		Genista tinctoria	54.60	7.49	37.91	SR [6]
		Ligustrum vulgare	77.07	11.76	11.17	S/CS [6]
		Pinus mugo	97.87	2.13	0.00	S [6]
		Rhamnus frangula	55.93	17.18	26.89	S/CSR [6]
		Rosa woodsii	63.44	18.42	18.14	S/CSR [6]
		Symphoricarpos albus	49.66	25.41	24.94	S/CSR [6]
		Andropogon gerardii	52.02	24.33	23.66	S/CSR [6]
		Deschampsia caespitosa	66.47	13.46	20.07	S/SR [6]
		Festuca ovina glauca	73.32	1.91	24.77	S/SR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Achillea millefolium	58.81	22.02	19.18	S/CSR [6]
		Anaphalis margaritacea	51.62	31.37	17.01	S/CSR [6]
		Armeria maritima 'compacta'	29.94	15.61	54.46	R/CSR [6]
		Dryas octopetala	80.63	7.47	11.91	S [6]
		Erigeron speciosis	40.04	22.85	37.11	SR/CSR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Bsk	East WA LID, 2013	*Filipendula vulgaris*	49.57	30.58	19.86	S/CSR [6]
		Iris sibirica	38.49	36.50	25.01	CSR [6]
		Linum perenne	21.24	1.17	77.59	R/SR [6]
		Matteuccia struthiopteris	0.00	67.80	32.20	C/CR [6]
		Origanum vulgare	69.98	5.11	24.91	S/SR [6]
		Saponaria ocymoides	42.23	2.19	55.58	SR [6]
		Arctostaphylos uva-ursi	88.66	11.34	0.00	S [6]
		Cerastium tomentosum	43.95	7.77	48.28	SR [6]
		Fragaria virginiana	61.80	27.38	10.82	S/CS [6]
		Helianthemum nummularium	68.87	11.78	19.35	S/SR [6]
		Polygonum affine	32.68	19.58	47.74	SR/CSR [6]
	Utah LID, 2018	*Populus fremontii*	42.17	49.88	7.95	CS [7]
		Betula nigra	0.00	40.97	59.03	CR [2]
		Betula occidentalis	34.65	47.30	18.05	CS/CSR [3]
		Amelanchier alnifolia 'Obelisk'	68.10	21.80	10.10	S/CS [4]
		Aronia melanocarpa var. elata	69.40	30.60	0.00	S/CS [4]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Acer rubrum	36.09	42.62	21.30	CS/CSR [5]
		Betula papyrifera	44.72	37.52	17.77	CS/CSR [5]
		Quercus macrocarpa	40.88	49.69	9.43	CS [5]
		Salix nigra	47.44	27.45	25.11	S/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Alnus rubra	36.09	42.62	21.30	CS/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Pennisetum alopecuroides 'Little Bunny'	44.73	35.02	20.26	CS/CSR [7]
		Acer negundo 'Sensation'	23.31	50.38	26.31	C/CSR [6]
		Acer saccharinum	56.44	27.13	16.43	S/CSR [6]
		Alnus incana sp. Tenufolia	35.30	40.12	24.58	CS/CSR [6]
		Betula pendula	73.18	17.04	9.78	S/CS [6]
		Salix alba	63.35	25.34	11.31	S/CS [6]
		Sambucus racemosa 'SMNSRD4' Lemony Lace	10.59	70.63	18.78	C/CR [6]
		Cornus sanguinea 'Midwinter Fire'	41.16	43.09	15.75	CS/CSR [6]
		Cornus stolonifera 'Neil Z' Pucker Up	63.76	21.89	14.36	S/CS [6]
		Sambucus nigra 'EIFFEL 1'	16.97	62.93	20.11	C/CSR [6]
		Festuca arundinacea	24.01	38.40	37.59	CR/CSR [6]
		Panicum virgatum 'Dallas Blues'	57.06	17.04	25.90	S/CSR [6]
		Poa pratensis	0.00	12.36	87.64	R [6]
		Schizachyrium scoparium	58.76	15.86	25.37	S/CSR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Bsk	Denver GI Guidelines, 2016	*Spirea betulufolia ‘Tor Gold’*	74.80	22.40	2.80	S/CS [4]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Quercus macrocarpa	40.88	49.69	9.43	CS [5]
		Ulmus americana	37.36	42.03	20.61	CS/CSR [5]
		Andropogon gerardii ‘Dancing Wind’	52.02	24.33	23.66	S/CSR [6]
		Deschampsia caespitosa	66.47	13.46	20.07	S/SR [6]
		Bouteloua gracilis ‘Blonde Ambition’	73.10	4.74	22.16	S/SR [6]
		Sporobolus heterolepis	66.26	14.34	19.40	S/SR [6]
		Anaphalis margaritacea	51.62	31.37	17.01	S/CSR [6]
		Iris missouriensis	51.10	48.90	0.00	CS [6]
		Monarda fistulosa	39.49	26.54	33.97	CSR [6]
		Ratibida pinnata	44.10	40.67	15.23	CS/CSR [6]
		Amorpha Canescens	60.02	24.04	15.95	S/CSR [6]
		Gleditsia triacanthos	24.62	61.82	13.56	C/CSR [6]
		Quercus robur	63.30	27.15	9.55	S/CS [6]
		Ginko biloba	15.45	33.59	50.96	CR/CSR [6]
Bwh	Tucson LID, 2015	*Encelia farinosa*	70.44	29.56	0.00	S/CS [7]
		Larrea tridentata	99.96	0.04	0.00	S [7]
		Olneya tesota	85.46	11.71	2.83	S [7]
		Prosopis velutina	74.24	20.48	5.28	S/CS [7]
		Chilopsis linearis	85.41	14.59	0.00	S [7]
		Aristida purpurea	100.00	0.00	0.00	S [6]
		Muhlenbergia rigens	88.68	11.32	0.00	S [6]
	Phoenix GI Handbook, 2019	*Encelia farinosa*	70.44	29.56	0.00	S/CS [7]
		Olneya tesota	85.46	11.71	2.83	S [7]
		Prosopis velutina	74.24	20.48	5.28	S/CS [7]
		Salvia clevelandii	82.69	17.31	0.00	S/CS [2]
		Amorpha fruticosa	39.09	40.38	20.53	CS/CSR [6]
		Aristida purpurea	100.00	0.00	0.00	S [6]
		Bouteloua curtipendula	66.01	15.21	18.78	S/SR [6]
		Helianthus annuus	0.00	77.25	22.75	C/CR [6]
		Muhlenbergia rigens	88.68	11.32	0.00	S [6]
		Penstemon barbatus	43.25	39.55	17.20	CS/CSR [6]
		Salvia nemorosa 'May Night"	9.12	41.67	49.21	CR [6]
		Sambucus nigra ssp. cerulea	16.97	62.93	20.11	C/CSR [6]
Cfa	Alabama LID, 2016	*Amelanchier arborea*	51.36	20.74	27.90	S/CSR [1]
		Carya glabra	42.97	31.58	25.45	CSR [1]
		Cornus florida	41.14	32.26	26.60	CSR [1]
		Quercus alba	46.66	34.83	18.51	CS/CSR [1]
		Betula nigra	0.00	40.97	59.03	CR [2]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Cfa	Alabama LID, 2016	*Clethra alnifolia*	57.86	23.56	18.58	S/CSR [2]
		Ilex opaca	75.30	24.70	0.00	S/CS [2]
		Magnolia virginiana	55.47	44.53	0.00	CS [2]
		Diodia virginiana	0.00	15.96	84.04	R [2]
		Eutrochium fistulosum	0.00	41.45	58.55	CR [2]
		Itea virginica	0.00	28.18	71.82	R/CR [2]
		Aesculus parviflora	25.10	47.60	27.30	C/CSR [4]
		Symphoricarpus orbiculatus	89.80	10.20	0.00	S [4]
		Fothergilla major	47.90	40.80	11.40	CS/CSR [4]
		Hamamelis virginiana	41.20	40.40	18.30	CS/CSR [4]
		Hydrangea arborescens	46.60	46.90	6.50	CS [4]
		Ilex verticillata	61.30	31.90	6.70	S/CS [4]
		Rhododendron catawbiense	62.00	38.00	0.00	CS [4]
		Acer saccharinum	42.72	42.50	14.78	CS/CSR [5]
		Fagus grandifolia	29.64	37.86	32.50	CSR [5]
		Gaultheria procumbens	73.13	18.40	8.47	S/CS [5]
		Ulmus americana	37.36	42.03	20.61	CS/CSR [5]
		Acer rubrum	36.09	42.62	21.30	CS/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Fraxinus pennsylvanica	45.70	44.60	9.70	CS [5]
		Tilia americana	14.96	52.91	32.14	C/CSR [5]
		Viburnum dentatum	14.96	52.91	32.14	C/CSR [5]
		Acer negundo	23.31	50.38	26.31	C/CSR [6]
		Acer saccharum	56.44	27.13	16.43	S/CSR [6]
		Achillea millefolium	58.81	22.02	19.18	S/CSR [6]
		Acorus calamus	61.14	5.83	33.03	S/SR [6]
		Antennaria plantaginifolia	27.76	20.45	51.79	R/CSR [6]
		Arisaema triphyllum	0.00	69.12	30.88	C/CR [6]
		Aruncus dioicus	3.34	70.58	26.08	C/CR [6]
		Asarum canadense	0.00	69.93	30.07	C/CR [6]
		Asclepias incarnata	28.26	36.06	35.69	CSR [6]
		Asclepias tuberosa	28.17	30.75	41.08	CSR [6]
		Athyrium filix-femina	0.00	69.03	30.97	C/CR [6]
		Baptisia alba	37.96	36.94	25.10	CSR [6]
		Caulophyllum thalictroides	17.73	36.50	45.77	CR/CSR [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Chamaecrista fasciculata	92.54	7.46	0.00	S [6]
		Cirsium discolor	42.93	57.07	0.00	CS [6]
		Claytonia virginica	0.00	26.96	73.04	R/CR [6]
		Coreopsis tinctoria	0.00	52.44	47.56	CR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Cfa	Alabama LID, 2016	*Dennstaedtia punctilobula*	31.47	22.71	45.81	R/CSR [6]
		Diospyros virginiana	80.64	12.77	6.59	S [6]
		Drosera rotundifolia	0.00	3.66	96.34	R [6]
		Eragrostis spectabilis	65.53	14.32	20.15	S/SR [6]
		Fragaria virginiana	61.80	27.38	10.82	S/CS [6]
		Fraxinus americana	53.19	27.10	19.71	S/CSR [6]
		Geranium maculatum	6.93	51.89	41.18	CR [6]
		Gleditsia triacanthos	24.62	61.82	13.56	C/CSR [6]
		Impatiens capensis	21.81	31.49	46.70	R/CSR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Juniperus virginiana	95.08	4.92	0.00	S [6]
		Maianthemum canadense	52.66	20.01	27.33	S/CSR [6]
		Matteuccia struthiopteris	0.00	67.80	32.20	C/CR [6]
		Mitella diphylla	0.00	46.90	53.10	CR [6]
		Nuphar lutea	9.61	88.77	1.62	C [6]
		Nymphaea odorata	6.32	87.36	6.32	C [6]
		Onoclea sensibilis	15.16	52.88	31.96	C/CSR [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Parthenocissus quinqefolia	13.06	66.23	20.71	C/CR [6]
		Phlox divaricata	14.40	18.62	66.99	R/CR [6]
		Pinus strobus	92.82	7.18	0.00	S [6]
		Prunus serotina	49.74	39.54	10.71	CS [6]
		Quercus rubra	57.31	32.72	9.97	S/CSR [6]
		Quercus virginiana	56.75	36.49	6.75	CS [6]
		Rhus glabra	45.27	44.62	10.10	CS [6]
		Robinia pseudoacacia	41.41	47.88	10.71	CS [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
		Ruellia humilis	77.95	14.73	7.32	S/CS [6]
		Sambucus nigra	16.97	62.93	20.11	C/CSR [6]
		Solidago rugosa	42.34	26.05	31.61	CSR [6]
		Sorghastrum nutans	58.88	23.81	17.31	S/CSR [6]
		Tiarella cordifolia	44.64	40.78	14.58	CS/CSR [6]
		Vaccinium corymbosum	63.04	34.65	2.31	S/CS [6]
		Vallisneria americana	0.00	68.44	31.56	C/CR [6]
		Verbena hastata	52.91	26.32	20.77	S/CSR [6]
		Viola sororia	0.00	44.74	55.26	CR [6]
		Amorpha fruticosa	39.09	40.38	20.53	CS/CSR [6]
		Osmunda regalis	12.03	84.01	3.96	C [6]
		Ostrya virginiana	53.73	19.18	27.09	S/CSR [6]
		Peltandra virginica	57.06	17.04	25.90	S/CSR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Cfa	Alabama LID, 2016	*Schizachrium scoparium*	58.76	15.86	25.37	S/CSR [6]
		Scirpus cyperinus	17.90	42.90	39.20	CR/CSR [8]
		Carex stricta	20.12	36.14	43.74	CR/CSR [8]
	Austin ECM, 2014	*Chilopsis linearis*	85.41	14.59	0.00	S [7]
		Buchloe dactyloides	11.38	49.44	39.18	SR/CSR [2]
		Callicarpa americana	12.02	55.79	32.20	C/CSR [2]
		Hemerocallis fulva	0.00	48.71	51.29	CR [2]
		Muhlenbergia lindheimeri	34.62	65.38	0.00	S/CS [2]
		Quercus marilandica	48.20	39.70	12.10	CS/CSR [2]
		Buddleia Davidii	29.70	42.90	27.40	CSR [4]
		Quercus macrocarpa	40.88	49.69	9.43	CS [5]
		Ulmus americana	37.36	42.03	20.61	CS/CSR [5]
		Viburnum dentatum	14.96	52.91	32.14	C/CSR [5]
		Cedrus deodara	99.12	0.88	0.00	S [6]
		Prunus serotina	49.74	39.54	10.71	CS [6]
		Rhus glabra	45.27	44.62	10.10	CS [6]
		Cercis canadensis var. 'Texensis'	71.98	12.49	15.53	S/SR [6]
		Nerium oleander	64.50	35.50	0.00	S/CS [6]
		Cotoneaster horizontalis	92.67	1.66	5.67	S [6]
		Rosmarinus officinalis	96.45	3.55	0.00	S [6]
		Hibiscus syriacus	44.41	34.22	21.37	CS/CSR [6]
		Origanum vulgare	69.98	5.11	24.91	S/SR [6]
		Santolina chamaecyparissus	0.00	0.00	100.00	R [6]
		Parthenocissus tricuspidata 'Veitchii'	31.41	55.15	13.44	C/CSR [6]
		Parthenocissus quinquefolia	13.06	66.23	20.71	C/CR [6]
		Artemisia ludoviciana	65.09	12.54	22.37	S/SR [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
		Asclepias tuberosa	28.17	30.75	41.08	CSR [6]
		Chrysanthemum leucanthemum	55.49	19.87	24.64	S/CSR [6]
		Achillea millefolium	58.81	22.02	19.18	S/CSR [6]
		Cynodon dactylon	41.52	11.97	46.51	SR/CSR [6]
		Bouteloua gracilis	73.10	4.74	22.16	S/SR [6]
		Schizachyrium scoparium	58.76	15.86	25.37	S/CSR [6]
		Bouteloua curtipendula	66.01	15.21	18.78	S/SR [6]
		Quercus virginiana	56.75	36.49	6.75	CS [6]
	NCDEQ, 2018	*Amelanchier arborea*	51.36	20.74	27.90	S/CSR [1]
		Betula nigra	0.00	40.97	59.03	CR [2]
		Callicarpa americana	12.02	55.79	32.20	C/CSR [2]
		Itea virginica	0.00	28.18	71.82	R/CR [2]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Cfa	NCDEQ, 2018	*Clethra alnifolia*	57.86	23.56	18.58	S/CSR [2]
		Ilex opaca	75.30	24.70	0.00	S/CS [2]
		Magnolia virginiana	55.47	44.53	0.00	CS [2]
		Aronia melanocarpa	69.40	30.60	0.00	S/CS [4]
		Hamamelis virginiana	41.20	40.40	18.30	CS/CSR [4]
		Ilex verticillata	61.30	31.90	6.70	S/CS [4]
		Viburnum dentatum	14.96	52.91	32.14	C/CSR [5]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Diospyros virginiana	80.64	12.77	6.59	S [6]
		Spiraea tomentosa	84.96	4.96	10.08	S [6]
		Vaccinium corymbosum	63.04	34.65	2.31	S/CS [6]
		Asclepias incarnata	28.26	36.06	35.69	CSR [6]
		Baptisia alba	37.96	36.94	25.10	CSR [6]
		Carex cherokeensis	32.48	25.32	42.20	CSR [6]
		Carex vulpinoidea	52.98	16.93	30.09	S/CSR [6]
		Coreopsis tinctoria	0.00	52.44	47.56	CR [6]
		Elymus canadensis	50.03	28.08	21.89	S/CSR [6]
		Eupatorium perfoliatum	45.21	41.38	13.42	CS/CSR [6]
		Helenium autumnale	85.51	9.87	4.62	S [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Juncus tenuis	65.77	6.68	27.55	S/SR [6]
		Monarda fistulosa	39.49	26.54	33.97	CSR [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Ratibida pinnata	44.10	40.67	15.23	CS/CSR [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
		Solidago canadensis	40.22	36.73	23.05	CS/CSR [6]
		Solidago rugosa	42.34	26.05	31.61	CSR [6]
		Sorghastrum nutans	58.88	23.81	17.31	S/CSR [6]
		Symphyotrichum laeve	33.85	39.07	27.09	CSR [6]
		Symphyotrichum novae-angliae	46.54	18.02	35.44	SR/CSR [6]
		Verbena hastata	52.91	26.32	20.77	S/CSR [6]
		Heliopsis helianthoides	43.54	37.41	19.06	CS/CSR [6]
		Symphoricarpos orbiculatus	89.80	10.20	0.00	S [6]
		Carex stricta	20.12	36.14	43.74	CR/CSR [8]
		Scirpus cyperinus	17.90	42.90	39.20	CR/CSR [8]
	LID SC, 2014	*Betula nigra*	0.00	40.97	59.03	CR [2]
		Clethra alnifolia	57.86	23.56	18.58	S/CSR [2]
		Panicum virgatum	8.44	46.15	45.41	CR [2]
		Cornus racemosa	58.10	24.90	17.00	S/CSR [4]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Cfa	LID SC, 2014	*Hamamelis virginiana*	41.20	40.40	18.30	CS/CSR [4]
		Ilex verticillata	61.30	31.90	6.70	S/CS [4]
		Acer rubrum	36.09	42.62	21.30	CS/CSR [5]
		Acer saccharinum	42.72	42.50	14.78	CS/CSR [5]
		Viburnum dentatum	14.96	52.91	32.14	C/CSR [5]
		Fraxinus pennsylvanica	45.70	44.60	9.70	CS [5]
		Acer negundo	23.31	50.38	26.31	C/CSR [6]
		Acer Saccharum	56.44	27.13	16.43	S/CSR [6]
		Acorus calamus	61.14	5.83	33.03	S/SR [6]
		Alnus incana	35.30	40.12	24.58	CS/CSR [6]
		Aster noviae angliae	46.54	18.02	35.44	SR/CSR [6]
		Aster puniceus	40.33	35.43	24.24	CS/CSR [6]
		Betula populifolia	68.27	15.93	15.80	S/CS [6]
		Cornus stolonifera	63.76	21.89	14.36	S/CS [6]
		Eleocharis palustris	0.00	45.68	54.32	CR [6]
		Impatiens capensis	21.81	31.49	46.70	R/CSR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Onoclea sensibilis	15.16	52.88	31.96	C/CSR [6]
		Osmunda regalis	12.03	84.01	3.96	C [6]
		Peltandra virginica	57.06	17.04	25.90	S/CSR [6]
		Quercus rubra	57.31	32.72	9.97	S/CSR [6]
		Thelypteris palustris	2.38	62.90	34.72	C/CR [6]
		Vaccinium corymbosum	63.04	34.65	2.31	S/CS [6]
		Eupotorium maculatum	37.42	44.87	17.71	CS/CSR [6]
		Eupotorium perfoliatum	45.21	41.38	13.42	CS/CSR [6]
		Iris versicolor	1.96	64.71	33.32	C/CR [8]
		Calamagrostis canadensis	20.96	34.27	44.77	CR/CSR [8]
	Walton LID, 2019	*Betula nigra*	0.00	40.97	59.03	CR [2]
		Callicarpa americana	12.02	55.79	32.20	C/CSR [2]
		Clethra alnifolia	57.86	23.56	18.58	S/CSR [2]
		Itea virginica	0.00	28.18	71.82	R/CR [2]
		Magnolia virginiana	55.47	44.53	0.00	CS [2]
		Arisaema triphyllum	0.00	69.12	30.88	C/CR [6]
		Baptisia alba	37.96	36.94	25.10	CSR [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Osmunda regalis	12.03	84.01	3.96	C [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
	Missouri GI, 2012	*Quercus alba*	46.66	34.83	18.51	CS/CSR [1]
		Hamamelus virginiana	41.20	40.40	18.30	CS/CSR [4]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Cfa	Missouri GI, 2012	*Andropogon gerardii*	52.02	24.33	23.66	S/CSR [6]
		Bouteloua curtipendula	66.01	15.21	18.78	S/SR [6]
		Carex vulpinoidea	52.98	16.93	30.09	S/CSR [6]
		Schizachyrium scoparium	58.76	15.86	25.37	S/CSR [6]
		Sporobolus heterolepis	66.26	14.34	19.40	S/SR [6]
		Aster novae-angliae	46.54	18.02	35.44	SR/CSR [6]
		Eryngium yuccifolium	76.37	23.63	0.00	S/CS [6]
		Eupatorium coelestinum	69.59	12.45	17.97	S/SR [6]
		Pycnanthemum tenuifolium	80.62	2.33	17.04	S/SR [6]
		Ratibida pinnata	44.10	40.67	15.23	CS/CSR [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
		Solidago rugosa	42.34	26.05	31.61	CSR [6]
		Zizia aurea	31.87	53.32	14.80	C/CSR [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
Csa	Tahoe BMP, 2014	*Carex praegracilis*	60.43	16.21	23.36	S/CSR [2]
		Amelanchier alnifolia	68.10	21.80	10.10	S/CS [4]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Lonicera involucrata	50.10	34.10	15.90	CS/CSR [4]
		Agropyron desertorum	87.88	12.12	0.00	S [6]
		Deschampsia caespitosa	66.47	13.46	20.07	S/SR [6]
		Elymus elymoides	67.26	15.40	17.35	S/SR [6]
		Elymus trachycaulus	48.15	12.90	38.95	SR/CSR [6]
		Festuca ovina	73.32	1.91	24.77	S/SR [6]
		Festuca rubra	35.70	10.41	53.89	SR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Phalaris arundinacea	35.61	35.72	28.66	CSR [6]
		Phleum alpinum	65.65	9.72	24.63	S/SR [6]
		Achillea millefolium	58.81	22.02	19.18	S/CSR [6]
		Anaphalis margaritacea	51.62	31.37	17.01	S/CSR [6]
		Chamerion angustifolium	30.69	39.12	30.19	CSR [6]
		Epilobium ciliatum	0.00	19.31	80.69	R/CR [6]
		Fragaria virginiana	61.80	27.38	10.82	S/CS [6]
		Geranium richardsonii	14.86	54.11	31.03	C/CSR [6]
		Geum macrophyllum	62.89	11.52	25.59	S/SR [6]
		Ipomopsis aggregata	0.00	45.35	54.65	CR [6]
		Linum lewisii	81.63	0.00	18.37	S/SR [6]
		Lupinus argenteus	0.00	60.41	39.59	CR [6]
		Lupinus polyphyllus	6.08	67.42	26.50	C/CR [6]
		Mimulus guttatus	0.00	36.05	63.95	R/CR [6]
		Nasturtium officinale	0.00	11.73	88.27	R [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Csa	Tahoe BMP, 2014	*Oxyria digyna*	0.00	22.10	77.90	R/CR [6]
		Solidago canadensis	40.22	36.73	23.05	CS/CSR [6]
		Thalictrum fendleri	33.01	53.78	13.21	C/CSR [6]
		Urtica dioica ssp. Holosericea	34.33	44.79	20.88	CS/CSR [6]
		Alnus incana ssp. tenuifolia	35.30	40.12	24.58	CS/CSR [6]
		Arctostaphylos uva-ursi	88.66	11.34	0.00	S [6]
		Mahonia aquifolium	52.13	47.87	0.00	CS [6]
		Populus tremuloides	56.76	25.53	17.71	S/CSR [6]
		Rosa woodsii	63.44	18.42	18.14	S/CSR [6]
		Sambucus nigra ssp. cerulea	16.97	62.93	20.11	C/CSR [6]
		Sambucus racemosa	10.59	70.63	18.78	C/CR [6]
		Festuca brevipila	93.56	6.44	0.00	S [6]
		Pinus ponderosa	91.00	9.00	0.00	S [6]
		Calamagrostis canadensis	20.96	34.27	44.77	CR/CSR [8]
	SDDM, 2016	*Platanus racemosa*	27.40	59.73	12.86	C/CSR [2]
		Leymus condensatus 'Canyon Prince'	56.69	39.24	4.06	CS [2]
		Alnus rhombifolia	39.46	33.80	26.75	CSR [3]
		Jucus patens	91.69	8.31	0.00	S [2]
		Juncus Mexicana	85.24	14.76	0.00	S [2]
		Muhlenbergia rigens	88.68	11.32	0.00	S [6]
		Carex spissa	69.53	30.46	0.02	S/CS [2]
		Carex praegracilis	60.43	16.21	23.36	S/CSR [2]
		Achillea millefolium	58.81	22.02	19.18	S/CSR [6]
		Festuca rubra	35.70	10.41	53.89	SR [6]
	SoCal LID, 2010	*Chilopsis linearis*	85.41	14.59	0.00	S [7]
		Populus fremontii	42.17	49.88	7.95	CS [7]
		Rhus ovata	74.44	25.56	0.00	S/CS [7
		Baccharis pilularis	84.14	11.14	4.72	S [2]
		Carex pansa	67.25	15.25	17.49	S/SR [2]
		Carex praegracilis	60.43	16.21	23.36	S/CSR [2]
		Juncus patens	91.69	8.31	0.00	S [2]
		Salvia clevelandii	82.69	17.31	0.00	S/CS [2]
		Ceanothus 'Anchor Bay'	87.10	12.90	0.00	S [9]
		Ceanothus impressus	100.00	0.00	0.00	S [9]
		Ceanothus megacarpus	100.00	0.00	0.00	S [9]
		Ceonothus verrucosus	100.00	0.00	0.00	S [9]
		Cercis occidentalis	36.18	45.72	18.10	CS/CSR [3]
		Cercocarpus betuloides	36.18	45.72	18.10	CS/CSR [3]
		Encelia californica	0.00	26.36	73.64	R/CR [3]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Csa	SoCal LID, 2010	*Encelia farinose*	7.04	55.58	37.38	CR [3]
		Fraxinus dipetala	59.15	20.02	20.84	S/CSR [3]
		Platanus racemosa	27.40	59.73	12.86	C/CSR [3]
		Prunus ilicifolia ssp. Ilicifolia	72.41	27.59	0.00	S/CS [3]
		Quercus engelmannii	81.77	16.33	1.90	S/CS [3]
		Rhus integrifolia	72.52	27.48	0.00	S/CS [3]
		Umbellularia californica	64.03	35.24	0.73	S/CS [3]
		Achillea millefoilum	58.81	22.02	19.18	S/CSR [6]
		Amorpha fruticosa	39.09	40.38	20.53	CS/CSR [6]
		Arctostaphylos uva-ursi 'Point Reyes'	88.66	11.34	0.00	S [6]
		Aristida purpurea	100.00	0.00	0.00	S [6]
		Artemisia ludoviciana	65.09	12.54	22.37	S/SR [6]
		Bouteloua curtipendula	66.01	15.21	18.78	S/SR [6]
		Deschampsia caespitosa	66.47	13.46	20.07	S/SR [6]
		Linum lewisii	81.63	0.00	18.37	S/SR [6]
		Muhlenbergia rigens	88.68	11.32	0.00	S [6]
Csb	SWMM, 2016	*Prunus virginiana 'Canada Red'*	61.93	7.01	31.05	S/SR [1]
		Arctostapylos uva-ursi	89.64	10.36	0.00	S [2]
		Baccaris pilularis 'Dwarf'	84.14	11.14	4.72	S [2]
		Juncus patens	91.69	8.31	0.00	S [2]
		Alnus rhombifolia	39.46	33.80	26.75	CSR [3]
		Amelanchier alnifolia	68.10	21.80	10.10	S/CS [4]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Ilex crenata	84.60	15.40	0.00	S [4]
		Lonicera involucrata	50.10	34.10	15.90	CS/CSR [4]
		Sambucus nigra ssp. cerulea	13.60	38.20	48.20	CR/CSR [4]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Alnus rubra	36.09	42.62	21.30	CS/CSR [5]
		Acer camperstre	29.41	42.29	28.30	CSR [6]
		Arbutus unedo	69.84	22.74	7.42	S/CS [6]
		Athyrium filix-femina	0.00	69.03	30.97	C/CR [6]
		Carex rupestris	98.19	1.81	0.00	S [6]
		Carex vesicaria	66.31	29.11	4.59	S/CS [6]
		Cistus albidus L.	0.00	37.15	62.85	R/CR [6]
		Cistus clusii Dunal	65.03	0.00	34.97	S/SR [6]
		Cistus creticus L. eriocephalus (Viv.) Greuter & Burdet	88.25	11.75	0.00	S [6]
		Cistus ladanifer L.	90.83	9.17	0.00	S [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Csb	SWMM, 2016	*Cistus laurifolius L.*	62.64	11.89	25.47	S/SR [6]
		Cistus monspeliensis L.	88.73	11.27	0.00	S [6]
		Cistus salvifolius L.	63.04	36.96	0.00	S/CS [6]
		Deschampsia cespitosa	66.47	13.46	20.07	S/SR [6]
		Eleocharis acicularis	0.00	0.00	100.00	R [6]
		Eleocharis ovata	52.38	9.86	37.76	SR [6]
		Eleocharis palustris	0.00	45.68	54.32	CR [6]
		Euonymus japonicas	70.90	29.10	0.00	S/CS [6]
		Festuca rubra	35.70	10.41	53.89	SR [6]
		Fragaria vesca	18.75	38.58	42.66	CR/CSR [6]
		Fragaria virginiana	61.80	27.38	10.82	S/CS [6]
		Gleditsia tricanthos	24.62	61.82	13.56	C/CSR [6]
		Hebe franciscana (Eastw.) Souster	76.75	15.07	8.17	S/CS [6]
		Iris sibirica	38.49	36.50	25.01	CSR [6]
		Juncus effusus var. pacificus	61.52	38.48	0.00	CS [6]
		Juncus tenuis	65.77	6.68	27.55	S/SR [6]
		Lavandula angustifolia	0.00	5.55	94.45	R [6]
		Lupinus polyphyllus	6.08	67.42	26.50	C/CR [6]
		Populus tremuloides	56.76	25.53	17.71	S/CSR [6]
		Salix purpurea	71.51	17.72	10.77	S/CS [6]
		Spirea japonica	35.64	30.18	34.19	CSR [6]
		Symphoricarpos alba	49.66	25.41	24.94	S/CSR [6]
		Viburnum tinus	47.63	35.00	17.37	CS/CSR [6]
		Carex stipata	27.80	15.91	56.29	R/CSR [6]
		Scirpus microcarpus	14.25	51.20	34.55	CR/CSR [8]
	Olympia BMPs, 2016	*Quercus velutina*	45.89	40.49	13.62	CS/CSR [1]
		Quercus coccinea	60.50	38.10	1.30	CS [2]
		Fraxinus pennsylvanica	45.70	44.60	9.70	CS [5]
		Acer rubrum	36.09	42.62	21.30	CS/CSR [5]
		Betula papyrifera	44.72	37.52	17.77	CS/CSR [5]
		Populus tremuloides	58.37	30.23	11.40	S/CSR [5]
		Quercus robur	40.27	40.25	19.48	CS/CSR [5]
		Quercus rubra	34.67	45.81	19.51	CS/CSR [5]
		Alnus rubra	36.09	42.62	21.30	CS/CSR [5]
		Tilia americana	14.96	52.91	32.14	C/CSR [5]
		Acer platanoides	35.31	48.76	15.93	CS/CSR [6]
		Acer saccharum	56.44	27.13	16.43	S/CSR [6]
		Fagus sylvatica	63.59	22.77	13.63	S/CS [6]
		Acer campestre	29.41	42.29	28.30	CSR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Csb	Olympia BMPs, 2016	*Acer pseudoplatanus*	54.93	37.51	7.55	CS [6]
		Carpinus betulus	33.33	35.74	30.93	CSR [6]
		Fraxinus americana	53.19	27.10	19.71	S/CSR [6]
		Ginko biloba	15.45	33.59	50.96	CR/CSR [6]
		Picea sitchensis	100.00	0.00	0.00	S [6]
		Tilia cordata	44.64	40.78	14.58	CS/CSR [6]
	Central Coast	*Juncus patens*	91.69	8.31	0.00	S [2]
		Festuca rubra 'Molate'	35.70	10.41	53.89	SR [6]
		Baccharis pilularis	84.14	11.14	4.72	S [2]
		Muhlenbergia rigens	88.68	11.32	0.00	S [6]
		Chilopsis linearis	85.41	14.59	0.00	S [7]
		Carex pansa	67.25	15.25	17.49	S/SR [2]
		Carex divulsa	47.20	15.92	36.87	SR/CSR [6]
		Carex praegracilis	60.43	16.21	23.36	S/CSR [2]
		Achillea millefolium	58.81	22.02	19.18	S/CSR [6]
		Quercus agrifolia	76.34	23.66	0.00	S/CS [3]
		Solidago californica	75.50	24.50	0.00	S/CS [2]
		Carex spissa	69.53	30.46	0.02	S/CS [2]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Cercis occidentalis	36.18	45.72	18.10	CS/CSR [3]
		Platanus racemosa	27.40	59.73	12.86	C/CSR [2]
Dfa	Fishers SW TSM	*Amelanchier arborea*	51.36	20.74	27.90	S/CSR [1]
		Cornus florida	41.14	32.26	26.60	CSR [1]
		Polygonatum biflorum	52.32	20.86	26.82	S/CSR [1]
		Prunus virginiana	52.32	20.86	26.82	S/CSR [1]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Gymnocladus dioicus	41.20	40.40	18.30	CS/CSR [4]
		Heliopsis helianthoides	61.30	31.90	6.70	S/CS [4]
		Ilex verticillata	61.30	31.90	6.70	S/CS [4]
		Acer rubrum	36.09	42.62	21.30	CS/CSR [5]
		Acer saccharum	42.72	42.50	14.78	CS/CSR [5]
		Alnus rugosa	40.87	39.54	19.59	CS/CSR [5]
		Betula papyrifera	44.72	37.52	17.77	CS/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Prunus americana	40.88	49.69	9.43	CS [5]
		Stipa spartea	14.96	52.91	32.14	C/CSR [5]
		Thuja occidentalis	37.36	42.03	20.61	CS/CSR [5]
		Tilia americana	45.66	39.64	14.70	CS/CSR [5]
		Verbena hastata	14.96	52.91	32.14	C/CSR [5]
		Quercus macrocarpa	40.88	49.69	9.43	CS [5]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfa	Fishers SW TSM	*Ulmus rubra*	45.66	39.64	14.70	CS/CSR [5]
		Acorus calamus	61.14	5.83	33.03	S/SR [6]
		Alisma plantago-aquatica	0.00	71.18	28.82	C/CR [6]
		Andropogon gerardii	52.02	24.33	23.66	S/CSR [6]
		Anemone canadensis	38.11	39.21	22.68	CS/CSR [6]
		Asclepias incarnata	28.26	36.06	35.69	CSR [6]
		Asclepias syriaca	17.32	63.44	19.24	C/CSR [6]
		Asclepias tuberosa	28.17	30.75	41.08	CSR [6]
		Asclepias verticillata	42.21	4.86	52.93	SR [6]
		Aster laevis	33.85	39.07	27.09	CSR [6]
		Aster novae-angliae	46.54	18.02	35.44	SR/CSR [6]
		Aster puniceus	40.33	35.43	24.24	CS/CSR [6]
		Aster umbellatus	4.36	48.65	46.99	CR [6]
		Betula alleghaniensis	58.50	17.86	23.64	S/CSR [6]
		Carex bicknellii	51.31	14.79	33.90	SR/CSR [6]
		Carex muhlenbergii	60.01	17.23	22.76	S/CSR [6]
		Carex vulpinoidea	52.98	16.93	30.09	S/CSR [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Coreopsis palmata	71.65	14.96	13.39	S/CS [6]
		Desmodium canadense	47.32	27.26	25.42	S/CSR [6]
		Echinacea pallida	0.00	0.00	100.00	R [6]
		Eleocharis acicularis	38.87	23.09	38.04	SR/CSR [6]
		elianthus pauciflorus	50.03	28.08	21.89	S/CSR [6]
		Elymus virginicus	65.53	14.32	20.15	S/SR [6]
		Eragrostis spectabilis	76.37	23.63	0.00	S/CS [6]
		Eryngium yuccifolium	37.42	44.87	17.71	CS/CSR [6]
		Eupatorium maculatum	45.21	41.38	13.42	CS/CSR [6]
		Eupatorium purpureum	83.59	6.70	9.70	S [6]
		Euphorbia corollata	67.32	12.25	20.43	S/SR [6]
		Euthamia graminifolia	34.80	37.68	27.52	CSR [6]
		Gentiana andrewsii	6.93	51.89	41.18	CR [6]
		Hamamelis virginiana	85.51	9.87	4.62	S [6]
		Helianthus giganteus	43.54	37.41	19.06	CS/CSR [6]
		Helianthus pauciflorus	43.54	37.41	19.06	CS/CSR [6]
		Iris virginica	61.52	38.48	0.00	CS [6]
		Juglans nigra	65.77	6.68	27.55	S/SR [6]
		Juncus tenuis	95.08	4.92	0.00	S [6]
		Juncus torreyi	72.85	14.21	12.95	S/CS [6]
		Koeleria macrantha	63.29	16.53	20.18	S/CSR [6]
		Larix laricina	45.01	20.32	34.67	SR/CSR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfa	Fishers SW TSM	*Lespedeza capitata*	71.73	13.90	14.37	S/SR [6]
		Lindera benzoin	65.27	4.36	30.37	S/SR [6]
		Liriodendron tulipifera	0.00	59.12	40.88	CR [6]
		Lobelia cardinalis	17.14	22.28	60.57	R/CSR [6]
		Lobelia siphilitica	39.49	26.54	33.97	CSR [6]
		Mimulus ringens	57.06	17.04	25.90	S/CSR [6]
		Physostegia virginiana	92.82	7.18	0.00	S [6]
		Pycnanthemum virginianum	57.31	32.72	9.97	S/CSR [6]
		Quercus bicolor	44.10	40.67	15.23	CS/CSR [6]
		Ratibida pinnata	69.25	12.23	18.53	S/SR [6]
		Rudbeckia laciniata	58.76	15.86	25.37	S/CSR [6]
		Scirpus atrovirens	48.94	51.06	0.00	CS [6]
		Smilacina racemosa	49.96	33.72	16.32	CS/CSR [6]
		Solidago ohiensis	58.88	23.81	17.31	S/CSR [6]
		Spartina pectinata	38.01	21.30	40.68	SR/CSR [6]
		Spiraea alba	20.57	16.18	63.25	R/CSR [6]
		Thalictrum dasycarpum	0.00	51.21	48.79	CR [6]
		Tradescantia ohiensis	52.91	26.32	20.77	S/CSR [6]
		Ulmus americana	65.40	27.91	6.69	S/CS [6]
		Viburnum dentatum	31.87	53.32	14.80	C/CSR [6]
		Zizia aurea	31.87	53.32	14.80	C/CSR [6]
		Carex stipata	27.80	15.91	56.29	R/CSR [6]
		Helenium autumnale	85.51	9.87	4.62	S [6]
		Helianthus occidentalis	43.54	37.41	19.06	CS/CSR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Juniperus virginiana	95.08	4.92	0.00	S [6]
		Liatris aspera	45.01	20.32	34.67	SR/CSR [6]
		Liatris cylindracea	71.73	13.90	14.37	S/SR [6]
		Lobelia spicata	65.27	4.36	30.37	S/SR [6]
		Lupinus perennis	0.00	59.12	40.88	CR [6]
		Monarda fistulosa	39.49	26.54	33.97	CSR [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Peltandra virginica	57.06	17.04	25.90	S/CSR [6]
		Phlox divaricata	14.40	18.62	66.99	R/CR [6]
		Pinus strobus	92.82	7.18	0.00	S [6]
		Quercus rubra	57.31	32.72	9.97	S/CSR [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
		Silphium terebinthinaceum	48.94	51.06	0.00	CS [6]
		Sorghastrum nutans	58.88	23.81	17.31	S/CSR [6]
		Calamagrostis canadensis	20.96	34.27	44.77	CR/CSR [8]

Table S4 Continued

Climate Zone	**Desing Manual**	**Plant Species**	**%S**	**%C**	**%R**	**CSR [ref]**
Dfa	Fishers SW TSM	*Carex lacustris*	15.36	53.08	31.56	C/CSR [8]
		Carex stricta	20.12	36.14	43.74	CR/CSR [8]
		Sagittaria latifolila	12.97	46.34	40.69	CR/CSR [8]
		Saururus cernuus	17.90	42.90	39.20	CR/CSR [8]
		Glyceria striata	15.21	34.66	50.13	CR/CSR [8]
		Scirpus cyperinus	17.90	42.90	39.20	CR/CSR [8]
	WVA SWM, 2012	*Amelanchier arborea*	51.36	20.74	27.90	S/CSR [1]
		Carya glabra	42.97	31.58	25.45	CSR [1]
		Cornus florida	41.14	32.26	26.60	CSR [1]
		Sassafras albidum	21.82	49.06	29.11	C/CSR [1]
		Betula nigra	0.00	40.97	59.03	CR [2]
		Clethra alnifolia	57.86	23.56	18.58	S/CSR [2]
		Ilex opaca	75.30	24.70	0.00	S/CS [2]
		Itea virginica	0.00	28.18	71.82	R/CR [2]
		Magnolia virginiana	55.47	44.53	0.00	CS [2]
		Amelanchier laevis	61.70	23.10	15.20	S/CSR [4]
		Cornus racemosa	58.10	24.90	17.00	S/CSR [4]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Hamamelis virginiana	41.20	40.40	18.30	CS/CSR [4]
		Ilex verticilata	61.30	31.90	6.70	S/CS [4]
		Rhododendron catawbiense	62.00	38.00	0.00	CS [4]
		Rhus aromatic	80.90	19.10	0.00	S/CS [4]
		Symphoricarpos orbiculatus	89.80	10.20	0.00	S [4]
		Acer pennsylvanicum	20.08	52.22	27.70	C/CSR [5]
		Acer rubrum	36.09	42.62	21.30	CS/CSR [5]
		Acer saccharinum	42.72	42.50	14.78	CS/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Fagus grandifolia	29.64	37.86	32.50	CSR [5]
		Fraxinus pennsylvanica	45.70	44.60	9.70	CS [5]
		Gaultheria procumbens	73.13	18.40	8.47	S/CS [5]
		Populus deltoides	43.85	43.91	12.23	CS/CSR [5]
		Viburnum dentatum	14.96	52.91	32.14	C/CSR [5]
		Acer negundo	23.31	50.38	26.31	C/CSR [6]
		Acer saccharum	56.44	27.13	16.43	S/CSR [6]
		Alnus incana spp. Rugosa	35.30	40.12	24.58	CS/CSR [6]
		Andropogon gerardii	52.02	24.33	23.66	S/CSR [6]
		Andropogon virginicus	77.51	15.84	6.66	S/CS [6]
		Arisaema triphyllum	0.00	69.12	30.88	C/CR [6]
		Asarum canadense	0.00	69.93	30.07	C/CR [6]
		Asclepias incarnata	28.26	36.06	35.69	CSR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfa	WVA SWM, 2012	*Asclepias tuberosa*	28.17	30.75	41.08	CSR [6]
		Aster novae-angliae	46.54	18.02	35.44	SR/CSR [6]
		Athyrium filix-femina	0.00	69.03	30.97	C/CR [6]
		Betula alleghaniensis	58.50	17.86	23.64	S/CSR [6]
		Caltha palustris	0.00	59.13	40.87	CR [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Coreopsis tinctoria	0.00	52.44	47.56	CR [6]
		Dennstaedtia punctilobula	31.47	22.71	45.81	R/CSR [6]
		Eupatorium coelestinum	69.59	12.45	17.97	S/SR [6]
		Fraxinus americana	53.19	27.10	19.71	S/CSR [6]
		Gentiana andrewsii	34.80	37.68	27.52	CSR [6]
		Geranium maculatum	6.93	51.89	41.18	CR [6]
		Helenium autumnale	85.51	9.87	4.62	S [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Juniperus virginiana	95.08	4.92	0.00	S [6]
		Kalmia angustifolia	89.98	10.02	0.00	S [6]
		Liatris squarosa	73.94	11.93	14.13	S/SR [6]
		Matteuccia struthiopteris	0.00	67.80	32.20	C/CR [6]
		Mimulus ringens	17.14	22.28	60.57	R/CSR [6]
		Monarda fistulosa	39.49	26.54	33.97	CSR [6]
		Nuphar lutea 'Advena '	9.61	88.77	1.62	C [6]
		Onoclea sensibilis	15.16	52.88	31.96	C/CSR [6]
		Osmunda regalis	12.03	84.01	3.96	C [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Pinus rigida	92.79	7.21	0.00	S [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
		Sambucus nigra ssp.	16.97	62.93	20.11	C/CSR [6]
		Schizachyrium scoparium	58.76	15.86	25.37	S/CSR [6]
		Spiraea tomentosa	84.96	4.96	10.08	S [6]
		Thelypteris palustris	2.38	62.90	34.72	C/CR [6]
		Tridens flavus	75.17	17.50	7.33	S/CS [6]
		Vaccinium angustifolium	40.61	11.35	48.05	SR/CSR [6]
		Vaccinium corymbosum	63.04	34.65	2.31	S/CS [6]
		Verbena hastata	52.91	26.32	20.77	S/CSR [6]
		Veronicastrum virginicum	65.40	27.91	6.69	S/CS [6]
		Zizia aurea	31.87	53.32	14.80	C/CSR [6]
		Carex stricta	20.12	36.14	43.74	CR/CSR [8]
		Lysimachia terrestris	12.32	31.80	55.88	R/CSR [8]
		Scirpus cyperinus	17.90	42.90	39.20	CR/CSR [8]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfb	Michigan LID, 2008	*Amelanchier arborea*	51.36	20.74	27.90	S/CSR [1]
		Cornus florida	41.14	32.26	26.60	CSR [1]
		Prunus virginiana	52.32	20.86	26.82	S/CSR [1]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Hamamelis virginiana	41.20	40.40	18.30	CS/CSR [4]
		Ilex verticillata	61.30	31.90	6.70	S/CS [4]
		Acer rubrum	36.09	42.62	21.30	CS/CSR [5]
		Acer saccharinum	42.72	42.50	14.78	CS/CSR [5]
		Alnus rugosa	40.87	39.54	19.59	CS/CSR [5]
		Betula papyrifera	44.72	37.52	17.77	CS/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Quercus macrocarpa	40.88	49.69	9.43	CS [5]
		Tilia americana	14.96	52.91	32.14	C/CSR [5]
		Ulmus americana	37.36	42.03	20.61	CS/CSR [5]
		Ulmus rubra	45.66	39.64	14.70	CS/CSR [5]
		Viburnum dentatum	14.96	52.91	32.14	C/CSR [5]
		Acorus calamus	61.14	5.83	33.03	S/SR [6]
		Alisma plantago-aquatica	0.00	71.18	28.82	C/CR [6]
		Andropogon gerardii	52.02	24.33	23.66	S/CSR [6]
		Anemone canadensis	38.11	39.21	22.68	CS/CSR [6]
		Asclepias incarnata	28.26	36.06	35.69	CSR [6]
		Asclepias syriaca	17.32	63.44	19.24	C/CSR [6]
		Asclepias tuberosa	28.17	30.75	41.08	CSR [6]
		Asclepias verticillata	42.21	4.86	52.93	SR [6]
		Aster laevis	33.85	39.07	27.09	CSR [6]
		Aster novae-angliae	46.54	18.02	35.44	SR/CSR [6]
		Aster puniceus	40.33	35.43	24.24	CS/CSR [6]
		Aster umbellatus	4.36	48.65	46.99	CR [6]
		Betula alleghaniensis	58.50	17.86	23.64	S/CSR [6]
		Carex bicknellii	51.31	14.79	33.90	SR/CSR [6]
		Carex muhlenbergii	60.01	17.23	22.76	S/CSR [6]
		Carex vulpinoidea	52.98	16.93	30.09	S/CSR [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Coreopsis palmata	71.65	14.96	13.39	S/CS [6]
		Desmodium canadense	47.32	27.26	25.42	S/CSR [6]
		Eleocharis acicularis	0.00	0.00	100.00	R [6]
		Eleocharis obtusa	38.87	23.09	38.04	SR/CSR [6]
		Elymus canadensis	50.03	28.08	21.89	S/CSR [6]
		Eragrostis spectabilis	65.53	14.32	20.15	S/SR [6]
		Eryngium yuccifolium	76.37	23.63	0.00	S/CS [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfb	Michigan LID, 2008	*Eupatorium maculatum*	37.42	44.87	17.71	CS/CSR [6]
		Eupatorium perfoliatum	45.21	41.38	13.42	CS/CSR [6]
		Euphorbia corollata	83.59	6.70	9.70	S [6]
		Euthamia graminifolia	67.32	12.25	20.43	S/SR [6]
		Gentiana andrewsii	34.80	37.68	27.52	CSR [6]
		Geranium maculatum	6.93	51.89	41.18	CR [6]
		Helenium autumnale	85.51	9.87	4.62	S [6]
		Helianthus occidentalis	43.54	37.41	19.06	CS/CSR [6]
		Heliopsis helianthoides	43.54	37.41	19.06	CS/CSR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Juncus tenuis	65.77	6.68	27.55	S/SR [6]
		Juniperus virginiana	95.08	4.92	0.00	S [6]
		Koeleria macrantha	72.85	14.21	12.95	S/CS [6]
		Lespedeza capitata	63.29	16.53	20.18	S/CSR [6]
		Liatris aspera	45.01	20.32	34.67	SR/CSR [6]
		Liatris cylindracea	71.73	13.90	14.37	S/SR [6]
		Lobelia spicata	65.27	4.36	30.37	S/SR [6]
		Lupinus perennis	0.00	59.12	40.88	CR [6]
		Mimulus ringens	17.14	22.28	60.57	R/CSR [6]
		Monarda fistulosa	39.49	26.54	33.97	CSR [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Pinus strobus	92.82	7.18	0.00	S [6]
		Quercus rubra	57.31	32.72	9.97	S/CSR [6]
		Ratibida pinnata	44.10	40.67	15.23	CS/CSR [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
		Schizachyrium scoparium	58.76	15.86	25.37	S/CSR [6]
		Silphium terebinthinaceum	48.94	51.06	0.00	CS [6]
		Solidago juncea	49.96	33.72	16.32	CS/CSR [6]
		Sorghastrum nutans	58.88	23.81	17.31	S/CSR [6]
		Thalictrum dasycarpum	38.01	21.30	40.68	SR/CSR [6]
		Thalictrum dioicum	20.57	16.18	63.25	R/CSR [6]
		Tradescantia ohiensis	0.00	51.21	48.79	CR [6]
		Verbena hastata	52.91	26.32	20.77	S/CSR [6]
		Veronicastrum virginicum	65.40	27.91	6.69	S/CS [6]
		Zizia aurea	31.87	53.32	14.80	C/CSR [6]
		Carex stipata	27.80	15.91	56.29	R/CSR [6]
		Spiraea tomentosa	84.96	4.96	10.08	S [6]
		Calamagrostis canadensis	20.96	34.27	44.77	CR/CSR [8]
		Carex lacustris	15.36	53.08	31.56	C/CSR [8]
		Carex stricta	20.12	36.14	43.74	CR/CSR [8]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfb	Michigan LID, 2008	*Scirpus atrovirens*	12.97	46.34	40.69	CR/CSR [8]
		Scirpus cyperinus	17.90	42.90	39.20	CR/CSR [8]
		Glyceria striata	15.21	34.66	50.13	CR/CSR [8]
	Vermont RGM, 2011	*Betula nigra*	0.00	40.97	59.03	CR [2]
		Clethra alnifolia	57.86	23.56	18.58	S/CSR [2]
		Aronia melanocarpa	69.40	30.60	0.00	S/CS [4]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Diervilla lonicera	76.10	23.90	0.00	S/CS [4]
		Hamamelis virginiana	41.20	40.40	18.30	CS/CSR [4]
		Ilex verticillata	61.30	31.90	6.70	S/CS [4]
		Acer rubrum	36.09	42.62	21.30	CS/CSR [5]
		Alnus rugosa	40.87	39.54	19.59	CS/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Fraxinus pennsylvanica	45.70	44.60	9.70	CS [5]
		Agrostis stolonifera	46.71	11.40	41.89	SR/CSR [6]
		Alchemilla mollis	24.15	60.01	15.84	C/CSR [6]
		Amorpha canescens	60.02	24.04	15.95	S/CSR [6]
		Andropogon gerardii	52.02	24.33	23.66	S/CSR [6]
		Andropogon virginicus	77.51	15.84	6.66	S/CS [6]
		Anemone canadensis	38.11	39.21	22.68	CS/CSR [6]
		Arisaema triphyllum	0.00	69.12	30.88	C/CR [6]
		Aruncus dioicus	3.34	70.58	26.08	C/CR [6]
		Asarum canadensis	0.00	69.93	30.07	C/CR [6]
		Asclepias incarnata	28.26	36.06	35.69	CSR [6]
		Asclepias tuberosa	28.17	30.75	41.08	CSR [6]
		Aster novae-angliae	46.54	18.02	35.44	SR/CSR [6]
		Aster umbellatus	4.36	48.65	46.99	CR [6]
		Athyrium filix-femina	0.00	69.03	30.97	C/CR [6]
		Bouteloua curtipendula	66.01	15.21	18.78	S/SR [6]
		Caltha palustris	0.00	59.13	40.87	CR [6]
		Carex flacca	56.58	33.26	10.16	S/CSR [6]
		Carex vulpinoidea	52.98	16.93	30.09	S/CSR [6]
		Caulophyllum thalictroides	17.73	36.50	45.77	CR/CSR [6]
		Convallaria majalis	14.11	44.90	41.00	CR/CSR [6]
		Desmodium canadense	47.32	27.26	25.42	S/CSR [6]
		Dryopteris filix-mas x marginalis	7.86	70.89	21.25	C/CR [6]
		Epilobium angustifolium	17.10	34.64	48.25	CR/CSR [6]
		Eupatorium coelestinum	69.59	12.45	17.97	S/SR [6]
		Eupatorium maculatum	37.42	44.87	17.71	CS/CSR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfb	Vermont RGM, 2011	Eupatorium perfoliatum	45.21	41.38	13.42	CS/CSR [6]
		Fraxinus americana	53.19	27.10	19.71	S/CSR [6]
		Gentiana andrewsii	34.80	37.68	27.52	CSR [6]
		Helenium autumnale	85.51	9.87	4.62	S [6]
		Heliopsis helianthoides	16.96	45.59	37.45	CR/CSR [6]
		Hydrophyllum virginianum	0.00	56.41	43.59	CR [6]
		Isopyrum biternatum	9.97	18.23	71.80	R/CR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Juniperus virginiana	95.08	4.92	0.00	S [6]
		Lobelia spicata	65.27	4.36	30.37	S/SR [6]
		Matteuccia struthiopteris	0.00	67.80	32.20	C/CR [6]
		Mentha arvensis	7.35	20.40	72.25	R/CR [6]
		Mimulus ringens	17.14	22.28	60.57	R/CSR [6]
		Mitella diphylla	0.00	46.90	53.10	CR [6]
		Onoclea sensibilis	15.16	52.88	31.96	C/CSR [6]
		Osmunda regalis	12.03	84.01	3.96	C [6]
		Ostrya virginiana	53.73	19.18	27.09	S/CSR [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Phlox divaricata	14.40	18.62	66.99	R/CR [6]
		Quercus rubra	57.31	32.72	9.97	S/CSR [6]
		Ratibida pinnata	44.10	40.67	15.23	CS/CSR [6]
		Rudbeckia hirta	69.25	12.23	18.53	S/SR [6]
		Salix purpurea	71.51	17.72	10.77	S/CS [6]
		Salvia verticillata	25.51	52.62	21.87	C/CSR [6]
		Schizachyrium scoparium	58.76	15.86	25.37	S/CSR [6]
		Sorghastrum nutans	58.88	23.81	17.31	S/CSR [6]
		Spirea latifolia	58.16	31.32	10.52	S/CSR [6]
		Tradescantia ohiensis	0.00	51.21	48.79	CR [6]
		Vaccinium corymbosum	63.04	34.65	2.31	S/CS [6]
		Veronicastrum virginicum	65.40	27.91	6.69	S/CS [6]
		Euthamia graminifolia	67.32	12.25	20.43	S/SR [6]
		Iris versicolor	1.96	64.71	33.32	C/CR [8]
	MSM Wiki, 2003	*Betula nigra L.*	0.00	40.97	59.03	CR [2]
		Ilex verticillata	61.30	31.90	6.70	S/CS [4]
		Cornus racemosa Lam.	58.10	24.90	17.00	S/CSR [4]
		Physocarpus opulifolius	52.80	28.40	18.80	S/CSR [4]
		Fraxinus pennsylvanica	45.70	44.60	9.70	CS [5]
		Acer saccharinum L.	42.72	42.50	14.78	CS/CSR [5]
		Celtis occidentalis L.	49.19	37.80	13.00	CS/CSR [5]
		Populus deltoides	43.85	43.91	12.23	CS/CSR [5]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfb	MSM Wiki, 2003	*Populus tremuloides*	58.37	30.23	11.40	S/CSR [5]
		Salix nigra	47.44	27.45	25.11	S/CSR [5]
		Osmunda regalis	12.03	84.01	3.96	C [6]
		Pteridium aquilinum	13.36	80.89	5.75	C [6]
		Typha latifolia	10.25	86.30	3.45	C [6]
		Arisaema triphyllum (L.) Schott	0.00	69.12	30.88	C/CR [6]
		Athyrium filix-femina ssp.	0.00	69.03	30.97	C/CR [6]
		Matteuccia struthiopteris	0.00	67.80	32.20	C/CR [6]
		Sambucus racemosa	10.59	70.63	18.78	C/CR [6]
		Onoclea sensibilis	15.16	52.88	31.96	C/CSR [6]
		Zizia aurea	31.87	53.32	14.80	C/CSR [6]
		Caltha palustris L.	0.00	59.13	40.87	CR [6]
		Tradescantia ohiensis	0.00	51.21	48.79	CR [6]
		Heuchera richardsonii	52.65	46.85	0.50	CS [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Alnus incana ssp. rugosa	35.30	40.12	24.58	CS/CSR [6]
		Amorpha fruticosa L.	39.09	40.38	20.53	CS/CSR [6]
		Anemone canadensis L.	38.11	39.21	22.68	CS/CSR [6]
		Aster puniceus	40.33	35.43	24.24	CS/CSR [6]
		Eupatorium maculatum L.	37.42	44.87	17.71	CS/CSR [6]
		Eupatorium perfoliatum L.	45.21	41.38	13.42	CS/CSR [6]
		Polygonum amphibium	33.51	43.09	23.40	CS/CSR [6]
		Ratibida pinnata	44.10	40.67	15.23	CS/CSR [6]
		Asclepias incarnata L.	28.26	36.06	35.69	CSR [6]
		Asclepias tuberosa L.	28.17	30.75	41.08	CSR [6]
		Chamerion angustifolium ssp.	30.69	39.12	30.19	CSR [6]
		Gentiana andrewsii	34.80	37.68	27.52	CSR [6]
		Helianthus grosseserratus Martens	33.40	37.74	28.87	CSR [6]
		Phalaris arundinacea	35.61	35.72	28.66	CSR [6]
		Viburnum opulus	32.04	38.68	29.28	CSR [6]
		Bidens cernua L.	27.44	25.93	46.62	R/CSR [6]
		Impatiens capensis	21.81	31.49	46.70	R/CSR [6]
		Lysimachia thyrsiflora	15.19	32.49	52.31	R/CSR [6]
		Equisetum fluviatile L.	84.23	15.77	0.00	S [6]
		Helenium autumnale L.	85.51	9.87	4.62	S [6]
		Carex aquatilis Wahlenb.	65.29	31.14	3.57	S/CS [6]
		Eryngium yuccifolium Michx.	76.37	23.63	0.00	S/CS [6]
		Veronicastrum virginicum	65.40	27.91	6.69	S/CS [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfb	MSM Wiki, 2003	*Andropogon gerardii Vitman*	52.02	24.33	23.66	S/CSR [6]
		Carex vulpinoidea Michx.	52.98	16.93	30.09	S/CSR [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Schizachyrium scoparium	58.76	15.86	25.37	S/CSR [6]
		Sorghastrum nutans	58.88	23.81	17.31	S/CSR [6]
		Verbena hastata	52.91	26.32	20.77	S/CSR [6]
		Acorus calamus L.	61.14	5.83	33.03	S/SR [6]
		Artemisia ludoviciana Nutt.	65.09	12.54	22.37	S/SR [6]
		Euthamia graminifolia	67.32	12.25	20.43	S/SR [6]
		Lythrum salicaria	65.97	15.88	18.14	S/SR [6]
		Galium boreale	50.66	5.38	43.96	SR [6]
		Aster pilosus	36.46	21.76	41.78	SR/CSR [6]
		Bromus ciliatus L.	48.80	11.83	39.37	SR/CSR [6]
		Eleocharis obtusa (Willd.)	38.87	23.09	38.04	SR/CSR [6]
		Scutellaria lateriflora	39.58	13.73	46.69	SR/CSR [6]
		Thalictrum dasycarpum	38.01	21.30	40.68	SR/CSR [6]
		Carex stipata Muhl.	27.80	15.91	56.29	R/CSR [6]
		Iris versicolor	1.96	64.71	33.32	C/CR [8]
		Carex lacustris Willd.	15.36	53.08	31.56	C/CSR [8]
		Alisma trivale	0.00	57.74	42.26	CR [8]
		Glyceria grandis	8.57	42.11	49.32	CR [8]
		Calamagrostis canadensis	20.96	34.27	44.77	CR/CSR [8]
		Carex stricta Lam.	20.12	36.14	43.74	CR/CSR [8]
		Glyceria striata	15.21	34.66	50.13	CR/CSR [8]
		Scirpus atrovirens	12.97	46.34	40.69	CR/CSR [8]
		Scirpus cyperinus	17.90	42.90	39.20	CR/CSR [8]
		Monarda fistulosa	39.49	26.54	33.97	CSR [2]
	PA BMP, 2006	*Amelanchier arborea*	51.36	20.74	27.90	S/CSR [1]
		Carya glabra	42.97	31.58	25.45	CSR [1]
		Cornus florida	41.14	32.26	26.60	CSR [1]
		Quercus alba	46.66	34.83	18.51	CS/CSR [1]
		Betula nigra	0.00	40.97	59.03	CR [2]
		Clethra alnifolia	57.86	23.56	18.58	S/CSR [2]
		Magnolia virginiana	55.47	44.53	0.00	CS [2]
		Quercus coccinea	60.50	38.10	1.30	CS [2]
		Aronia melanocarpa	69.40	30.60	0.00	S/CS [4]
		Cornus racemosa	58.10	24.90	17.00	S/CSR [4]
		Cornus sericia	71.20	28.50	0.40	S/CS [4]
		Hamamelis virginiana	41.20	40.40	18.30	CS/CSR [4]
		Ilex verticillata	61.30	31.90	6.70	S/CS [4]

Table S4 Continued

Climate Zone	**Desing Manual**	**Plant Species**	**%S**	**%C**	**%R**	**CSR [ref]**
Dfb	PA BMP, 2006	*Acer rubrum*	36.09	42.62	21.30	CS/CSR [5]
		Alnus Rugosa	40.87	39.54	19.59	CS/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Fagus grandifolia	29.64	37.86	32.50	CSR [5]
		Fraxinus pennsylvanica	45.70	44.60	9.70	CS [5]
		Populus deltoides	43.85	43.91	12.23	CS/CSR [5]
		Populus grandidentata	39.16	39.11	21.73	CS/CSR [5]
		Quercus rubra	34.67	45.81	19.51	CS/CSR [5]
		Salix nigra	47.44	27.45	25.11	S/CSR [5]
		Tilia americana	14.96	52.91	32.14	C/CSR [5]
		Viburnum dentatum	14.96	52.91	32.14	C/CSR [5]
		Dennstaedtia punctilobula	31.47	22.71	45.81	R/CSR [6]
		Onoclea sensibilis	15.16	52.88	31.96	C/CSR [6]
		Alisma plantago-aquatica	0.00	71.18	28.82	C/CR [6]
		Asclepias incarnata	28.26	36.06	35.69	CSR [6]
		Asclepias syriaca	17.32	63.44	19.24	C/CSR [6]
		Asclepias tuberosa	28.17	30.75	41.08	CSR [6]
		Aster novae-angliae	46.54	18.02	35.44	SR/CSR [6]
		Eupatorium maculatum	37.42	44.87	17.71	CS/CSR [6]
		Eupatorium perfoliatum	45.21	41.38	13.42	CS/CSR [6]
		Mimulus ringens	17.14	22.28	60.57	R/CSR [6]
		Panicum virgatum	57.06	17.04	25.90	S/CSR [6]
		Sorghastrum nutans	58.88	23.81	17.31	S/CSR [6]
		Schizachyrium scoparium	58.76	15.86	25.37	S/CSR [6]
		Carex pennsylvanica	35.00	15.00	50.03	SR/CSR [6]
		Carex volpinoidea	52.98	16.93	30.09	S/CSR [6]
		Juncus effusus	61.52	38.48	0.00	CS [6]
		Typha angustifolia	34.32	65.68	0.00	C/CS [6]
		Typha latifolia	10.25	86.30	3.45	C [6]
		Rhus glabra	45.27	44.62	10.10	CS [6]
		Rubus allegheniensis	49.23	27.97	22.80	S/CSR [6]
		Vaccinium corymbosum	63.04	34.65	2.31	S/CS [6]
		Acer negundo	23.31	50.38	26.31	C/CSR [6]
		Acer saccharinum	56.44	27.13	16.43	S/CSR [6]
		Betula populifolia	68.27	15.93	15.80	S/CS [6]
		Fraxinus americana	53.19	27.10	19.71	S/CSR [6]
		Juniperus virginiana	95.08	4.92	0.00	S [6]
		Pinus rigida	92.79	7.21	0.00	S [6]
		Pinus strobus	92.82	7.18	0.00	S [6]
		Populus tremuloides	56.76	25.53	17.71	S/CSR [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dfb	PA BMP, 2006	*Prunus serotina*	49.74	39.54	10.71	CS [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Calamagrostis canadensis	20.96	34.27	44.77	CR/CSR [8]
		Carex scoparia	22.92	25.58	51.50	R/CSR [8]
		Carex stricta	20.12	36.14	43.74	CR/CSR [8]
		Glyceria striata	15.21	34.66	50.13	CR/CSR [8]
		Ilex opaca	1.96	64.71	33.32	C/CR [8]
		Iris versicolor	1.96	64.71	33.32	C/CR [8]
		Scirpus cyperinus	17.90	42.90	39.20	CR/CSR [8]
Dsb	Boise SW Resource Guide, 2000	*Populus fremontii*	42.17	49.88	7.95	CS [7]
		Prunus virginiana	52.32	20.86	26.82	S/CSR [1]
		Betula occidentalis	34.65	47.30	18.05	CS/CSR [3]
		Amelanchier alnifolia	68.10	21.80	10.10	S/CS [4]
		Cornus sericea	71.20	28.50	0.40	S/CS [4]
		Lonicera maackii	62.60	25.70	11.70	S/CS [4]
		Potentilla fruticosa	83.20	5.90	10.90	S [4]
		Rhus aromatica	80.90	19.10	0.00	S/CS [4]
		Betula papyifera	44.72	37.52	17.77	CS/CSR [5]
		Celtis occidentalis	49.19	37.80	13.00	CS/CSR [5]
		Fraxinus pennsylvannica	45.70	44.60	9.70	CS [5]
		Quercus macrocarpa	40.88	49.69	9.43	CS [5]
		Salix nigra	47.44	27.45	25.11	S/CSR [5]
		Tilia americana	14.96	52.91	32.14	C/CSR [5]
		Alnus rubra	36.09	42.62	21.30	CS/CSR [5]
		Acer negundo	23.31	50.38	26.31	C/CSR [6]
		Alnus incana spp. tenuifolia	35.30	40.12	24.58	CS/CSR [6]
		Bromus erectus	64.39	11.81	23.80	S/SR [6]
		Bromus inermis	38.80	37.28	23.93	CS/CSR [6]
		Caragana arborescens	52.59	19.66	27.74	S/CSR [6]
		Carex aquatilis	65.29	31.14	3.57	S/CS [6]
		Cercis canadensis	71.98	12.49	15.53	S/SR [6]
		Cotoneaster integerrimus	68.17	16.95	14.88	S/CS [6]
		Dactylis glomerata	27.94	43.70	28.36	CSR [6]
		Deschampsia cespitosa	66.47	13.46	20.07	S/SR [6]
		Eleocharis palustris	0.00	45.68	54.32	CR [6]
		Festuca arundinacea	24.01	38.40	37.59	CR/CSR [6]
		Festuca ovina	73.32	1.91	24.77	S/SR [6]
		Festuca rubra	35.70	10.41	53.89	SR [6]
		Juncus tenuis	65.77	6.68	27.55	S/SR [6]
		Juniperus virginiana	95.08	4.92	0.00	S [6]

Table S4 Continued

Climate Zone	Desing Manual	Plant Species	%S	%C	%R	CSR [ref]
Dsb	Boise SW Resource Guide, 2000	*Pascopyrum smithii*	67.23	22.27	10.50	S/CS [6]
		Phalaris arundinacea	35.61	35.72	28.66	CSR [6]
		Phleum pratensis	30.95	26.86	42.19	CSR [6]
		Pinus mugo	97.87	2.13	0.00	S [6]
		Pinus ponderosa	91.00	9.00	0.00	S [6]
		Poa pratensis	0.00	12.36	87.64	R [6]
		Populus tremuloides	56.76	25.53	17.71	S/CSR [6]
		Rhus glabra	45.27	44.62	10.10	CS [6]
		Rhus typhina	23.59	67.40	9.01	C/CS [6]
		Rosa woodsii	63.44	18.42	18.14	S/CSR [6]
		Salix alba	63.35	25.34	11.31	S/CS [6]
		Sambucus racemosa	10.59	70.63	18.78	C/CR [6]
		Scirpus maritimus	48.02	38.42	13.55	CS/CSR [6]
		Sorbus aucuparia	39.29	53.01	7.71	CS [6]
		Syringa vulgaris	50.83	36.83	12.34	CS/CSR [6]
		Tilia cordata	44.64	40.78	14.58	CS/CSR [6]
		Typha latifolia	10.25	86.30	3.45	C [6]
		Verbena hastata	52.91	26.32	20.77	S/CSR [6]
		Calamagrostis canadensis	20.96	34.27	44.77	CR/CSR [8]
		Carex utriculata	13.51	51.73	34.75	CR/CSR [8]
		Glyceria striata	15.21	34.66	50.13	CR/CSR [8]

[1] Brym et al., 2011 [2] Field Measurements [3] John et al., 2018 [4] Kalenius 2020 [5] Loranger and Shipley 2010
[6] Pierce et al., 2016 [7] Aparecido et al., 2020 [8] Vernescu and Ryser 2009 [9] Fletcher et al. 2018

Table S5: Amount of Evapotranspiration Stimulated per mm Irrigation by Scenario and Climate

Climate Zone	**Scenario**	**Amount of ET[1] Stimulated per mm Supplemental Irrigation (mm)**
Bsk	S1w	0.221048833
	S1h	0.162933235
	S2w	0.22656967
	S2h	0.180254949
	S3w	0.249126411
	S3h	0.173245396
Bwh	S1w	1.03926335
	S1h	1.310265507
	S2w	1.004367072
	S2h	1.398131372
	S3w	1.026812001
	S3h	0.86703791
Cfa	All Scenarios	--
Csa	S1w	0.226393525
	S1h	--
	S2w	0.237435192
	S2h	--
	S3w	0.239364398
	S3h	0.195022782
Csb	S1w	0.085749301
	S1h	--
	S2w	0.105952924
	S2h	--
	S3w	0.258900677
	S3h	--
Dfa	All Scenarios	--
Dfb	All Scenarios	--
Dsb	S1w	0.261208623
	S1h	--
	S2w	0.224163587
	S2h	--
	S3w	0.256750132
	S3h	0.373399764

1: ET = Evapotranspiration

Scenarios with -- indicate that no supplemental irrigation water was applied

Table S6: Pre-Urban I:H Ratios for each Climate Zone

Climate Zone	MAR inches	Pre-Urban Forest Fraction	Pre-Urban I:H Ratio	Scenario	Simulated I:H Ratio Not Irrigated (Range)	Simulated I:H Ratio, Irrigated (Range)
Bsk	15.29	0.030	0.195	S1w	4.37 - 12.48	2.64 - 7.52
				S1h	5.23 - 13.56	5.21 - 13.12
				S2w	4.39 - 12.48	2.66 - 7.53
				S2h	5.23 - 13.83	5.22 - 13.18
				S3w	3.58 - 9.71	1.78 - 5.83
				S3h	4.49 - 12.16	4.22 - 10.79
Bwh	6.77	0.001	0.055	S1w	1.55 - 4.15	0.78 - 3.24
				S1h	2.31 - 5.53	1.89 - 5.23
				S2w	1.34 - 4.22	0.59 - 3.07
				S2h	2.00 - 5.33	1.63 - 5.12
				S3w	1.17 - 3.22	0.54 - 2.32
				S3h	1.73 - 4.56	1.61 - 4.27
Cfa	49.38	0.245	0.802	S1w	14.88 - 26.60	15.28 - 26.98
				S1h	14.88 - 27.73	15.28 - 27.70
				S2w	14.88 - 26.60	15.28 - 26.98
				S2h	16.50 - 27.73	17.03 - 27.70
				S3w	10.47 - 19.33	10.78 - 19.56
				S3h	13.25 - 22.70	13.60 - 22.75
Csa	26.12	0.059	0.416	S1w	2.52 - 8.21	2.11 - 7.12
				S1h	2.92 - 9.71	2.74 - 9.69
				S2w	2.53 - 8.32	2.25 - 7.28
				S2h	2.93 - 9.71	2.91 - 9.70
				S3w	1.97 - 6.52	1.51 - 4.97
				S3h	2.45 - 7.86	2.31 - 7.21
Csb	64.51	0.695	0.705	S1w	25.88 - 43.61	24.99 - 43.18
				S1h	29.27 - 53.18	29.20 - 52.92
				S2w	25.83 - 43.69	24.75 - 43.25
				S2h	29.06 - 53.33	29.20 - 52.92
				S3w	19.17 - 35.79	17.74 - 32.37
				S3h	24.02 - 44.59	23.78 - 44.34
Dfa	34.35	0.082	0.592	S1w	27.20 - 40.72	27.28 - 41.55
				S1h	30.62 - 43.17	30.51 - 43.86
				S2w	27.20 - 40.72	27.28 - 41.55
				S2h	30.62 - 43.17	30.51 - 43.86
				S3w	19.07 - 28.76	19.07 - 29.47
				S3h	23.99 - 34.03	23.86 - 34.83
Dfb	34.81	0.295	0.482	S1w	37.6 - 63.29	37.85 - 62.68
				S1h	43.27 - 75.37	43.32 - 74.65
				S2w	37.60 - 63.29	37.85 - 62.68
				S2h	45.82 - 75.37	45.90 - 74.65
				S3w	26.65 - 44.25	26.70 - 43.75
				S3h	36.12 - 58.31	36.23 - 57.98
Dsb	32.33	0.363	0.404	S1w	2.61 - 7.06	2.19 - 4.73
				S1h	2.96 - 8.80	2.61 - 8.78
				S2w	2.63 - 7.04	2.20 - 4.75
				S2h	4.05 - 8.95	4.05 - 8.78
				S3w	1.82 - 5.44	1.44 - 3.24
				S3h	3.12 - 7.64	3.13 - 6.24