Estimating Annual Water Demands from Irrigation Flow Rates

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Abstract.

Landscape design is widely recognized as influencing sites' water demands. While continually developing, "green" efficiency programs, standards and codes now often include various design criteria for new landscapes with a goal of promoting water efficiency. These are typically one of two types, water budgeting-based or founded on restrictions on plantings. Both of these have pros, but also significant cons, and are not easily worked into a framework that relies on auditors with limited site visit time and lack of expertise in evaluating plantings. Ideally a metric that integrates aspects of landscape design in an easy, robust, repeatable manner that is linked to water use is needed.

In some startling findings, the Southern Nevada Water Authority (SNWA) demonstrates that for single-family home sites, all of these considerations can be considered summarized within a single metric that expresses and, even predicts within a range, likely annual irrigation use. Totalizing flow rates of all stations and normalizing this and comparing this to submeter usage reveals this relationship in the Southwest.

Even more surprising, the relationship holds nationally when data from the Residential End Uses of Water Version 2 is examined. For a recent specification, RESNET's $\mathrm{HERS}_{\mathrm{H2O}}$ water efficiency rating, *this has been developed and introduced as an optional method for demonstrating outdoor efficient design and is a points opportunity in that standard. For this purpose, the measure is area normalized and defined as the Residential Irrigation Capacity Index (RICI) where each change in RICI equates to a 10% change in outdoor use relative to a baseline condition.*

In this presentation, the author explains the development of this new metric and its advantages in rating the water efficiency of new homes' landscape designs and irrigation systemsfrom a water conservation perspective.

Keywords.

Turf/Landscape (Residential), Water Manager, Water Provider, Water Conservation, Design, Auditing, Standards, Water Budget, RICI

Introduction.

There are, at present, several organizations working on "green" (high-efficiency / better for the environment / healthier) standards, specifications, and code language for new buildings and development. One of these is the Residential Energy Services Network (RESNET), a 501 (C)(3) membership corporation that makes standards relating to building efficiency and associated rating standards. It is probably best known for its core Home Energy Rating Standards (HERS). RESNET is in the process of developing a water component to its ratings in partnership with the International Code Council (ICC). This was known as the Water Efficiency Rating Index (WERI) though recently RESNET has named it $HERS_{H2O}$ which serves to emphasize that the index is designed to build on and work in concert with the HERS index system (RESNET News, 2018). It also helped to practically differentiate it from another similarly named standard that has been developed. In addition to RESNET's partner, the ICC, major contributors to the effort include the Natural Resources Defense Council (NRDC), EPA's WaterSense Program, and KB Homes. While the focus of this manuscript is on the Residential Irrigation Capacity Index (RICI), and RICI can standalone as a distinct topic from $HERS_{H2O}$, there is no denying that the index nature of the rating provided the constraints and the necessity for RICI's invention which was also reliant on availability and analyses of large sets of field data by others, including the author.

The need for a new way of estimating future irrigation demand when auditing a new home.

First, an understanding of part of $HERS_{H2O}$ is required. $HERS_{H2O}$ is a true mathematical index with a "starting point" of 100, which is representative of a reference home's 2006 water usage, where the reference home is a theoretical similar construct. Decreases in water use are directly represented by the score. For example, a home with a $HERS_{H2O}$ score of 60 uses 40% less water that the 2006 reference home. It should be noted that the reference home and the rated home have similar assumptions (i.e. for example, a 2500 square foot home on a 4200 square foot results in the reference home having the same considerations). The $HERS_{H2O}$ model in entirety is sophisticated relative to the more normative manner typically used in efficiency standards and specifications that are intended to improve water efficiency in new buildings. While an in-depth examination of the functions of the model is beyond the scope of this manuscript, looking at some excerpts is necessary to understand how and why the Residential Irrigation Capacity Index (RICI) was developed.

Here are excerpts of Sections 3.0 and 5.0 of the RESNET $HERS_{H2O}$ Technical Guidelines (RESNET, 2018) pertaining to calculations of outdoor use:

> **3.0 Determining the Outdoor Reference Home Annual Water Use** (in thousands of gallons per year)**.** The reference home outdoor annual water use shall be calculated using the following two equations
>
> *If the rated home has a netET of less than 12 inches/year* ***OR*** *the rated home has an automatic irrigation system, use Equation 1.*
>
> Equation 1: $\left[\frac{exp(A)}{1 + exp(A)}\right] * 1.18086 * [2.0341 * netET^{0.7154} * Ref\_Irr\_Area^{0.6227} + 0.5756 * ind\_Pool * netET]$
>
> *If the rated home has a netET of greater than 12 inches/year* ***AND*** *the rated home does NOT have an automatic irrigation system, use Equation 2.*
>
> Equation 2: $\left[\frac{\exp(\mathrm{B})}{1 + \exp(\mathrm{B})}\right] * 1.22257 * [1.4233 + 0.6311 * \mathrm{netET} + 0.9376 * \mathrm{Ref\_Irr\_Area}]$

Either equation shall be constrained as follows:

IF

Rate_Irr_Area < Ref_Irr_Area

THEN

Ref_Out= equation 1 or 2 (as identified above) equation 1 (Using Rate_Irr_Area and pool indicator=0) equation 1 (with Ref_Irr_Area and pool indicator=0)

AND

Outdoor Reference Home GPD shall never be lower than equation 2

Where:

3.1 Reference Irrigated Area. Reference irrigated area shall be calculated as:

IF

the lot size of the rated home is < 7,000 ft²

THEN

$$Ref\_Irr\_Area = \text{Lot\_Area} * (0.002479 * \text{Lot\_Area}\text{^}0.6157)$$

IF

The lot size of the rated home is ≥7,000 ft² Then

*Ref_Irr_Area = lot_area * 0.577*

Where:

Ref_Irr_Area= The size of the landscape that receives supplemental water in the reference home

Lot_Area= The size of the lot on which the rated home is being constructed

And,

5.0 Determining Outdoor Rated Home GPD. The rated home outdoor GPD shall be calculated as:

If the rated home has an automatic irrigation system

$$\left[\frac{exp(A)}{1 + exp(A)}\right] * 1.18086 * \left[2.0341 * netET^{0.7154} * Rate_{Irr_{Area}}{}^{0.6227} + 0.5756 * ind_{Pool} * netET\right]$$

Constrained such that:

Outdoor Rated Home GPD shall never be lower than

$$\left[\frac{\text{exp(B)}}{1 + \text{exp(B)}}\right] * 1.22257 * [1.4233 + 0.6311 * \text{netET} + 0.9376 * \text{Rate\_Irr\_Area}]$$

Where:
Exp(A)= exponent of [1.4416 + 0.5069 * (Rate_Irr_Area/1,000)]
Exp(B)= exponent of [0.6911 + 0.00301 * netET * (Rate_Irr_Area/1,000)]
Irr_Area= The size of the landscape that might receive supplemental water in the rated home
netET= The annual historic sum of mean reference evapotranspiration minus the mean precipitation for all months that evapotranspiration exceeds precipitation
ind_Pool= Indicator representing the presence or absence of a swimming pool

Ref_Irr_Area= The size of the irrigated area in the reference home, calculated in accordance with section 3.1
Rate_Irr_Area= The size of the irrigated area in the rated home

(Though somewhat different from the expressions under consideration at the time the early draft standard was first presented to the RESNET Outdoor Subcommittee, the currently available version on RESNET's web are restated here to avoid causing confusion.)

While there are several assumptions that could be discussed about the calculations, the RESNET Outdoor Subcommittee which was made up of several stakeholder parties, including it should be noted, the IA, came to focus on what variables were important in the equations predicting outdoor use. In brief, the model treats outdoor use as a function of whether or not an automated system is installed, Net ET, irrigated area, and pool area (if a pool is installed at the time of construction, a rare occurrence).

No one on the Outdoor Subcommittee felt such a narrow focus was sufficient to estimate water use in irrigated landscapes. Anyone that has taken the IA's Certified Landscape Auditor course or even just informally compared use with plant type immediately recognizes that the plantings and irrigation system absolutely impact a site's water use. Landscape design, including irrigation was missing from the considerations.

While a number of creative ways to address irrigation and landscape design have been developed for various specifications and, in some places, these have even been codified, the approaches tend to fall into one of two major categories:

- The site is subjected to some kind of landscape water budget which, at least in theory, helps drive design decisions about features, plantings, and irrigation towards reducing water use relative to what would have been normally done.

OR

- The site is subjected to limitations on certain types of high water use plantings and/or other high-volume irrigation or features. In the case of plantings, ornamental turfgrass is typically at least one of the plantings that is restricted in use. Savings result because past development norms emphasized these higher use areas of plantings, features, etc.

In an ideal world, these alternatives should result in similar savings if proper care is taken in developing them. In practice, most green industry and product trade associations tend to support the budget-based approach while most governmental agencies (that are trying to conserve water) tend to favor the planting restrictions or budget-based with some modifications that act as a backstop to maintain integrity of the statute (i.e. in reality, a less explicit restriction).

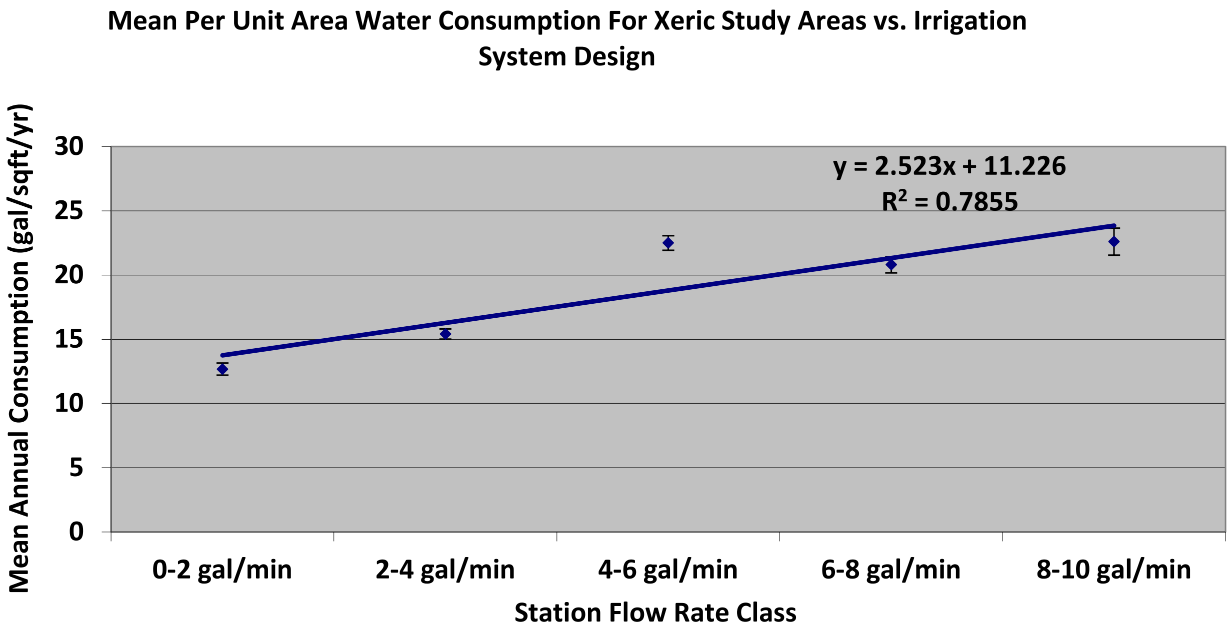
The Outdoor Subcommittee began to consider landscape design but was confronted with some difficult challenges:

- The HERS auditors are not landscape specialists and would not have the necessary knowledge of plant water use and site characteristics to do a budget.
- Even if they were trained in this, there really isn't time to do a budget in the time allotted for audits.
- Turf area provisions work but they are unpopular and putting them into the standard would draw significant opposition from the landscape industry and trade associations.
- While available residual area to landscape around the house can be typically broken into rectangular shapes for area size estimation, the landscape plantings themselves are often non-standard in shape. While this non-orderly arrangement is no doubt more natural appearing than totally uniformly-spaced plantings, it would translate into lots of area estimation work.
- Commonly the plantings are one of the last things installed. This presents a significant practical barrier to implementing either of the archetypical paths.

The Subcommittee recognized that builders understandably want relatively new, attractive, fresh plantings to accompany their product from a customer preference and relatively little leaf litter. Where builder provided irrigation systems typically are provided, these are often installed in advance of the plantings. The group considered how this status and these challenges could be overcome and landscape and irrigation design could be incorporated into $HERS_{H2O}$.

Research to the rescue.

From the mid-1990s to the early 2000s, SNWA ran a research study (Sovocool and Morgan, 2005) that involved submetering discrete areas of landscaping for purposes of quantifying per unit area application of water volumes, among other things. While the focus of that research was confirming and quantifying savings of water efficient landscaping, the author noted, first informally, that annual per unit area use through the submeter could often within a range, be approximated if one simply looked at the average irrigation station flow rates. An example from one of the manuscripts associated with that work (Sovocool and Rosales, 2001), in this case for xeric areas only, appears below:

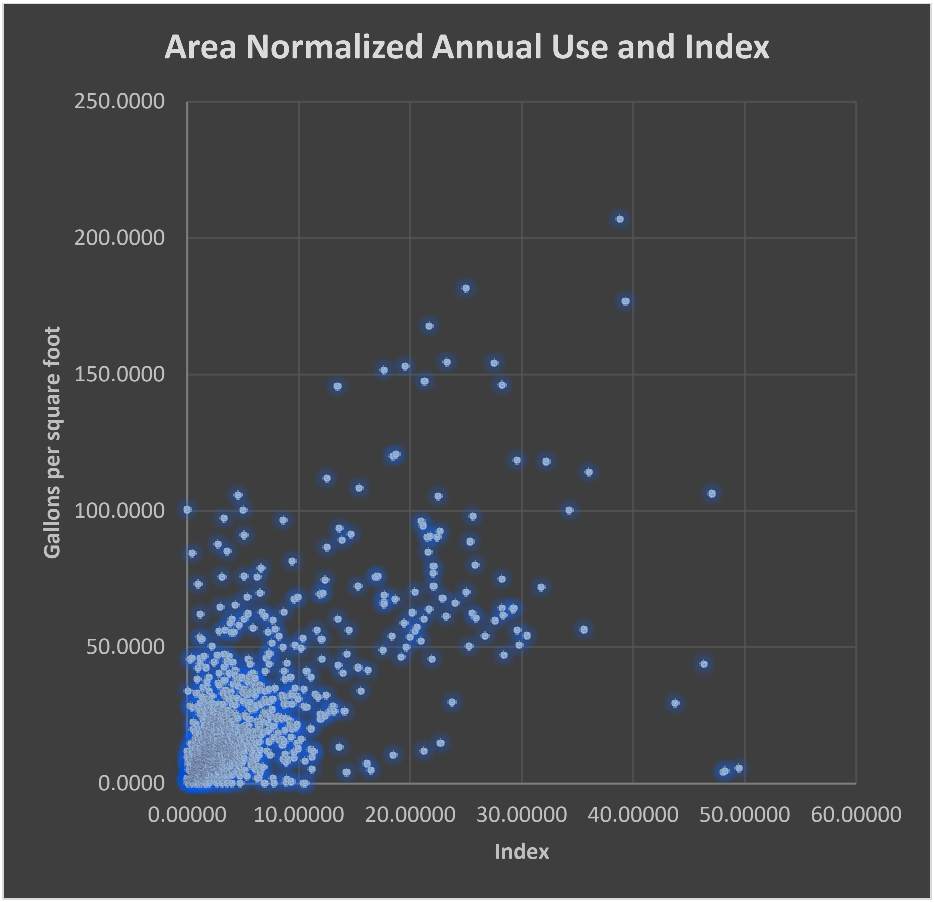


While xeric application volume are is best explained with multiple regression, the graphic demonstrates that annual usage on a per square foot basis tended to increase and was correlated, with increasing station flow rates in the monitored areas.

The finding was significant enough that it was incorporated into the final report linear regression model that quantified known sources of variability in xeric areas' use (Sovocool and Morgan, 2005). The correlation was scientifically quantifiable, interesting, and helped to inform SNWA about how savings would vary for more lush landscaping with lots of emitters. Beyond this though, nothing further was done with the finding for many years with the author assuming it was interesting nuance probably confined to the Southwest.

During the discussions of incorporating design into $HERS_{H2O}$ by the Outdoor Subcommittee, the research SNWA had done, including the observation that use could be estimated by station flow rates came to light. The author and the chair of the Subcommittee, Doug Bennett, decided to further explore the phenomenon as an avenue for overcoming the identified challenges.

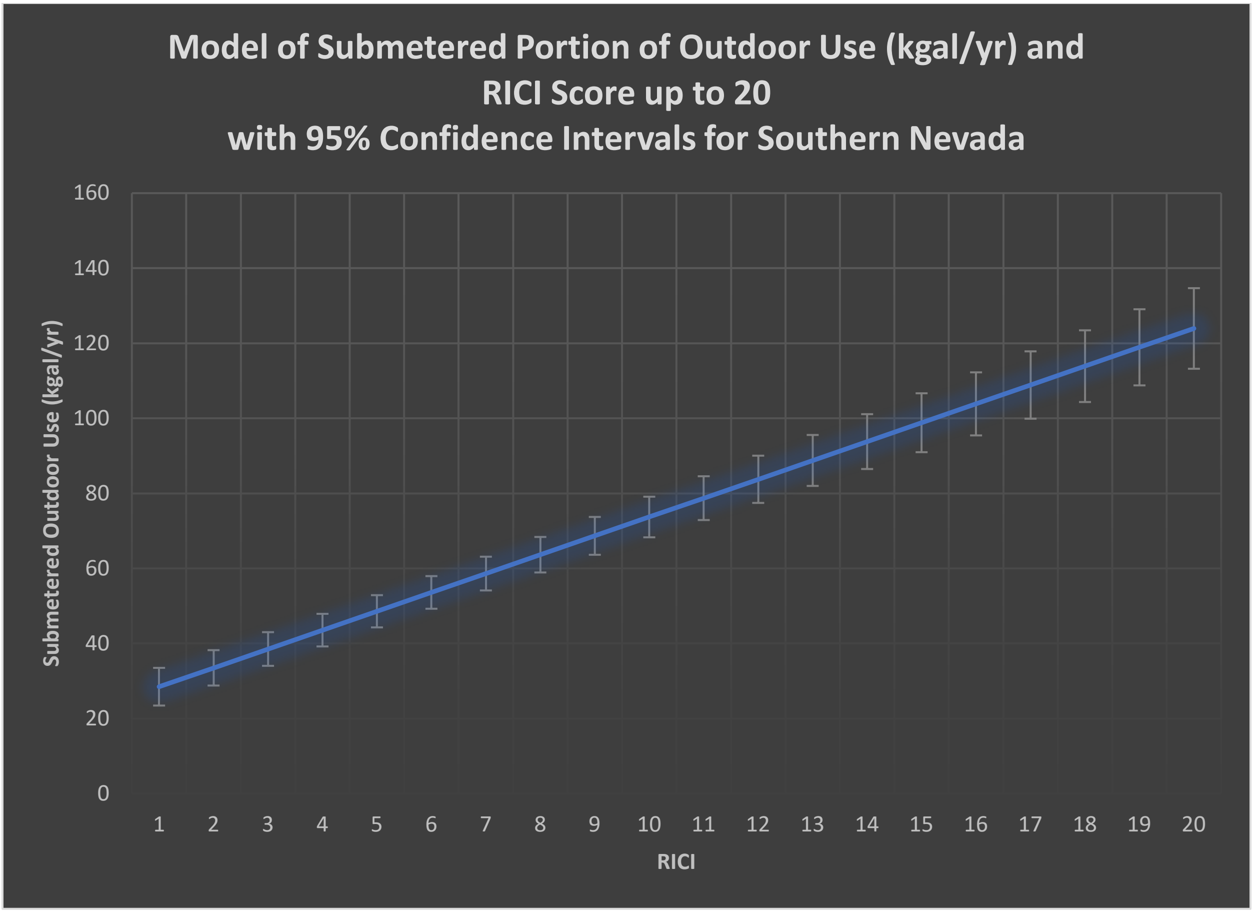
The next logical analyses were to examine larger datasets for all types of landscaping to see if this trend endured or was only landscape-type specific or a local phenomenon. It was realized that some kind of index needed to be created to accomplish this. A scatterplot exploring correlation between area normalized summed flow rates (i.e. the Index) and annual use for 1211 data points across all local landscape types was developed and is shown below.



A relationship appeared to exist, though above an index value of 20 the pattern looked more random. A regression summary shows that a fitted line would have a correlation coefficient of .410 for this data. That it wasn't a near fit was not surprising as there are numerous variables that impact outdoor irrigation. What was surprising was how strong the relationship is to this one variable (t=29.00; p<000001). Within a range, the concept of using an irrigation capacity based-index to approximate use appeared plausible.

Invention of the Residential Irrigation Capacity Index (RICI).

This finding was reasonable enough that the author formulated what he called a Residential Irrigation Capacity Index or, "RICI". He defined this, as the totalized flow rates in gpm, from discrete flow rate field measures of each irrigation station installed, divided by the area served by these stations (i.e. irrigated area) times 1000. While defining RICI as an independent variable is a simplification of reality, for purposes of understanding its use, this is a helpful designation. Annual irrigation, that is water application, to that irrigated area in gallons per year is then the dependent variable. For the discretely metered landscapes in southern Nevada, this graphic demonstrates the model relationship between RICI and submetered use for RICI values of less than 20, of which the great preponderance of landscapes fell and over which the relationship is linear:



In southern Nevada a one unit change in RICI, above, is equivalent to 10.6% change in outdoor irrigation. Still, these were just local findings for southern Nevada.

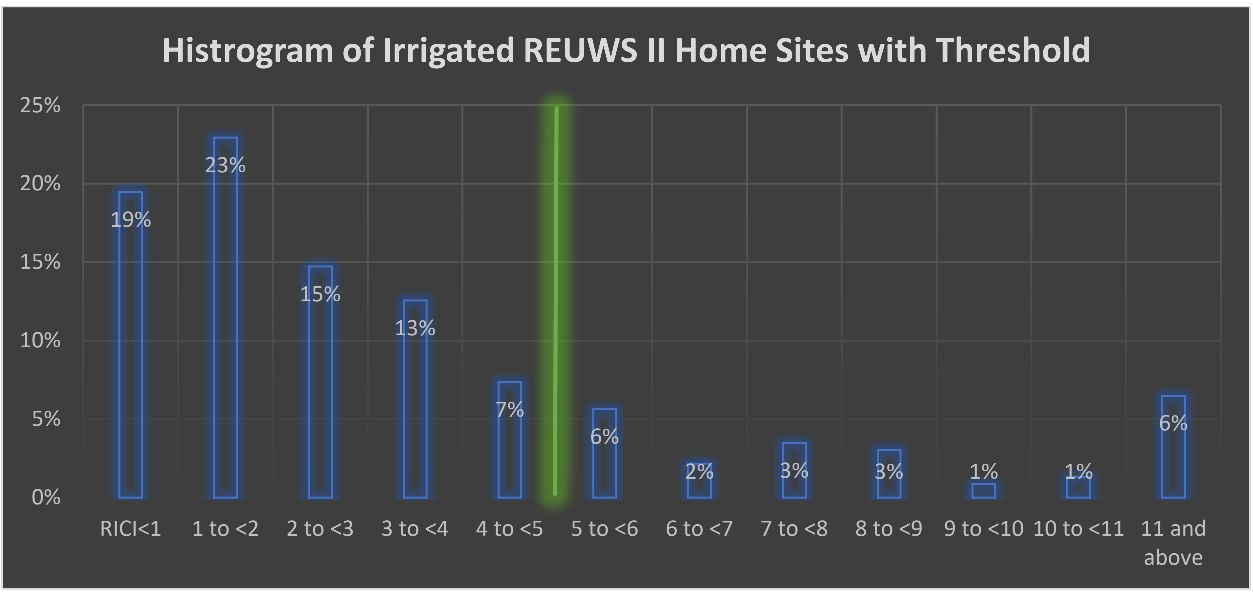
Simultaneously though, the EPA under an effort being led by Jonah Schein, was reviewing outdoor irrigation use as they looked at the same challenges. EPA was on the Outdoor Subcommittee and a major partner in developing $HERS_{H2O}$ and the supporting equations and calculation tools. Specifically, they were utilizing trace flow records and other data that were collected and used in the Residential End Uses of Water Study, Version 2 (DeOreo et. al., 2016), abbreviated as REUWS II hereafter. Trace flow records are characterized as having very high-resolution use data, here having and interval of 10s between reads. In REUWS II the trace flow data was used to characterize and quantify how water was used at homes, both indoors and outdoors. EPA queried all homes with automated irrigation and recorded irrigation events and then proceeded to assemble the flow rates data by assuming that flow values within 15% of one another were from the same irrigation zone. Informed of SNWA's analyses, they compiled the flow rates data per property and used the irrigated area values as determined in the REUWS II research to calculate RICI in an analogous manner to SNWA.

The similarities in the outcomes were impressive. Not only did the distributions appear highly similar, the statistics appeared to align as well as is briefly summarized below:

Analytical Similarities between Local and Nationwide Findings Relating to RICI

SNWA service area (local to southern Nevada using submeter data)	EPA (using nationwide REUWS II data and trace flow data)
Distribution clumped towards low values end.	Distribution clumped towards low values end.
Average RICI = 4.97	Average RICI = 4.90
If average assumed as baseline threshold, 76% of homes would make threshold (i.e. They have RICI scores lower than this.).	If average assumed as baseline threshold, 73% of homes would make threshold (i.e. They have RICI scores lower than this.).

Based on the similarity in findings, the EPA provided their RICI values from the national REUWS II data set to the author and they had a dialog about whether RICI could successfully meet the need and at what level a threshold RICI should be set. An analysis of a histogram of the RICI values and the average RICI score above led them to suggest a baseline RICI score of 5:



EPA felt a slight conservative rounding down of the expected yield from what SNWA observed was in order so a 10% reduction in outdoor use was to be assumed for each one-unit reduction in RICI score that a builder achieved. EPA also felt most comfortable with treating RICI as an option that a builder could turn on or off given it is a truly new approach to estimating future outdoor irrigation volumes. The author concurred as he agreed it's important to evaluate a new metric such as RICI carefully. The only practical way to see how it works is to have builders try it out and generate sufficient sample for analyses. Starting with making it optional essentially eliminates the risk to builders of RICI causing harm and thus makes it an enticing option to consider.

SNWA and EPA brought the concept to the Outdoor subcommittee and it was unanimously endorsed as the ideal solution to the challenges identified. It ultimately went into, and has remained contained within, the version of $HERS_{H2O}$ current as of this writing (RESNET, 2018). The metric has been included as an option in the standard and is mathematically incorporated into associated calculation sheets. It appears formalized in $HERS_{H2O}$ as:

5.2 Residential Irrigation Capacity Index (RICI). In rated homes where documentation is provided, a RICI may be calculated as

$$RICI\_rat = \frac{sum\ of\ flow\ (gpm)\ of\ all\ irrigation\ valves}{ft^2\ irrigated\ area}\ X\ 1{,}000$$

5.2.1 Applying RICI. A rated home where documentation for a RICI is provided may adjust the portion of water use associated with irrigation (less the water use associated with pools) in the rated home's outdoor gpd by 10% for every point from a baseline RICI (RICI_ref) of 5.

The selected RICI threshold of 5 means that nationally the majority of homes (77%) would be expected to be advantaged by RICI and that is only if they installed landscaping and irrigation systems as they have in the past. It is to be expected that a higher percentage would be below 5 given several parts of the country have in place some kind of provisions intended to promote more sustainable landscape installations by builders. Finally it should be again noted that if a builder was not going to be advantaged by using RICI, then they would simply forgo the option to apply it.

Measuring the Residential Irrigation Capacity Index (RICI).

Determining a RICI score is easy and requires minimal training and field supplies.

1. **Determine the installed irrigated area**. This can be done in the field by breaking up the installed landscape into rectangles and figuring out areas of the rectangles. Because plantings individually are not being counted rather the entirety of the landscape being irrigated is, typically all angles are right angles. An alternative to field measurement for larger lots would be to examine plans or aerial images showing the areas served by irrigation. In most new homes this is simply the area of the front-yard.
2. **Turn off all water sources and taps**. The test requires running stations so don't turn off water at the meter, rather assure all taps and appliances that could use water are off and that the irrigation controller will not run any scheduled programs that may interfere with the test. After everything is off, open the meter box lid and check that there is no movement in the meter. Be careful not to inadvertently disconnect or damage any of the utility's infrastructure including remote reading devices. This is also a de facto test for leaks. Leave the meter box lid open for step 3.
3. **Set the controller to provide sufficient pre-sampling equilibrium time for each station.** Each station needs to be run separately with the other ones off. Set the irrigation controller to manually run the station to test for a long enough period for the auditor to get from the controller to the meter, for the valve to fully open, and for air in the system to be purged. There are distinct audio cues for both the valve opening and the air spitting out of the system. The

amount of time to wait varies for a number of reasons including the components and pressures and is typically less than a minute for a spray system to sometimes several minutes for a drip station. Practice will better allow the auditor to estimate how long to wait before taking readings in a given area and development.

4. **Measure the flow rate.** This is done by recording the volume of water that passes through the meter in a defined amount of time. With a stopwatch or countdown timer, observe how much water passes through the meter in 30 seconds and multiply this by 2 to get gallons per minute (gpm). For most home meters gallons are marked on the meter face with each rotation equaling 10 gallons for meters displaying in gallons. If a meter reads in cubic feet, a conversion must be done by multiplying the cubic feet by 7.48 to change the value into gallons terms. Turn off the station after measurements are completed.
5. **Repeat steps 3 and 4 to record gpm for each station.** Remember to do each station individually and check for no movement between runs that would indicate use during the test. It is best to cross correlate with the controller which station is which where many stations are present.
6. **Get the RICI score.** Sum together all the flow rates and divide this number by the landscape area in square feet. Finally multiply this number by 1000 to get the RICI value.

What Residential Irrigation Capacity Index (RICI) Means.

What does RICI reveal about irrigation system and landscape design? At its most basic level it demonstrates that higher use is associated with higher capacity to use a resource. This is why lighter sports cars still use more gas than subcompacts with less powerful engines. It is why usually a high butane gas grill burns through a gas cylinder more quickly than a low output grill. And, more to the point, it’s why homes that have a 3/4” service use more water on average than those with a 5/8”meter. In each of these cases more use on average is to be expected while recognizing for any given case it is not a guarantee.

Part of this is that, where a human is involved, there is a behavioral tendency to use capacity to whatever extent it exists. To a degree, for irrigation, taking some control away from the person could save water and the $HERS_{H2O}$ rating to its credit has added to the outdoor model a 15% decrease if builders provide a smart controller. This links also to education and time when considering irrigation. For example, a homeowner may set a station of microsprays for an hour because they treat it identically to a point drip system they have because hey lack education about it. Thus the higher output system results in higher use than it should. But clearly more than just human behavior is involved.

RICI integrates the major inputs that would otherwise go to water budgeting schemes in a way that is landscape size neutral and, uniquely, that is relatively unbiased with respect to where the site is located. Higher demands whether from plant type, planting density, or other factors it seems, based on the analyses by SNWA and EPA, to be reflected in the capacity of the irrigation stations installed. While this seems entirely logical given these are specified systems, somehow measuring the capacity of a system as a means to estimate future demands has not to date been considered to the author’s knowledge. It may be that the tendency to focus on the controller and the user has caused a bit of to neglect of an obvious predictor of use. And the other paths worked have worked until the aforementioned challenges related to practical and timely auditing of new irrigated landscapes by non-horticultural experts was encountered. As with other advancements, it was necessity and, here, large samples of powerful datasets, that revealed the correlation and powered the development of RICI.

Is RICI really a long-sought third way to promote water conservation in landscape design that doesn't involve prescriptive turf limitations or complicated water budgets? The analyses alluded to herein suggest the answer could well be "yes". Only time and further use of RICI within the $HERS_{H2O}$ rating system, and possibly in other efficiency initiatives and studies, will tell us if this path works as well as it appears to and is embraceable by those that currently are limited to the two standing approaches for promoting efficient design.

Conclusions.

The desire to consider landscape design and challenges encountered during development of that preference for RESNET's $HERS_{H2O}$ standard has resulted in innovation of a remarkable and simple metric for estimating future demands in builder installed irrigated landscapes at new homes. The Residential Irrigation Capacity Index (RICI) is based on summing together flow rates for irrigation stations installed at the time of construction and normalizing this for area served. This new RICI score is:

- Based on state-of-the-art research examining real-world correlation between the capacity of residential irrigation systems to deliver water and water consumption.
- Developed based on a national data set in addition to development local to southern Nevada. It is anticipated to work nationwide.
- Currently in $HERS_{H2O}$ as an option. Each one unit decrease in RICI from a baseline value of 5 is associated with a 10% decrease in outdoor use.
- Normalized on a per unit area basis, meaning homes with a diversity of landscape sizes and configurations are treated in an apples-to-apples manner.
- Not a metric that requires specialized knowledge of plant water use or taxonomy and does not rely on variable, mutable and unadjudicated assumptions about plant water use in a given area.
- Is not dependent on plantings being installed in time for the audit.
- Not a trade industry disliked turf limitation.
- Easy, straightforward and can be done by anyone. The sampling method is rapidly learned and RICI audits are quickly completed in the field.
- A metric that integrates not just irrigation capacity, but the contributions to water use resulting from species composition and density as well.

RICI may represent an innovative approach to evaluating new landscapes for future water use levels and is just starting to be tried out. Future findings will further qualify the interest and success of this novel approach for considering landscape design for water conservation.

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