TABLE OF CONTENTS

1. INTRODUCTION................................................................................................................. 4
   Purpose of the Watershed Health Scorecard ................................................................. 4
   Scope of this phase of the Watershed Health Scorecard ............................................. 4
   Intended audiences ......................................................................................................... 5
   Scope and limits of the Scorecard .................................................................................. 6
   Related projects ............................................................................................................. 6
   Online resources ........................................................................................................... 7

2. METHODOLOGY .................................................................................................................. 7
   Scorecard Vocabulary ..................................................................................................... 7
   Conceptual framework ................................................................................................... 8
   Screening potential indicators and data .......................................................................... 12
   Data Analysis and Evaluation ......................................................................................... 12
   Status of this Report ....................................................................................................... 13

3. INDEX: NATURAL SUPPLY .............................................................................................. 14
   Index: Natural Supply, Indicator: Precipitation ............................................................. 16
   Index: Natural Supply, Indicator: Annual Flow ............................................................. 18

4. INDEX: STORAGE ............................................................................................................... 22
   Index: Storage, Indicator: Groundwater Table Elevation .............................................. 23
   Index: Storage, Indicator: Surface Storage .................................................................... 29

5. INDEX: STREAMS .............................................................................................................. 33
   Index: Streams, Indicator: Dry Season Flow ................................................................. 34
   Index: Streams, Indicator: Dry Reaches ....................................................................... 37

6. INDEX: LANDSCAPE PERMEABILITY ............................................................................ 42
   Index: Landscape Permeability, Indicator: Impervious Area ......................................... 43

7. INDEX: STEWARDSHIP .................................................................................................... 49
   Index: Stewardship, Indicator: Water Independence ..................................................... 49
   Index: Stewardship, Indicator: Water Conservation ..................................................... 52

INTRODUCTION .................................................................................................................. 52
   Index: Stewardship, Indicator: Sustainable Policy ....................................................... 62

8. RECOMMENDATIONS FOR FUTURE EFFORTS ............................................................ 65

9. ACKNOWLEDGEMENTS .................................................................................................. 65
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Hydrologic cycle</td>
<td>8</td>
</tr>
<tr>
<td>2.</td>
<td>Conceptual model of water balance</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>the mean</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Annual rainfall probability distribution for City of Sonoma</td>
<td>17</td>
</tr>
<tr>
<td>6.</td>
<td>Annual cumulative discharge on Sonoma Creek at the Agua Caliente Road</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>gauge</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Annual runoff probability distribution for Sonoma Creek</td>
<td>20</td>
</tr>
<tr>
<td>8.</td>
<td>Typical annual spring and fall series of groundwater level data for Sonoma</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Valley north basin</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Probability distribution for groundwater levels in spring and fall in the</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>north basin, and for recharge in the north basin</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Probability distribution for groundwater levels in spring and fall in the</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>south basin, and for recharge in the south basin</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Annual drawdown and recharge for Lake Suttonfield and Fern Lake</td>
<td>29</td>
</tr>
<tr>
<td>12.</td>
<td>Farm pond development within Sonoma Creek watershed</td>
<td>31</td>
</tr>
<tr>
<td>13.</td>
<td>Dry season flow as a percent of annual rainfall, by year</td>
<td>34</td>
</tr>
<tr>
<td>14.</td>
<td>Probability distribution of dry season flow ratio (missing)</td>
<td>34</td>
</tr>
<tr>
<td>15.</td>
<td>Water conservation</td>
<td>51</td>
</tr>
</tbody>
</table>
1. **Introduction**

**Purpose of the Watershed Health Scorecard**

The Watershed Health Scorecard’s purpose is to provide, in a highly accessible format, information that is needed for adaptive, responsive, and transparent watershed management. To meet this objective, the Scorecard is designed to identify and evaluate a carefully selected set of indicators that accurately reflect basic watershed functions. Tracking these indicators over time should help to evaluate the effectiveness of contemporary approaches to watershed management, and answer the question “are we managing our natural resources in a sustainable manner?”

To meet this challenge, our community needs tools that focus attention on watershed management, describe current conditions and trends, and provide a common vocabulary for discussing natural resource stewardship in watersheds. The ever-growing stressors on natural resources, including development and climate change impacts, only increase the value of and demand for accurate measures of natural resource health. The Scorecard is a tool for prioritizing monitoring needs and engaging and informing the public, resource managers, decision makers, and scientists.

The complete Watershed Health Scorecard could include indicators that report on water quantity, water quality, landscape condition, community well-being, and health of biological resources. The Watershed Health Scorecard approach assumes that sustainable, healthy communities and economies are the result of healthy, sustainable ecosystems. Implicit in its structure is the concept of a “triple bottom line” of ecology (environmental health), economy (economic health), and equity (social health).

To build a Watershed Health Scorecard, respected scientists from a variety of regional organizations are invited to scrutinize available data and technical information, and devise a set of meaningful indices and indicators of watershed health. The strength of this approach lies in the marriage of credibility and accessibility. The conceptual framework that divides watershed condition into indices and multi-metric indicators provides a means to aggregate environmental data into categories that can be scored to report on overall ecosystem health.

**Scope of this phase of the Watershed Health Scorecard**

This report describes the water availability topic of an overall Watershed Health Scorecard. This scorecard is based primarily on data for water year 2007, the most recent year for which data were available. This report, and its associated Scorecard, is the product of a collaboration between two watershed-based organizations, the Sonoma Ecology Center (SEC) and the Napa County Resource Conservation District (Napa RCD) and numerous technical partners to answer the following question:
"How is our watershed doing in terms of supplying quantities of water needed to support human and ecosystem uses?"

The answer hinges on interactions between nature’s supply—how much rain falls from year to year—and human influences on watershed processes such as infiltration, recharge, and runoff. As water has been termed by some “the oil of the 21st Century,” we anticipate increased public focus on wise and equitable management of our invaluable water supply.

This scorecard is based primarily on data for water year 2007, the most recent year for which data were available when the analysis was undertaken in 2008. A long-term goal of the Watershed Health Scorecard is to build support for watershed protection and restoration through increased awareness of the natural resources that define and sustain our communities. The 2007 Scorecard was completed simultaneously for the watersheds of Sonoma Creek and Napa River, to compare and contrast local needs and converge on a design with potentially broader applicability. The assessment and evaluation process employed here should be applicable to other watersheds. In the process of developing this Water Supply Scorecard, we have developed a framework for completing subsequent Watershed Health Scorecard sections as funding becomes available.

**Intended audiences**

The Watershed Health Scorecard is designed to reach a variety of audiences: three products were planned to serve the potentially different needs of those audiences.

1) The Scorecard itself, modeled on a school report card, 4 pages maximum, rich with graphics, and written for the general public. This product is intended to serve the layperson, ranging from middle school students to busy local landowners, and other interested members of the general public. The format is designed to be clear, easy to read, and free of technical jargon.

2) The scorecard report, an executive summary of the process and research behind the Scorecard, approximately 20 pages, written for the interested lay reader. This audience may include policy-makers, agency managers, technically minded stakeholders, college and graduate students, business owners, farmers, and elected decision makers. This report would be of interest to other communities who would like to apply this model to their own watershed. THIS PRODUCT WAS NOT COMPLETED DURING THE CURRENT PROJECT.

3) This technical report, providing several pages per indicator, describes data availability and analysis, scoring methodology, results and recommendations, is written for the technical reader. Its intended audience is scientists, water policy specialists, and other natural resource specialists. It provides information for planning purposes as well as recommendations for monitoring, regulation, restoration, and management actions.
Scope and limits of the Scorecard

The primary limitation of this Scorecard is that due to budget constraints indicators were restricted to relying on data that has already been collected, is readily available, and in many cases has already been analyzed. The benefit of this approach is that in some cases we are taking advantage of data that has been collected for over 50 years and perhaps has to date been underutilized. The practicality inherent in this approach is that this data will in many cases continue to be collected, assuming ongoing levels of institutional commitments. This means that the scorecard can be applied into the future without significant additional expenditures beyond existing levels of monitoring.

The Scorecard also does not address future scenarios or estimate the inevitable impacts of climate change. However, modeling tools are in development that may be able to test the effects of different watershed management scenarios on indicators and watershed functions. By providing a basis for consistent watershed monitoring into the future, application of the Scorecard will result in an empirical baseline capable of testing hypotheses developed using models and other theoretical constructs. It will provide the basis for a “reality check” of common assumptions regarding cause and effect in watershed processes.

The detailed discussion of each indicator, below, addresses data gaps and recommendations for filling those gaps into the future. In many cases, the scorecard suggests how maximum information may be gained from minimal additional investments in monitoring, by providing a framework for interpretation and application to real world problems.

Related projects

The Scorecard described here was inspired by, and modeled after, The Bay Institute’s San Francisco Bay Index.

The Scorecard complements several efforts to monitor and publicize the status of watershed health. These include the following:

Local project

- There are several locally-driven watershed health monitoring efforts based on the Surface Water Ambient Monitoring Program’s monitoring strategy, recently approved by US EPA, Region 9.
- The Limiting Factors Analysis for Steelhead in the Sonoma Creek Watershed (SEC, 2006) found that inadequate water in streams in summer was a major limiting factor for threatened steelhead; this finding increased the motivation to assess overall water availability in the watershed.
- The Scorecard will inform the Integrated Regional Water Management Plan that is under development by a consortium of Bay Area drinking water purveyors, wastewater treatment, stormwater management, and natural resource agencies.
• The project will provide important information for local planning processes including the Sonoma Valley Groundwater Management Plan, the Sonoma Creek Enhancement Plan, Critical Coastal Areas plans, and recovery plans for threatened Steelhead trout.

Regional or statewide projects
• Several watersheds around the state are using the Watershed Assessment Framework (WAF) to develop indicator sets that include socioeconomic wellbeing in addition to biophysical condition. Most partners on the Napa-Sonoma Scorecards are also working on a Napa/north bay WAF indicators project.
• The North Bay Watershed Association recently developed indicators for ecological health, water management, watershed stewardship, and recreation, to be applied consistently across that subregion.

The need for accessible information about local water conditions and measures for evaluating restoration activities is acute throughout California. The benefits of the Scorecard will be shared in regional and statewide watershed forums like the Watershed Information Center and Conservancy of Napa County, the North Bay Watershed Association, and the Bay Area Water Forum. Beneficiaries include the general public, students, public officials and decision-makers, nonprofits, Resource Conservation Districts, local water utilities, and other public agencies.

**Online resources**

The Scorecard, its associated reports, the raw data behind the Scorecard – along with metadata describing data sources and data analysis – can be found at [http://sfcommons.org/scorecards/sonoma](http://sfcommons.org/scorecards/sonoma). The Technical Report is available only online.

2. **Methodology**

**Scorecard Vocabulary**

Watershed health is a broad and multifaceted concept. In order to assess watershed health, the components of watershed health can be divided into indices, indicators, and metrics.

*Index*: a function or component of the watershed that is used to report on overall watershed condition. For example, *storage* is an index of watershed health.

*Indicator*: a function or component of an index that is used to report on the condition of the index. For example, groundwater storage is an indicator of water storage.

*Metric*: a variable that is directly measured to report on the condition of an indicator. For example, the level of groundwater in wells, in springtime, in a single groundwater basin is a metric of groundwater storage.
Conceptual framework

This Scorecard aims to create a protocol for evaluating both the condition of our watershed’s physical resources and the extent to which watershed management is meeting community goals for sustainability of our water resources. By sustainability we mean the ability to provide for the beneficial uses central to the health of human communities and ecosystems now and into the future. Examples of beneficial uses include water supply, fisheries habitat, and recreation. In order to develop a Scorecard, the first step is to create a conceptual model that establishes linkages between parts of the water cycle, beneficial uses, and impacts of human uses on the system as a whole. Here we describe the thought process leading to our watershed conceptual model and the major components of that model.

The simplest kind of model hydrologists use to describe a watershed is called a “box model,” sometimes illustrated in college classrooms by suspending a paper towel by a clip from a scale over a bowl. A squeeze bottle represents model inputs, precipitation, the watershed is represented by the paper towel, and the bowl underneath represents the receiving waterbody (San Francisco Bay estuary, in our case). Rainfall can be applied consistently or intermittently to the top of the paper towel, and the timing and amount of “runoff” into the bowl depend on both the pattern of rainfall and the condition of the “watershed.” If we wish to turn our simple box model into an equation, it would look like this, where I equals input, ΔS equals change in storage, and O equals output:

$$I - \Delta S = O, \quad \text{or} \quad I - O = \Delta S,$$

These simple equations provide the building blocks for hydrologists’ numerical models. Such models can become exceedingly complex as we begin to account for subdivisions within these basic categories and the impacts of human diversions, uses, and discharges within the watershed system.

The box model also allows the development of a water balance or water budget, which keeps track of water quantities moving from one category to another. Using the “budget” analogy, inputs can be thought of as deposits to an account, outputs are equivalent to withdrawals, and fluctuations in the account balance reflect changes in storage. Establishing a conceptual model requires making a decision about where to draw your box. The box is of course an artifice, since all elements of the system are interconnected. However, clearly defining this boundary is essential to properly constructing the relationship of inputs, outputs, and storage elements.

Figure 1 below depicts relationships between inputs, storage, and outputs in a real watershed without any human disturbance. Here we see that precipitation may travel different routes once it hits the land surface. It may collect on the surface of a leaf and then evaporate, and it may run off the surface of the ground directly into a stream. Water that infiltrates into the ground may return to the atmosphere, either by direct evaporation or by transpiration through plants, or it may recharge groundwater. Groundwater may eventually discharge to a stream. At the bottom
of our watershed, channel flow and groundwater discharge into the San Francisco bay estuary, “the end of the line” for our freshwater resource.

Figure 1. Hydrologic Cycle showing partitioning of input (precipitation) into phases of storage (infiltration; recharge to groundwater; discharge to stream) and outputs (evaporation from open water, soils, plant canopies; plant transpiration; channel outflow).

We are now ready to present a schematic diagram of the water balance of the Napa River watershed, which underlies the rest of this technical report. Figure 2 below illustrates the key elements of the water balance for this watershed, simplified and organized to spotlight the role of withdrawals for human use in the overall picture. The figure may be summarized in the following equation:

\[ P + I = ET + RO + \Delta S_s + \Delta S_g \]

where

- **P** = precipitation
- **I** = imported water
- **ET** = evapotranspiration
- **RO** = surface runoff
- \( \Delta S_s \) = change in surface water storage
- \( \Delta S_g \) = change in groundwater storage

All terms are understood as volumes corresponding to a specific time step (normally annual). In the figure, the elements related to the input terms (the left
side of the equation) are shaded in a lighter tint, while the elements related to output are in a darker tint.

In order to spotlight the role of human withdrawals, the terms relating to change in storage may be rewritten in terms of additions and withdrawals. If we let $A$ denote additions to storage and $W$ withdrawals, the equation becomes

$$ P + I = ET + RO + (A_s - W_s) + (A_g - W_g) $$

The withdrawal terms include all sources for human use (the blue arrows in the figure). Note that three of the source arrows are lumped into the $W_s$ term in the equation.
Fig. 2. Conceptual Model of Water Balance
Screening potential indicators and data

The leap from the conceptual framework just discussed to the set of indices and indicators that went into the Scorecard was not a simple one. We used the conceptual framework as an initial guide in identifying potential indices and indicators. Three of our indices, natural supply, storage, and streams, refer to recognizable elements in the conceptual model, but none of these is a direct translation of an element in the model. Rather, they are organized around groups of metrics and indicators that are defined from the point of view of human water users. This is most apparent with regard to the stewardship index, but it is true of all of them. The rationale for identifying and pursuing each index is discussed in the introduction to its section of the report.

Selection of indicators for inclusion in the report turned out to be the key practical step. We identified criteria for choosing indicators and datasets – the two obviously go together, since quality data of the right sort are essential to analyzing any indicator. We aimed for indicators and datasets that

- have been collected consistently over time in the past
- are expected to be collected consistently in the future with reliable funding
- are publicly available (not proprietary)
- are reliable and accurate
- are in a form readily usable without much additional work
- can inform management decisions
- are understandable in the public arena

The process of selecting the indicators that appear in this report and in the Scorecard included many tentative selections that turned out to be impractical for reasons of data availability or quality. We rejected several interesting and potentially important indicators, because the datasets we had identified turned out not to be sensitive to the particular issue we had identified. In some cases, we had to reject potentially useful datasets because they would have to be reworked for this project. These issues are discussed under the various indicator headings below. In all cases, our goal was to come up with something that was practical and could be repeated in the future without a large analytic effort.

To avoid repeating this vetting process in future iterations of the Scorecard that we or others undertake, we kept records, more detailed than the explanations that appear in this report, of which indicators and datasets we investigated but did not ultimately use. Any reader is welcome to contact us to obtain these records.

Data Analysis and Evaluation

For the indicators we selected, we carried out a comprehensive search for appropriate data, relying strongly on the experience of project partners who had worked on similar assessments in the Bay Area as well as the local knowledge of the local Napa and Sonoma partners. We decided to concentrate on scoring a
single year, feeling that we lacked a convincing rationale for the identification of an appropriate multi-year interval for evaluation. This scorecard is based generally on a comparison of data from the most recent year for which data were available – 2007 - with reference conditions defined in varying ways, as we judged appropriate for the various indicators. In the case of data that are collected less frequently, we used the most recent high-quality dataset available.

For most hydrologic variables, annual data are expressed in terms of the hydrologic (water) year, which is particularly appropriate for our Mediterranean climate in that it includes an entire wet season in the same water year. The water year is usually defined to run either from July through June or from September through October. In our climate, the difference in rainfall or surface flow totals between the two systems is slight.

In our efforts to score the various indicators, various data issues made it difficult to distinguish meaningful levels in the metrics which would justify detailed scoring systems. After an extensive trial with a five-point scale, the team decided to limit our scoring system to three levels, awarding from one to three points. The three levels are labeled poor (1 point), fair (2 points) and good (3 points). As far as possible, these labels are related to a quantitative measure of reference conditions, and where there is no obvious basis for defining thresholds between levels, we have tried to define quantitative bins of equal magnitude. The sections on the individual indicators describe what was done in each case; note especially that in some cases no score was assigned, for reasons we discuss.

The scoring system for the Natural Supply indicators is different from the other indicators, with values of 1 (Dry), 2 (Average), and 3 (Wet) instead of 1 (Poor), 2 (Fair), and 3(Good). This was done to convey the fact that the Natural Supply Index provides the hydrologic background for the time period being scored and is not an index of environmental health as influenced by human activity.

Besides scoring the most recent year under the various indicators, we examined the data for multiple years in search of trends that should be reported. This turned out to be a complex question, in several cases, and the subject of trends is discussed in the individual indicator sections too.

The reference conditions used in scoring were derived from a variety of sources, including review of the literature, comparison with a reference period in past data, and professional judgment.

**Status of this Report**

Because of circumstances outside the control of the project team, we were not able to complete all project tasks in the intended fashion. This report, which is being presented as a draft, has not had the desired level of technical review, and some important elements are missing.
We intended to include a more thorough and systematic discussion of the methodology used to identify indices and indicators, as well as the actual metrics used in our analyses. This discussion would have treated the elements in the conceptual model which were not parameterized; candidate indicators for which the data gaps are currently too significant; the possible consequences of important indicators being missing; and why some indicators were included but not scored.

Perhaps most important, this report lacks a quantitative statement of the uncertainties associated with the various results, scores and trends noted. For this reason, in particular, we stress that the current (February 2010) version of this report should be regarded as a draft.

3. **Index: Natural Supply**

The defining characteristic of our Mediterranean climate is the extreme contrast between our wet and dry seasons. Typically, almost all rain falls during the wet season between October and April, while the rest of the year sees little or none. In addition, the amount of rain received by the watershed can vary drastically from year to year based on weather conditions over the Pacific Ocean. Predicting rainfall conditions is confounded by oceanic dynamics driving the "Pineapple Express" meteorology that creates storms bound for the Northern California coast. Over the period of hydrologic record, total annual rainfall amounts have varied by a factor of five. Resultant streamflow displays even greater variability, since in low rainfall years most water infiltrates the soil, compared to high rainfall years when a much higher proportion of rainfall is available to supply runoff to stream channels.

The purpose of the Natural Supply Index is to provide the hydrologic background for the time period being scored. Strictly speaking, this is not an index of environmental health. Although we have scored the two indicators of Natural Supply, the scores do not have the same evaluative character as the scores to be assigned to the other indicators below. Rather, they should be understood as pieces of basic information, to be borne in mind in evaluating the other sections of the Scorecard. The message to be conveyed is essentially this: how wet is the overall hydrologic picture for the period covered by the Scorecard? The importance of this notion cannot be overestimated. In order to evaluate the condition of water quantity in the watershed in light of the sustainability of human activities, we must consider the inputs to the system. If there is less rain, there will naturally be less water in the channels or in storage.

To examine this index we will look at two indicators, total annual precipitation and total annual flow. Each of these has advantages and disadvantages as an indicator of hydrologic condition, and we have chosen to include both. Rainfall would be the ideal way of representing the total hydrologic input into the system (snow not being a factor at this elevation), but it is not necessarily the most practical. Rainfall has the disadvantage of being spatially varied, so that to estimate total basin rainfall requires an extended network of rain gages and some means of assigning weights to them to represent the whole. Although there are currently a number of privately
monitored rain gauges in the Sonoma Creek watershed, there are only two state maintained gauges with long records.

Streamflow is, by contrast, easier to study, in that it is naturally aggregated at a single point where it can be measured. Annual streamflow data are available over the relatively long period of record on Sonoma Creek. Although it does not capture the entire hydrologic picture, total annual flow does track in a general way how wet the overall hydrologic condition is, and creek discharge has the attractive feature that it vividly represents the lion’s share of the water available for human use. The data on which this index is based are illustrated in Figure 3, which shows the annual series of both total annual rainfall and total annual flow for Sonoma Creek. Figure 4 shows the same data, displaying each dataset in terms of the cumulative departure from the mean. These figures and the underlying data will be discussed in the following sections 3.1 and 3.2.

![Figure 3. Rainfall and Runoff for Sonoma, 1956-2007: Annual Totals](image)

![Figure 4. Annual Rain and Runoff for Sonoma, 1956-2007: Cumulative Departure from Mean](image)
Index: Natural Supply, Indicator: Precipitation

Score: 1 (dry)  Trend: None observed
Time period reflected in score: water year 2007 (July 2006 – June 2007)

Introduction

There are few long-term rainfall records in the Sonoma Creek watershed. However, there is one long-term dataset recorded at the City of Sonoma and another recorded at the campus of the Sonoma Developmental Center in Eldridge. We are interested in rainfall records that are representative of the drainage area upstream of the point at which streamflow is measured, so that the rainfall and flow records can be directly related to each other. The USGS streamgauge is station 11458500 located on Sonoma Creek at Agua Caliente, which is upstream of the City of Sonoma but downstream of Eldridge. We made use of both rainfall records in this analysis, finally choosing to use the Sonoma record as our primary source.

In order to quantify how wet or dry a particular year was, we developed a probability index by ranking annual streamflows for a baseline period of 45 years. We then distributed the results into thirds, representing wet, average, and dry water years.

Data availability

Rainfall data for the City of Sonoma were downloaded from the Western Regional Climate Center website at http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca8351. Total monthly rainfall records are available since 1951. The Sonoma Developmental Center has recorded monthly totals since 1954, which are retained in the SDC logbook. The latter dataset was transcribed and converted to an excel spreadsheet for this project. It is expected that both datasets will continue to be recorded. Additionally, there is a growing network of private citizens that record monthly rainfall totals around Sonoma Valley. Sonoma Ecology Center is working to assemble these records into a rainfall database that will better track variability in rainfall throughout the watershed.

Analysis, methodology, calculations

The rain data obtained for the City of Sonoma for hydrologic years 2003 through 2007 were used to create estimates of total rainfall in the portion of the Sonoma Creek watershed upstream of the Agua Caliente gauge. Rainfall data obtained from SDC were compared to the rainfall data from the City of Sonoma. It was found that the City of Sonoma receives an average of 34% less rainfall than the SDC gauge located on the leeward side of Sonoma Mountain. It was decided that the City’s gauge would more accurately represent conditions throughout the watershed. Total rainfall in inches was multiplied by the total watershed area to arrive at a volume converted to acre feet. The resulting annual dataset is shown in Figure 4 above, along with a record of flow at Agua Caliente to be discussed in section 3.2.
Evaluation and scoring

Although strictly speaking we are not *scoring* this indicator, it is necessary to establish a baseline dataset and probability index for comparison with the period of this scorecard. For this we took advantage of the relatively long period of record to create a probability distribution for a period of 52 years for which flow data are available, 1956-2007, to compare the *current* annual flow with. It is important to note that for hydrologic years 1982 – 2001 we used a synthetic hydrograph to estimate flow in Sonoma Creek, the details of which are in the following section. We considered the use of a subset of the data to define the baseline period: in the case of a very long record, with the possibility of significant change in the response of the watershed to rainfall, it would be worthwhile to identify an earlier period as the baseline. In this case, however, inspection of the flow record did not justify the use of any particular subset of the data to define a baseline condition, so essentially the entire dataset was used. The annual values of rainfall for the 1956-2007 period were arranged in ascending order, and exceedance probabilities were assigned to each value. Figure 5 shows the resulting probability distribution.

![Cumulative Annual Rainfall Probability Distribution at Sonoma](image-url)

**Figure 5. Annual Rainfall Probability Distribution at City of Sonoma**

In order to score the metric, scoring breakpoints were defined by dividing the probability range (from 0 to 1) into equal-sized sections. As the figure shows, the entire probability distribution is divided into thirds. A probability in the lowest third, for example, which lies in the interval (0,0.33), is assigned the lowest score (Dry, for a value of 1). A value in the next third is scored as Average (value 2), and so on. To score a particular value, one finds the value on the X-axis and uses the curve to find the corresponding probability on the Y-axis.

We stress that, in spite of our use of the word “score” to describe this procedure, we are not evaluating environmental health but rather simply noting the magnitude of rainfall. This should be understood as a value-free quantifier of the overall hydrologic picture on a year-by-year basis.
Discussion

This indicator tells us how wet the general hydrologic condition is in the period under evaluation. As was discussed in the introduction to section 3 above, this is not an indicator of environmental health, but it is nevertheless fundamental to understanding the hydrologic condition. The message is that, on the basis of total rainfall, the hydrologic condition is in the range of dry years. See section 3.2.5 for related discussion of the annual flow indicator.

Summary and Recommendations

We have characterized the dryness of water year 2007 by comparing the 2007 rainfall total with the long-term record since 1960. Because our long-term stream flow record is at Aqua Caliente, we are interested in rainfall upstream of that point. We created a probability distribution from the long-term record and used it to rate the current year, which receives a score of dry. Examination of the last decade, however, shows an upward trend compared with the overall record.

This rainfall analysis would be improved by the addition of more long-term rainfall records. If we had many rain gauges throughout the watershed by which to measure variability and storm intensity, we could get a better idea of the type of wet or dry period we are considering. It is to be hoped that the recent proliferation of automatic recording rain gauges and electronic data storage will translate into increased data availability in the future.

Missing from our analysis, for lack of time, is a quantitative statement of the uncertainty associated with the results, the score and the trend.

References

Monthly rainfall at Sonoma Developmental Center, Eldridge, California, 1953-2008: http://knowledge.sonomacreek.net/node/138
Western Regional Climate Center: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca8351

**Index: Natural Supply, Indicator: Annual Flow**

Score: 1 (Dry)  
Trend: None observed  
Time period reflected in score: water year 2007 (October 2006 – September 2007)

Introduction

In order to evaluate current flow conditions in Sonoma Creek, we need a baseline for comparison. To obtain this, we looked at the total annual flow of Sonoma Creek at the Agua Caliente stream gauge near Glen Ellen, California, which is maintained by the United States Geological Survey (USGS). We take the hydrologic year to run from October through September, following the convention of the USGS, and by
total annual flow we mean the total measured flow for the hydrologic year, converted to units of volume. These are the data illustrated in Figure 3 above. Although the precipitation indicator used a different definition of hydrologic year (July through June), the two sources of data are still comparable, because there is virtually no recorded rainfall in the months July, August and September in any year.

In order to quantify how wet or dry a particular year was, we developed a probability index and ranked annual flows for a baseline period of 45 years accordingly. We then distributed the results into thirds representing wet, average, and dry water years.

Data availability

Currently there are two USGS stream gauges operating in Sonoma Valley. The gauge at Agua Caliente, station 11458500, which was installed in February 1955, and another installed in October 2008 at Kenwood, station 11458433. The Agua Caliente gauge is located roughly at the mid point of Sonoma Creek; the site drains an area of approximately 58.4 square miles or about one-third of the total watershed area. Although a gauge farther down in the watershed would give a more complete picture of the hydrologic response of the watershed, practical considerations preclude locating a stream gauge within the tidal range of the creek.

Both gauges measure water level continuously, recording at 15-minute intervals, while a rating curve is maintained to convert the stage record into a discharge record.

Daily discharge records are available from 1955 to 1981 and from 2001 to the present. The gauge was lost to a flood in 1982 and not replaced until 2001. Stream gauge data are available for download from the USGS website (http://waterdata.usgs.gov/nwis/sw).

Figure 6. Annual cumulative discharge on Sonoma Creek at the Agua Caliente Road gauge.
To fill in the missing years, we used a synthetic hydrograph. Previously developed by Chris Farrar of the USGS for the Sonoma Valley Groundwater Management Plan, the synthetic hydrograph uses a comparative regression model. A coefficient multiplier was derived by comparing flow records for coinciding years at Sonoma Creek and the nearby Napa River; the multiplier was then applied to the Napa flow record to generate synthetic data for the missing years in Sonoma.

It is likely that these gauges will be maintained and flow data will continue to be available into the future.

Analysis, methodology, calculations

Daily average flow data were downloaded from the USGS and compiled in an Excel spreadsheet. Daily flow values in cubic feet per second were summed by water year (October – September) and converted to annual acre-feet for convenience. The synthetic hydrograph was incorporated for missing years. The annual data are shown in Figure 6 above.

This analysis is based on the best available data. Ideally we would have a gauge at the mouth of Sonoma Creek that would allow us to track the total annual flow for the entire watershed. Similarly, a longer period of record might show us more in the way of long term trends.

Evaluation and scoring

Although strictly speaking we are not scoring this indicator, it is necessary to establish a baseline dataset and probability index for comparison with the period of this scorecard. For this we took advantage of the relatively long period of record to create a probability distribution for the period 1956-2000 and compare the current annual flow with it. We considered the use of a subset of the data to define the baseline period: in the case of a very long record, with the possibility of significant change in the response of the watershed to rainfall, it would be worthwhile to identify an earlier period as the baseline. In this case, however, inspection of the record did not justify the use of any particular subset of the data to define a baseline condition, so essentially the entire dataset was used. The annual values of dry season flow for the entire 45-year period were arranged in ascending order, and exceedance probabilities were assigned to each value. Figure 7 shows the resulting probability distribution.
In order to score the metric, scoring breakpoints were defined by dividing the probability range (from 0 to 1) into equal-sized sections. As the figure shows, the entire probability distribution is divided into third. A probability in the lowest third, for example, which lies in the interval (0,0.33), is assigned the lowest score (Dry, for a value of 1). A value in the next third is scored as Average (value 2), and so on. To score a particular value, one finds the value on the X-axis and uses the curve to find the corresponding probability on the Y-axis.

We stress that, in spite of our use of the word “score” to describe this procedure, we are not evaluating environmental health but rather simply noting the magnitude of annual flow. This should be understood as a value-free quantifier of the overall flow picture on a year-by-year basis.

Discussion

This indicator tells us how wet the general hydrologic condition is in the period under evaluation. As was discussed in section 3.2.1, this is not an indicator of environmental health, but it is nevertheless fundamental to understanding the hydrologic condition. The message is that, on the basis of total creek flow, the hydrologic condition is somewhat wetter than average – near the top of the range labeled “average” in Figure 7. Water is available for use by the watershed community.

The indicator does not tell us about the prospects for the immediate future. There is some carryover from one hydrologic year to the next, and this will affect runoff. However, the prime driver of hydrology is future rainfall, and it is always well to remind ourselves that current hydrology is no predictor of that.

The range of the overall dataset is considerable, from a minimum of 1001 ac-ft in 1977 to 136,167 ac-ft in 1983. These two values differ by a factor of 136, while the difference in rainfall between 1977 and 1983 was only about 5 times, according to the Western Regional Climate Center record for the City of Sonoma.
In very low rainfall years, most water infiltrates and there is little surface runoff to the river, while in high rainfall years there can be a great deal of runoff. This example of typical hydrologic variation shows how a difference in rainfall is tremendously magnified in cumulative flow and it argues for the usefulness of this indicator in assessing watershed condition.

Summary and Recommendations

We have characterized the underlying hydrology of 2007 by comparing the annual creek flow total with the long-term record since 1960. We used the most downstream flow record available, which is measured at Agua Caliente, as a baseline for our comparison. We created a probability distribution from the long-term record and used it to rate water year 2007, which was scored as dry. Examination of the last decade, however, shows no trend, up or down, compared with the overall record.

For future reporting it may be worthwhile to consider the timing and intensity of storm events, to give greater depth to the context of a wet vs. dry year. This level of detail would tell us whether the runoff occurred in a few intense storms, or whether there were many small precipitation events spread out over the wet season. The difference is very important to such processes as groundwater recharge, for example.

Our data remain limited by the practical necessity of locating the gauge site upstream of the range of tidal influence. It would be ideal to have a gauge at the mouth of Sonoma Creek that would allow us to account for the entire watershed drainage.

Missing from our analysis, for lack of time, is a quantitative statement of the uncertainty associated with the results, the score and the trend.

References

Western Regional Climate Center, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca8351

4. Index: Storage

As we mentioned in Section 2 above, an important part of the water picture is storage in the watershed. Water is stored in two principal places: on the surface and underground. This Water Storage index aims to measure the degree to which storage in these places is adequate to the demands placed on it – whether it is being preserved or depleted.
In the Sonoma Creek watershed, there is relatively little surface storage, the largest reservoirs being two owned by the state on the campus of the Sonoma Developmental Center (SDC). There are, however, a considerable number of small farm ponds. The two major surface storage facilities in Sonoma Valley have been in operation since the 1930s and are kept at or close to capacity nearly year round. The two reservoirs are fed from a diversion of Mill Creek which pours into the smaller of the two, Fern Lake, on the east side of Sonoma Mountain. The water is then moved via gravity fed pipes to Lake Suttonfield on the east side of the SDC campus. Groundwater storage is not so obvious, but it may be even more important, especially because it is not readily restored once depleted. In our climate, both surface and groundwater storage tend to be at their highest in the spring, near the end of the rainy season, and at their lowest in late fall, before the rains resume.

Two key terms we use are drawdown and recharge. Drawdown is defined as the reduction in storage in a surface reservoir occurring between the spring and late fall. This quantity is a volume, usually measured in acre-feet. An acre-foot is the volume of water it would take to cover an acre of land to a uniform depth of one foot.

To quantify our groundwater storage indicator, we define recharge as the increase in level between the fall of one year and the spring of the next, measured in feet. This metric does not literally indicate the change in volume of groundwater storage, which would be difficult to measure with any confidence. Notice that in contrast to drawdown, this term measures the recovery of the resource rather than its consumption.

Water supply planning is important to local government. The capacity of surface and groundwater storage to meet present and future needs has been studied often, most recently in the Sonoma Valley Groundwater Management Plan (Sonoma County Water Agency 2007). The goal of the Plan is to locally manage, protect and enhance groundwater resources for all beneficial uses in a sustainable, environmentally sound, economical, and equitable manner for generations to come.

**Index: Storage, Indicator: Groundwater Table Elevation**

Score: North Basin: 1 (Poor)  Trend: Down
Score: South Basin: 3 (Good)  Trend: Down
Period covered by the score: water year 2005 (October 2004 – April 2005)

**Introduction**

The purpose of this indicator is to track groundwater storage, which we do by comparing groundwater levels – the changing level of the water table – over time. We considered the possibility of measuring groundwater use more directly, instead of relying on the condition of the water table. Detailed pumping records are not generally available for private wells, but it would be possible to collect statistics on the number of wells, their depth, etc. and one might estimate from them the
amounts withdrawn. However, this method of defining the indicator was not used, because of the effort required and the uncertainty that the results would justify it. Ideally of course, tracking withdrawal trends would be desirable, because they clearly reflect human management.

The intent is to get an idea of the extent to which the resource is being depleted or enhanced. In a more perfect world, we would track groundwater levels on the basis of a dense physical array of well sites, with a long term record for each, and we would be able to identify rising or falling trends with some precision. We would also have a good idea of the storage in the aquifers underlying our watershed. However, the groundwater data available are somewhat sparse, and we are forced to make do with fairly large-scale spatial averages of groundwater level.

Data availability

The California State Department of Water Resources (DWR) maintains a database of groundwater information (http://www.water.ca.gov/iwris/). The database was searched for well sites in the Sonoma Creek watershed with continuous records since 1980; we included all sites having at least one spring and one fall measurement each year. Groundwater levels are generally at their highest in the spring and at their lowest in the fall. Typically measurements were made in April and October, but there is some variability in timing. For this study, measurements made at other times in the spring or fall were treated as if made in April or October respectively.

The measurements were made by a variety of individuals over a period of many years and may be subject to some variation in observation method. It is likely that the data will continue to be available in future years, although, it is possible that some of the sites used for this study may be discontinued and others added.

To find a year for which there were measurements for all 10 wells, we had to go back to 2005.

Analysis, methodology, calculations, uncertainty

Depth-to-groundwater data were available for a total of 10 sites in the Sonoma Creek watershed for years 1980 through 2007. We grouped these sites by associated groundwater basin, reflecting the notion that water levels within a groundwater basin are tied to each other in a way that levels in adjacent basins are not. We divided the Sonoma Creek watershed into two groundwater basins, north and south. Grouping our data by basin gave us 5 sites in the north basin and 5 in the south basin.

Besides considering the spring and fall annual data series, we also looked at recharge, or the change in level from one fall to the following spring, or the annual replenishment of the resource, perhaps the most important part of the picture. For all three data series (fall, spring, and recharge) and for each basin, we calculated an average value for each year. We reasoned that the use of average values would
make for a simpler subsequent analysis and that, in any case, the data are too sparse to represent local effects well.

We tried two methods of calculating averages: weighting all sites equally and weighting each site in proportion to the total basin surface area which is closer to that site than to any other. The latter is essentially the Thiessen polygon method, as is used for weighting rain gauges in a hydrologic model. We found the differences in results between the two methods to be minimal and determined to use the simple average, with all sites weighted equally. The spring and fall data for the north basin are illustrated in Figure 8.

![Graph showing typical annual spring and fall series of groundwater level data for Sonoma Valley north basin.](image)

**FIGURE 8.** Typical annual spring and fall series of groundwater level data for Sonoma Valley north basin

**Evaluation and scoring**

The three metrics (spring level, fall level, and recharge) were scored by comparing current values with a baseline period. To identify an appropriate baseline period, we first looked at the history of groundwater use for vineyard development and residential use. According to the Sonoma Valley Groundwater Management Plan, the period of largest growth in both agriculture and residential water use occurred between 1974 and 2000. According to a USGS estimate, groundwater use has increased by 38 percent between 1974 and 2000 (USGS 2006). Since the period for which we have groundwater data (1980-2007) shows fairly steady increase in groundwater reliance for both agricultural and residential use, we selected the period 1980-1999 as the baseline.
For each of the three metrics and for each basin, the baseline period values were arranged in order of decreasing depth, and exceedance probabilities were assigned to each value. Figure 9 shows probability distributions for the north basin, and Figure 10 shows probability distributions for the south basin.

![Sonoma Valley North Basin Recharge Probability](image1)

**Figure 9.** Probability distribution for groundwater levels in spring and fall in the north basin, and for recharge in the north basin

![Sonoma Valley North Basin Average Spring and Autumn Water Level Probability](image2)
In order to score the three metrics, raw values were converted to probabilities, and scoring breakpoints were defined by dividing the probability range (from 0 to 1) into equal-sized sections. As the figures show, the entire probability distribution is divided into thirds. A probability in the lowest third, i.e. in the interval (0, 0.33), is assigned the lowest score of 1 (poor). A value in the next third is scored as 2 (fair), and in the top third as 3 (good). To score a particular value, one finds the value on the X-axis and uses the curve to find the corresponding probability on the Y-axis.

The probability we find for the north basin was 0.23, so it scored a 1 (poor), and the probability for the south basin was 0.97, so it scored a 3 (good).

Trends for spring and fall levels in the entire 1980-2007 dataset are similar for the two basins although we see a steeper decline in the north basin. For the north
basin, the trendlines of average level for fall and spring each show a drop of around 20 ft since 1980. In the south basin, the fall trendline is not quite as steep but both the spring and fall show a drop of about 15 ft. Although the overall trend is downward, the south basin exhibits a slightly upward trend in both spring and fall since 1995.

Discussion

The downward trends observed for both spring and fall in the north basin have a strong effect on the current values and are the main explanation for the poor score given to the north basin. In the south basin, by contrast, the groundwater level is being drawn down less since the mid 1990s than in previous years, and the wintertime recharge has been adequate to restore the resource to previous levels. The combination of strong recharge with more consistent springtime levels is the reason for the higher score assigned to this basin.

The message of the indicator is that the annual use of the groundwater resource is increasing, as measured by the fall data series for both basins. Since the groundwater resource is necessarily limited, increasing our demands on it must at some point become unsustainable, so this message should sound a note of caution for water users. In the south basin, spring levels appear to be rebounding to previous levels, which give some comfort: so far, the recharge capacity of the basin is adequate to the challenge. In the north basin, on the other hand, the resource is not rebounding well in the spring, so that the current pattern does not seem sustainable.

It is important to note that this indicator is based on a relatively small number of wells (5 in each basin), which cannot be regarded as truly representative.

Summary and Recommendations

The data for this indicator are sparse, and the strength of the indicator would be greatly improved by increasing the number of monitoring wells. However, it would take a long time to reap the benefit of such an increase, because the nature of the indicator requires a record of at least several decades. In any case, we strongly recommend that as many as possible of the existing monitoring wells be retained in the state database. Their value will only increase as the records become longer.

Missing from our analysis, for lack of time, is a quantitative statement of the uncertainty associated with the results, the score and the trend.

For the next iteration of the Technical Report, we recommend including a map showing wells, monitoring wells, reservoirs, pipelines, water supply district service areas, groundwater recharge areas, former wetlands, and other features important for understanding water in the watershed.
References

**Index: Storage, Indicator: Surface Storage**

Score: Not evaluated  Trend: Not evaluated

**Introduction**

The purpose of the surface storage indicator is to compare the amount of surface water used with the amount available. Broadly put, the question is this: are we living within our means? Ideally we would have a very long hydrologic record, not subject to climate change, and we would have precise measurements of withdrawals for use to compare with what we expect each reservoir to yield; and we would have this information for all reservoirs, large and small.

Lacking such complete information, we sought to simplify the picture considerably in order to quantify this indicator. We considered comparing the drawdown, or the difference in reservoir volume between the springtime maximum and the fall minimum in a calendar year, with the *average-year yield* – that is, the amount of water that flows into the reservoir in an average year. Establishing a meaningful trend proved to be difficult as the two major reservoirs are kept at or near capacity and we have no estimates for drawdown of farm ponds.

Most of the surface storage water in Sonoma Valley is in the form of farm ponds which are used for agricultural irrigation. In Sonoma Valley there are only two major reservoirs, Fern Lake and Lake Suttonfield. These surface storage reservoirs are located at the east and west ends of the Sonoma Developmental Center (SDC). Although state owned and operated, they provide water for the SDC only and not the general public. As such, like most of the farm ponds in Sonoma Valley, they are essentially private reservoirs. These two reservoirs are alternately filled and drawn down with infill from the Mill Creek diversion and exchanges between the reservoirs. Exchange is facilitated through gravity fed pipes that cross below the SDC campus in an effort to keep them at or near capacity.

**Data availability**

Dam records were available from the Sonoma Developmental Center’s log book, in which weekly water levels have been recorded since the dams were constructed. However, these records are hand-recorded and required transcription into an excel table for analysis. Inspection of the data revealed that the two reservoirs work in tandem to stay at or near capacity in all but the very driest of conditions.

Farm pond data was available from David Newburn at Texas A & M University through a partnership with the CDFG Hopland research station.

Sonoma Ecology Center maintains a GIS coverage of land cover that was originally digitized using aerial photography from 2000, and updated using 2004 aerial
photography. The 2004 coverage was used to estimate the area of agricultural land irrigated by farm ponds.

Analysis, methodology, calculations

The GIS coverage of farm ponds provided by David Newburn was digitized from aerial photos form 1954, 1973, 1993, 2000, 2002, and 2005. Using the pond surface area and reported storage capacity of around 100 parcels, a regression of the storage capacity as a function of the surface area was developed. This regression was used to estimate the storage capacity of the remaining 250 farm ponds. Ponds were dated for the aerial photo in which they first appeared. Thus any in place before 1954 are dated 1954 as this is the earliest record we have. It is unclear whether this dataset will be maintained and updated using future aerial photos.

Using ArcGIS software, a query was performed to select all land cover polygons that were labeled “vineyard” or “row crop”. The resultant layer was then overlaid with the farm pond GIS coverage, only polygons that intersected farm ponds were selected and total acreage was calculated. Total acre-feet of surface storage was summed from the farm ponds and divided by total acreage of irrigated agricultural land.

Annual minimum and maximum reservoir levels were recorded for both Fern Lake and Lake Suttonfield for the past 10 years and the results plotted in Figure 11.
Evaluation and scoring

With no municipal reservoirs in the Sonoma Creek watershed, we have to approach this indicator with a slightly different mindset. They do not provide an additional source of water per se. They do however provide a means of stretching the water budget through the dry season.

With two types of surface storage in the Sonoma Creek watershed, agricultural irrigation (farm ponds) and state facility (SDC reservoirs), we calculated the two separately and then averaged the scores. The two major reservoirs in the Sonoma Creek watershed were analyzed for their annual drawdown vs. recharge. On the other hand, total acre-feet of storage in farm ponds was divided across the total number of acres that were estimated to benefit from farm pond storage.

In terms of scoring how much water is available vs. how much is being used, this is difficult given the current data. We do have records for the two major reservoirs; however they are kept close to, or at capacity year round (Figure 12). Given the scoring criteria, both major reservoirs score very well. As for farm ponds, although we assume that they are filled exclusively in wet winter months, it is difficult to estimate how much drawdown they experience during dry months. At the very least, we do have data for the number of, surface area, and estimated volume of all farm ponds in the Sonoma Creek watershed.

This presents us with another question regarding scoring. We assume that a greater number of farm ponds will have a positive effect on groundwater recharge as water slowly seeps into the ground from the impounded water. Likewise, we assume that surface storage allows us to stretch our water budget and capture water in months when it is plentiful for use in months of scarcity, which too is a benefit. However, the development of farm ponds indicates a need for increased surface storage. A decrease or leveling off of surface storage development indicates that we don’t have a need for more storage and we would score higher for less development of farm ponds.

Therefore in the case of the Sonoma Creek watershed we scored this indicator using an average of: a score for the two major reservoirs, and a score for acre-feet of farm pond per acre of irrigated row crop and vineyard land. This is to say that we assume farm ponds are developed when a need arises. As we see the current situation, a leveling off of farm pond development indicates less of a need.

As SDC’s reservoirs are kept at capacity, with a predictable and consistent drawdown, the resultant score would be considered a 5. However, since they only serve the SDC which represents a little over 3% of the watershed, it is difficult to justify that score. When compared with the score for farm pond capacity / acre of irrigated farmland, we can give only a neutral score as we realize that only .3 acre feet of water is contained for every acre of irrigated agricultural land that contains a farm pond.
The number of farm ponds on average increased significantly during the 1970s and 80s which coincides with the increase in groundwater demand (1974 – 2000). However a leveling off in development of ponds has been observed in recent years. The question is then, have we reached a point where we no longer need to increase surface capacity to maintain our current needs? If so then we can score this.

In scoring this indicator, we are considering that surface storage has not significantly increased in recent years and thus is not necessary to maintain our current needs.

![Graph showing farm pond development within Sonoma Creek watershed](image)

**Figure 12. Farm pond development within Sonoma Creek watershed**

**Discussion**

Surface storage differs from groundwater storage in that its quantity is easily measurable thus it is regulated in a very tangible way. As long as the records exist, we can easily measure the quantity of impoundment or distribution. Whereas with groundwater, we cannot readily calculate the amount of storage we have and recharge quantification is subject to many variables. However, comprehensive data does not always exist and we have to make our best judgment based on available data.

SDC reservoirs aside, the Sonoma Creek watershed does not currently have any major surface storage, and none for municipal water. That in itself could be scored poorly because surface storage is considered to be a plus in the overall water budget. Then again, the same could be viewed as a sign that large surface storage
is not necessary in Sonoma Valley, simply because we are already living within our means.

In scoring this indicator, we had to consider the data that we do have. Even the two largest reservoirs are small in comparison to many that serve most municipalities. Furthermore, these reservoirs are somewhat unique in that they have a predictable and consistent drawdown; they serve the SDC campus, and have had the same annual water use for decades. There is not much of a story that can be told of these reservoirs, except that they may serve as potential municipal water supply in an emergency. That said, they are the largest reservoirs in the watershed and cannot be excluded from the analysis.

Although we have no drawdown or recharge records for farm ponds, we do have a comprehensive estimate of farm pond capacity and taken together they total roughly three times the combined capacity of the SDC reservoirs. This record should not be ignored simply because it is made up of several small impoundments.

Summary and Recommendations

We were fortunate to have received the farm pond data in time for this analysis and hope that it will continue to be updated. The Sonoma Development Center data will continue to be available, however until there is a change in distribution of the water from SDC, there will be no change in the score for the SDC Reservoirs.

Missing from our analysis, for lack of time, is a quantitative statement of the uncertainty associated with the results, the score and the trend.

References

5. **Index: Streams**

The Streams index aims to measure the degree to which flow in Sonoma Creek persists into the summer months. The underlying assumption is that in a fairly natural, undisturbed watershed, flow will persist longer over a greater area of stream channels. In the Mediterranean climate of Sonoma Valley, rainfall is concentrated in the winter and early spring, and the degree to which flow in the creek persists into the summer months reflects the continuing capacity of the watershed to soak up rainfall and slowly release it to stream channels as subsurface flow. Therefore, in a less developed watershed, the expectation is that streams will respond more slowly to rainfall, and hydrograph peaks will be less extreme—lower, less “flashy”—whether one is considering individual storms or entire rainy seasons.

We considered various indicators to capture streamflow as an index of overall water quantity in a watershed. One idea was to measure *dry season flow*, the number of days of zero flow per year, either at a gauging station on the main stem of the creek or at a tributary site where such observations are available. Another idea
was to use measurements of the length of dry reaches of tributaries as the indicator. These ideas were applied to Sonoma Creek and reported below.

**Index: Streams, Indicator: Dry Season Flow**

Score: Not scored  
Trend: Not evaluated

**Introduction**

In the Sonoma Creek watershed, daily flow records are available for a considerable length of time, but no records of comparable time period are available at tributary sites. Data from the Sonoma Creek gauge were analyzed and the number of days of zero flow per year compared with rainfall records. The number of zero flow days, however, did not correlate well with rainfall and consultations with USGS regarding gauge performance indicated that there may be significant uncertainty in the validity of zero value flow measurements.

In fact, there is some uncertainty about the meaning of zero flow, despite the regular efforts of the United States Geological Survey (USGS) field personnel to identify it. On gravel-bedded streams like Sonoma Creek, the level at which actual surface flow ceases is a shifting target. Accordingly, we turned our attention to the total amount of flow recorded during the summer months. This appears to be a more robust approach, and it is the one we have used.

**Data availability**

Sonoma Creek flow data were compiled for the USGS gauge site at Agua Caliente Road. Daily flow data are available for water years 1956 – 1981 with a gap from 1982-2002. The gap in data was filled using a synthetic hydrograph based on the flow of the nearby Napa River, together these form a continuous period of record from 1956-2007. This dataset was described in Section 3.1.2 above.

**Analysis, methodology, calculations, uncertainty**

The approach used was based on the daily average flow record for USGS station 11458500 (Sonoma Creek at Agua Caliente Road) for the entire period of record 1956-2007. The flow for the months of June through September was summed for each year. Because the amount of this “dry season” flow is related to rainfall, we accounted for the influence of rainfall by dividing the volume of dry season flow by estimated total rainfall volume.

Total rainfall volume was estimated on the basis of annual rainfall totals for the City of Sonoma downloaded from the Western Regional Climate Center (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca8351). This dataset is available for the period from 1952 - 2007. To evaluate the appropriateness of this data record for the entire area above the USGS station, we compared annual totals from this record with data collected in nearby Napa Valley at the Napa State Hospital.
Although in a neighboring watershed, the patterns of rainfall were consistent and therefore considered accurate. Finally, we calculated the ratio of dry season flow to total annual rainfall, both expressed as volumes, to use as our indicator. The resulting dataset is illustrated in Figure 13.

![Figure 13. Dry season flow as a percent of annual rainfall, by year.](image)

Ideally it would be preferable to have physically distributed datasets for both dry season flow and rainfall. This would make it possible to observe and evaluate local variations in the overall picture, which would be most useful for land managers. Because such data are not available, the basin-wide methods described above were used.

**Evaluation and scoring**

To score the indicator, we took advantage of the length of the dataset to create a probability distribution for the period 1956-1996 and compare the current average dry season flow ratio with it. Since the work on cumulative flow (see Section 3.1 above) did not suggest that a smaller portion of the record would be a more appropriate baseline period, we have used the long period indicated. The annual values of dry season flow for the entire 40-year period were arranged in ascending order, and exceedance probabilities were assigned to each value. Figure 14 shows the resulting probability distribution.
To score the metric, we followed the same procedure as in section 3.1.4 above. Raw values were converted to probabilities, and scoring breakpoints were defined by dividing the probability range (from 0 to 1) into equal-sized sections. As the figure shows, the entire probability distribution is divided into quintiles. A probability in the lowest quintile, for example, which lies in the interval (0,0.2), is assigned the lowest score (Very Low, for a value of 1). A value in the next quintile is scored as Low (value 2), and so on. To score a particular value, one finds the value on the X-axis and uses the curve to find the corresponding probability on the Y-axis.

As in the section on cumulative flow, the method employed answers the question how high or low the metric is, compared with the period of record. In this case, in contrast to the earlier section, we make the assumption that higher and lower levels correspond to better and worse environmental health, respectively, for the reason given in Section 6.2.1 above. To reduce the effect of year-to-year variations, the current condition was scored on the basis of the average of the years 2004-2007. That is, the probability values for each of the four most recent years were averaged and converted into a score for the watershed. The resulting score is 3 (Fair).

The slightly upward trend in the data are not statistically significant.

Discussion

This indicator suggests that dry season flow has if anything increased slightly during the period of record, a surprising result. Given that there has been some development in the watershed, we expected any trend in the data to be downward. Other than this unexpected trend, the indicator turns out to exhibit considerable variation from year to year, even when the variability in rainfall is taken into account. The current condition scores slightly above average for the entire period.

We explored possible reasons for the upward trend observed in the data. The period of record has seen an increase in vineyard development in the Sonoma Creek watershed, replacing other land uses ranging from orchards to cattle grazing. It is possible that the increase in irrigation associated with vineyard development has led to increased agricultural return flows during the summer. One would not expect this to be a large factor, because of the nature of typical vineyard irrigation practices: the virtually universal practice is to use drip irrigation and applied water volumes are quite low, rarely more than 0.5 ac-ft per surface acre. However, any water applied to irrigate plants that is not consumed by evapotranspiration will remain in the upper soil layer and slowly make its way to the creek, and this is water which would not otherwise have been available in the summer (it is either impounded during the winter, for summertime use, or pumped from groundwater at the time of use).
Another possible reason for the observed increase in dry season flow is the increased use of cover crops in vineyards. With strong encouragement from state and county regulatory policies, the use of cover crops in vineyards in this watershed has increased greatly since about 1990. This increase has had the effect of putting more water into the soil during the summer, but there is little reason to expect farmers to be wasting irrigation water by overwatering what is not a cash crop. In addition, the timing of this historical development does not match the dry season flow data, which show an increase well before 1990.

It should be borne in mind that we are comparing small flows in the application of this indicator. In all but two of the years (1967 and 1996) for the baseline period, the total summertime discharge is less than 1% of the total estimated rainfall volume, so it is a relatively small portion of the total annual discharge. Although USGS, the agency that collects the data, is committed to making the most accurate measurements possible at all flow levels, it may be that the upper part of the flow rating curve gets more attention, because of its importance in assessing flood risk.

We conclude that the uncertainties associated with this indicator are too great to use it in the Scorecard.

Summary and Recommendations

The data necessary to calculate this indicator should be available as long as the USGS maintains the Sonoma Creek gauging station referenced above. Given the importance of this gauging station for multiple purposes, it seems likely to be maintained. Future reporting on this topic will be improved, though, if additional data sources can be made available.

We recommend that other metrics reflecting summer stream conditions be explored, because the metric reported here is problematic.

References

**Index: Streams, Indicator: Dry Reaches**

Score: Poor (1)  Trend: insufficient data record  
Time period: 2000 - 2003

Introduction

Numerous stream reaches in Central California, including Sonoma Creek and its tributaries, become completely dry during the summer and fall. While there remains uncertainty regarding the extent of dry stream beds in the watershed under historical “pre-disturbance” conditions, anecdotal evidence from local residents suggests that there has been a declining trend in the extent of flowing stream lengths during the summer/fall season.
Maximizing watershed stream flow during the dry season is fundamental to the health of the ecosystem and local communities. Reduced flows in stream channels increase water temperatures, impede migration, increase predation and competition for scarce food and habitat, or affect territorial behavior and aggression among members of the same species. Absent sufficient flow, juvenile steelhead and other cold water species may experience low growth, weight loss, or mortality (Stillwater Sciences 2002). Significant mortality of over-summering fry, estimated to be on the order of thousands, has been observed in the field in the course of habitat surveys. Dry stream beds also indicate low groundwater table elevations and reduced rates of recharge via flow through streambeds into the aquifer during the dry season. Adequate dry season stream flow helps maintain aquatic conditions and serves to connect habitat so that organisms may shift location as necessary to follow food and other resources. The ecological beneficial uses of summer base flows may include groundwater sustainability for the long-term.

There remain many diversions (pumps that transfer water from the stream to adjacent properties) on Sonoma Creek and tributaries that support local households, primarily with irrigation water. While there is uncertainty about the legality of all of these diversions (responsible parties are required to file a permit with the State Water Resources Board), those who rely on streamflow for any part of their water supply during the dry season are impacted when flows diminish or disappear. Another impact on human supply is reduced availability of groundwater near riparian zones during periods of stream desiccation. The linkage between dry season flow and local groundwater resources is supported by Stream Stewards’ anecdotal evidence of reduced streamflow synchronized with the operation of large irrigation pumps nearby.

Given naturally low summer base flows, we hypothesize that even small human-induced flow reductions can have an adverse effect on the extent of wetted streams during the summer and fall. Groundwater pumping, small dams, and flow diversions all serve to reduce base flow. Channel incision, estimated at over twenty feet deep on the mainstem of Sonoma Creek, has also served to draw the local riparian water table down by allowing adjacent aquifers to drain from exposed bedrock into stream channels. Agricultural withdrawals reduce potential recharge to the groundwater system. Conversely, the importation of water from other basins, in this case the Russian and Eel Rivers, for irrigation and residential use, has the potential to augment summer base flows, particularly in urban areas due to watering of gardens and lawns. However, these withdrawals pose adverse effects to those contributing watersheds and may not continue indefinitely.

Local observers of trends in surface flows and groundwater table levels are concerned that there is a pattern of declining base flows in conjunction with groundwater table lowering in the Sonoma Creek basin (Nelson pers. comm. 2004). Habitat surveys conducted between 1996 and 2007 encountered extended stream lengths that were completely dry, causing direct mortality to estimated thousands of juvenile fish (SEC 2003 and 2007). Current stewardship efforts in Sonoma and other watersheds focus on minimizing the magnitude of diversions during the summer season, to help sustain adequate base flows for healthy aquatic habitats.
Monitoring the magnitude and spatial distribution of wetted streambeds during the dry season provides important information about the value of potential summer rearing habitat for juvenile fish and points to the sustainability of groundwater resources.

Data availability

For the Sonoma Creek Limiting Factors Analysis, Sonoma Ecology Center staff supplemented Low-Flow Monitoring (discussed above), with Dry Reach Measurements (see http://knowledge.sonomacreek.net/montype/dry-reach-measurements). With the help of technical advisors for the LFA, we developed a protocol to map the maximum extent of dry versus wetted stream reaches for representative streams.

Through the dry season, as we recorded data at low-flow monitoring stations, we also recorded the upstream and downstream boundary between wetted and dry streambeds using a hand-held Garmin GPS unit. We resurveyed approximately bi-weekly from April until the first fall rain, to capture the maximum extent of dry streambed for the season. These GPS data were input into a GIS to facilitate mapping. We also input the extent of dry stream reaches measured during habitat surveys (SEC 2003 and 2007) using routed stream network values to augment our database of stream reaches prone to drying out.

This evaluation of dry stream lengths represents a compilation of data collected between 2000 and 2003. Future evaluations will include analysis of data collected in subsequent years. Sources of data include the above-described dry-stream measurements taken during low-flow monitoring, as well as dry streambeds mapped for habitat surveys conducted using California Department of Fish and Game protocols and archived using the Habitat-8 program (SEC 2003 and 2007). We will maintain this analysis as a permanent part of our watershed monitoring program.

Analysis, methodology, calculations

Using the 2000-2003 data, the length of dry streambed at its maximum, in miles, was compared to the length of total potential stream habitat on each tributary. Total potential stream habitat was defined as the total length of stream, both dry and wetted, available to migrating fish downstream of natural barriers. In cases where there are natural barriers further downstream that remain unmapped, our calculations underestimate the total percentage of habitat lost due to summer dry reaches.

Evaluation and scoring

Table 1. Comparison of dry reaches with all available fish habitat on ten streams, 2000-2003, Sonoma Creek Watershed
The table below proposes a scoring scheme, with the percentage shown a measure of the extent of wetted streambeds for a given known length of functional habitat on indicator tributaries. The scoring bins span the indicator values for all reported tributaries. Because 2008 wetted stream channel surveys are underway, it will be important to use this data collected during a drought year to calibrate the scoring table.

Table 2. Proposed scoring scheme for dry reaches on ten streams, 2000-2003, Sonoma Creek Watershed

<table>
<thead>
<tr>
<th>Creek Name</th>
<th>Length Dry Creek Beds (mi)</th>
<th>Length of Fish Habitat (mi)</th>
<th>% Dry Stream Length</th>
<th>% Wetted Stream Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rodgers</td>
<td>4.13</td>
<td>9.41</td>
<td>44%</td>
<td>56%</td>
</tr>
<tr>
<td>Carriger/Lower Fowler</td>
<td>5.75</td>
<td>8.91</td>
<td>64%</td>
<td>36%</td>
</tr>
<tr>
<td>Mill</td>
<td>0.08</td>
<td>2.78</td>
<td>3%</td>
<td>97%</td>
</tr>
<tr>
<td>Sonoma (trib)</td>
<td>1.16</td>
<td>7.37</td>
<td>16%</td>
<td>84%</td>
</tr>
<tr>
<td>Calabazas</td>
<td>0.34</td>
<td>3.79</td>
<td>9%</td>
<td>91%</td>
</tr>
<tr>
<td>Stuart</td>
<td>0.79</td>
<td>2.65</td>
<td>30%</td>
<td>70%</td>
</tr>
<tr>
<td>Hooker</td>
<td>2.05</td>
<td>2.40</td>
<td>86%</td>
<td>14%</td>
</tr>
<tr>
<td>Agua Caliente</td>
<td>3.39</td>
<td>5.22</td>
<td>65%</td>
<td>35%</td>
</tr>
<tr>
<td>Nathanson</td>
<td>1.18</td>
<td>6.34</td>
<td>19%</td>
<td>81%</td>
</tr>
<tr>
<td>Arroyo Seco</td>
<td>1.60</td>
<td>7.17</td>
<td>22%</td>
<td>78%</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td></td>
<td>36%</td>
<td>64%</td>
</tr>
</tbody>
</table>

Results and Discussion

This data shows that for representative surveyed streams, a watershed average of 36% of potential salmonid rearing habitat was lost due to lack of flow. A minimum value of 3% measured was measured on Mill Creek.

Conversely a watershed average for wetted stream length is 64%. Minimum values for wetted stream length were measured on Hooker (24%), Agua Caliente (35%), and Carriger/Fowler (36%) Creeks. Wetted stream lengths on Sonoma, Rodgers, Calabazas, Nathanson, Stuart, and Arroyo Seco Creeks ranged from 81% to 66% percent.

Comparison of the above data with landform maps indicates that the reaches where creeks go dry tend to coincide with the intersection of streams with deposits of alluvium, waterlain deposits of coarse sediments eroded from the ancient mountain...
ranges, rather than bedrock. In the cases of Rodgers and Carriger Creeks, the transition from dry creek bed to wetted creek bed coincides quite closely with the transition from alluvial fan to upland hillslopes. In the cases of Agua Caliente, Hooker, and Sonoma Creeks, lower reaches of dry streambed coincide with alluvial fan and terrace deposits, while upper dry reaches coincide with mapped floodplain deposits of alluvium. On these creeks, both endpoints of mapped floodplain alluvium mark transitions to wetted beds.

On Nathanson and Arroyo Seco Creeks, streambeds are dry in the alluvial fan deposits at the base of the Mayacamas, but return to wetted conditions through downtown Sonoma, which could be a product of residential irrigation return flow. Asbury and Mill Creeks show short dry reaches that return to a wetted condition upstream of confluences with Sonoma Creek. There are essentially no alluvial fan deposits mapped at the base of Sonoma Mountain where these creeks run. The short dry reaches mapped on Asbury and Mill Creeks occur very close to the boundary between medium-relief non-uniform hillslopes, characterized by mountain-scale landslides, versus high-relief uniform hillslopes, characterized by intact bedrock upstream. The short dewatered reaches mapped on Asbury and Mill could indicate the influence of a fault or landslide scarp on differential rates of subsurface flow.

Summary and recommendations

Linking patterns of dry season flow to landform units and other controls on stream channel permeability and flow can help to predict where streams may be prone to drying out during the summer. Zones where the stream is prone to drying out during summer, because they consist of coarse, highly permeable deposits, are also most likely zones where groundwater recharge may occur during the wetter months. A water balance that quantifies total water inputs and outputs would help to model potential response between aquifer recharge/drawdown rates and surface flow patterns. We recommend that future research focus on measuring relationships between groundwater and surface flows during the summer season and establish a predictive relationship between the spatial extent of dry reaches and streamflow measured at the USGS gauges. We also recommend pursuing a program of shallow groundwater monitoring stations linked to surface flow stations to gather empirical data to strengthen our understanding of these complex relationships. A better understanding of how dry stream reaches form, expand, and contract will help inform management decisions influencing water resource sustainability and related ecological beneficial uses.

Missing from our analysis, for lack of time, is a quantitative statement of the uncertainty associated with the results, the score and the trend.

References

Stillwater Sciences. 2002. Absent sufficient flow, juvenile steelhead and other cold water species may experience low growth, weight loss, or mortality.

SEC. Limiting factors analysis
6. **Index: Landscape Permeability**

One of the most significant anthropogenic impacts to our watersheds has been to effectively reduce their water recharge capacity. A technical term to define this process is “hydromodification,” the extent to which natural processes of water storage and release have been changed due to human impacts.

Prior to European contact and American settlement, our watersheds were characterized by vast expanses of wetland systems, including fresh water and tidally-influenced ponds and marshes, particularly on the valley floor and estuarine portions of the watershed. These wetlands served as terrestrial receiving areas for precipitation and upland runoff. For example, early Spanish explorers of the Sonoma watershed reported that low areas of the valley floor were inundated for the majority of the spring and early summer season. This retention of winter flows allowed for recharge of the valley's aquifer and delayed release of base flows into the stream network.

Human alterations to this system were part of the “drain and reclaim” land ethic of early American settlers. With the advent of livestock and dedication of lands to grazing areas, there was an incentive to ditch and drain wetlands in order to increase the productivity and accessibility of grazing lands. Simultaneously, stream channels were mined for gravel and cobbles, while the mouths of Sonoma Creek and the Napa River were dredged to enhance navigability. These factors initiated a cycle of channel incision, degradation of the stream bed resulting in deeper and narrower creeks, and reduction in floodplain width and associated riparian wetlands. The overall result has been to accelerate the flow of water through the system and to eliminate the wetland “sponges” that used to absorb and then slowly release water over the dry season.

Contemporary approaches to watershed management aim to reverse this pattern through cumulative measures designed to begin to restore the water recharge function of the watershed. These include restoration of creek floodplains and wetlands and guidelines for new development aimed at enhancing retention and recharge of water on site.

The best way to track watershed modification would be via a monitoring program to link watershed modification to response variables including streamflow and groundwater recharge. The landscape permeability index as presently developed, however, relies solely on a direct measurement of watershed impervious area. We recommend that this metric be complemented in future iterations of the Scorecard with an assessment of the runoff coefficient, a measure of what is termed the...
“flashiness” of the system, at a subwatershed scale, to track impacts of watershed development in terms of hydrologic response over time.

**Index: Landscape Permeability, Indicator: Impervious Area**

Score: 2 (Fair)  
Trend: Down  
Time period covered by score: 2001

**Introduction**

The extent of watershed impervious area, a measure of the portion of watershed area occupied by materials like roofing and asphalt that do not allow penetration of water into underlying substrate, is an important indicator of the extent of hydromodification in a watershed. Hydromodification is an umbrella term that includes a range of possible changes to natural flow and storage pathways of the hydrologic cycle (see Conceptual Framework in Section 2 above), including direct anthropogenic reduction of watershed recharge potential. The conversion of a portion of the watershed area to fully impervious materials means that all of the rainfall hitting that area will be converted to surface runoff. In the terminology of the broadly used universal soil loss equation (USLE), impervious area is assigned a runoff coefficient of 1.0 (given a range from 0 to 1), meaning that 100% of intercepted rainfall is estimated to be converted to surface runoff. This value may be compared to a runoff coefficient value of 0.1 (meaning that only 10% of intercepted rainfall is expected to run off, while 90% is expected to infiltrate) which is typically estimated for a pasture or grassland.

Direct impacts of the expansion of impervious watershed area include 1) reducing recharge potential, or the amount of water that can infiltrate into subsurface soils and/or weathered bedrock and 2) accelerating the amount and rate of runoff delivered to downslope areas, including stream channels. Cumulative results may include accelerating the concentration of peak flood flows and reductions in long-term rates of aquifer recharge. By accelerating the rate of flow concentration, peak flows may grow in magnitude, causing greater shear stress and in turn greater erosion of stream bed and banks. The result would be a net increase in runoff into San Francisco Bay estuary and a net reduction of water retained in the watershed for human and ecological uses. A net increase in runoff may bring increased pollutant loads from impervious surfaces and deposited into streams.

Examination of the literature, discussed in more detail below, suggests that watershed impairment can occur at values as low as 3% impervious watershed area. The most applicable studies to our region of interest were based in Southern California: no empirical studies of impervious area response are known for the Napa and Sonoma Valleys. There are numerous challenges to accurately capturing the effects of impervious area on a watershed hydrograph, including the natural variability in total quantity of rainfall and stream flows, variability in rainfall spatial distribution not captured by monitoring networks, and the limited locations of accurate streamflow gauges. There is evidence to suggest that to be successful
such studies may need to focus on a sub watershed to be able to accurately capture change in the response variables.

Existing studies suggest that watershed scale and the spatial distribution of impervious area influence hydrologic response. For example, Coleman et al (2005) examined the hydromodification response of southern California streams to increasing impervious area. They found two key aspects of a watershed affected this response: 1) the size of the watershed, and 2) the seasonality of a stream channel. They found that hydromodification from changes in impervious area is most recognizable in watersheds smaller than about 20 square miles, and management of impervious area is most critical in watersheds less than 2.5 square miles. These findings suggest the value of evaluating impervious area and hydrological response at the scale of a subwatershed for the larger Sonoma Creek or Napa River watersheds. Further, the effects of hydromodification are much more pronounced in small storms than in larger storms. We will revisit these issues under Data Gaps and Recommendations, below.

Data availability

There are a range of methodologies for estimating or calculating impervious area, including using data from satellites, ground surveys, global positioning system technology, aerial interpretation, land use designations, or a combination of methodologies. The data sources considered here are based on methodologies that have been developed in a standardized manner for the United States, allowing for applications in other watersheds in California or across the country for comparison.

Two major datasets were considered for the percent impervious area (IA) indicator: the National Land Cover Database (NLCD) which covers the entire United States and a dataset based on General Plan land use data developed by the Information Center for the Environment at UC Davis for the state of California. The reliability of NLCD (as a federally funded and widely-used dataset) and the shorter time needed to calculate impervious area made it the best choice for this project.

NLCD was developed through a partnership called Multi-Resolution Land Characteristics Consortium (MRLC), a group of several federal agencies (USGS, EPA, USFS, NOAA, NASA, BLM, NPS, NRCS and USFWS). The first version of NLCD was developed in 1992, and updated for 2001. Percent imperviousness was calculated using Landsat imagery and ortho photographs to calibrate an algorithm that produces % imperviousness per 30 meter pixel. This particular dataset is ideal because it applies a consistent methodology to all 50 United States and Puerto Rico, so that data for imperviousness can be compared across many watersheds and regions. There are a few caveats about the NLCD that stem from it being a widely applied dataset across a large area. First, the dataset is by now over 9 years old. A large amount of development has occurred in both watersheds since then, and it is difficult to estimate the % change in total impervious area (TIA). Second, the data are based on an algorithm that was calibrated using a sample of photographs, and there may be errors due to how certain structures or landscapes appear in a photograph and how much impervious area is actually present. A detailed
description of the methodology and dataset is explained in Homer et al 2004 and at http://www.mrlc.gov.

It is likely that this dataset will see a third version within the next few years so that there is a new version every 10 years. However, there is no information from MRLC yet about the timing of the next update.

Analysis, methodology, calculations, uncertainty

For this analysis we calculated total impervious area (TIA) (to be distinguished later in our discussion from effective impervious area (EIA)). TIA was calculated using the NLCD data layer in combination with the computer program ArcGIS by the Bay Area Open Space Council (2008). The NLCD was loaded into a map document, along with watershed boundary shapefiles. A mask for the watershed boundary was applied, with the analysis extent for the impervious layer set as the same for the watershed. Then the raster calculator was used to calculate the percent of watershed area categorized as impervious within the watershed boundary.

The total impervious area for the Sonoma Creek watershed in 2001 was 3.63%.

Other methods are more time consuming, although they may be slightly more up-to-date or detailed due to changes in resolution.

Evaluation and scoring

There are concerns about the utility of using simple rules of thumb regarding the relationship between TIA and watershed health in semi-arid regions such as the Sonoma and Napa Valleys. While the Center for Watershed Protection (CWP) in Ellicot City, MD has popularized the idea that watersheds consisting of more than 10% impervious area tend to exhibit impaired stream health, and others argue that with IA over 25%, the system may be “non-supporting” to aquatic life (Schueler 2000), we believe these thresholds are far too high to use as effective targets for IA in our local watersheds. While degradation occurring at these thresholds has been confirmed by numerous other studies, the literature also points to greater sensitivity in semi-arid regions. In studies based in southern California, streams have been more sensitive to IA than the CWP 10% threshold would suggest, with “physical degradation of stream channels... [detected] when basin impervious cover is between 3% and 5%.” However, biological effects are probably occurring at even lower levels (Stein and Zaleski 2005). Some studies have concluded that any amount of IA, under existing management practices, will negatively affect aquatic systems (Booth et al 2002).

Coleman et al (2005) examined the response of southern California streams to increasing IA and the accompanying hydromodification. Besides the size of the watershed influencing response, they found vulnerability to change was also influenced by the seasonality of a stream channel. Most watersheds in the study had at least some channels with ephemeral or intermittent flow, since they are very common in semi-arid climates, even in larger watersheds that have more
contributing runoff. The researchers found that ephemeral channels are more sensitive to change in total IA, and exhibit signs of degradation at 2-3% IA, in contrast to perennial channels in humid regions in the literature, which start to degrade at 7-10%. Since ephemeral channels are plentiful in this watershed, these features may be considered highly vulnerable to changes in IA. Thus we used 2% TIA as the boundary between “good” and “fair.”

If 25% TIA has been shown to create “poor” conditions in humid watersheds, a substantially lower TIA is likely to create those conditions in semi-arid watersheds with many ephemeral channels. Based on this logic, we chose a boundary of 10% TIA between a “fair” score and a “poor” score.

<table>
<thead>
<tr>
<th>Score</th>
<th>1 (poor)</th>
<th>2 (fair)</th>
<th>3 (good)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent total impervious area of the watershed</td>
<td>&gt; 10.00</td>
<td>2.00 – 9.99</td>
<td>0 – 1.99</td>
</tr>
</tbody>
</table>

By this method, the Sonoma Creek watershed receives a score of 2 (fair) for 2001.

We did not attempt to calculate a trend in this indicator from the 1992 data, due to lack of time. However, we state that there is a downward trend in the indicator, based on the amount of development, and therefore increase in TIA, that has occurred since 2000. Low impact development, and other efforts to reduce the effective imperviousness of new development and redevelopment have not yet been implemented on a scale that has caused EIA to diverge substantially from TIA, although this divergence may be seen in the next 10 years or so.

Missing from our analysis, for lack of time, is a quantitative statement of the uncertainty associated with the results, the score and the trend.

Discussion

Short term trends are difficult to predict but over the long term it is inevitable that more development will occur in both Napa River and Sonoma Creek watersheds, potentially leading to an increase in impervious area throughout the watershed. However, the amount of “effective” impervious area (EIA), is the area of impervious surface directly connected to stream channels, may decrease over time. With the growing popularity of low impact development (LID) design and techniques implemented for stormwater control and provisions showing up in building codes, it is possible that more runoff will be treated onsite before being discharged into stream channels. Pervious pavement, filter strips, and other similar designs allow for the more natural percolation of water into the ground so that large flows do not inundate stream channels, erode banks, and further exacerbate hydromodification that is occurring in the watershed.

This metric tells us that Sonoma Creek is at higher risk for hydromodification and the negative impacts that such action brings to river systems. Because the scope of this scorecard does not include analyses of macroinvertebrate taxa richness, or other biological indicators of riparian health, it is difficult to determine whether the
ecological health of the system is at great risk for degradation and at what scale the problem has reached. However other studies, such as those related to the sediment, nutrients, and pathogens TMDLs for both watersheds, indicate that there are major problems common across both watersheds that are caused by increasing development (urban, suburban, and agricultural) and are affecting water quality.

Summary and Recommendations

Ideally, this indicator would use a dataset updated more frequently than the NLCD. This evaluation sets a baseline that may need to be re-evaluated should funding become available for more localized and frequent assessments of impervious cover. Ideally higher resolution photographs taken from aircraft would be analyzed and impervious areas delineated for both watersheds to have more exact area calculations. Using this alternative method, statistics on impervious area could be obtained for individual subwatersheds or even smaller scales to allow for more site-specific planning of development and riparian area management.

It can be argued that EIA is the more accurate indicator of stream health (Brabec et al 2002). The argument against the use of TIA (total impervious area) comes from the fact that watersheds with a comparable percentage of TIA can have a wide range of biological conditions, due in part to the varying percentages of impervious areas that directly feed runoff into streams without some kind of pretreatment. This is particularly relevant in watersheds with little urban development (Walsh 2004; Booth et al 2002). Walsh conducted a study in 16 watersheds near Melbourne, Australia to test this theory (2004). His results showed that the amount of storm water connections, or degree of drainage connectivity, was a better predictor of macroinvertebrate taxa richness and composition that simply TIA. He also suggested that in order to restore stream health and improve degraded watersheds in an urban setting, local governments should focus first on reducing the number of direct connections between streams and the storm water system and then later address habitat restoration. Even if riparian buffers and other natural filters for runoff are implemented, their potential for filtration might not be fully utilized as long as storm water systems bypass these areas. Further, the offsite causes of habitat degradation would still be in place without first reducing drainage connectivity.

If possible in the future, the Scorecard should use EIA as the metric instead of TIA. EIA may be considerably different because it only includes the impervious surfaces that are directly connected to streams and other water bodies. There are several possible means of connection, including a storm drain system, or agricultural areas with extensive engineered hill slope drainage or plastic covering for crops, which direct runoff directly into ditches and streams. EIA excludes those areas that direct runoff into some sort of treatment area because it is less likely that those areas contribute a significant amount of pollution to receiving waters (Booth and Jackson 1997; Walsh 2004).

However, given the variable distribution within a watershed, and varying recognition of impacts, precision may not always be important. Many applications
do not require the use of IA as a precise indicator, but instead apply it more broadly as a screening device used to make a rough estimate of where in a watershed pollutant loads or other impacts could be high, where effects of hydromodification might be more pronounced, or where to prioritize the implementation of management measures in order to identify current and predict future impacts so they can be mitigated or prevented. To make coarse calculations, it is not necessary to have a precise means of measurement.

We recommend that this metric be complemented in future iterations of the scorecard with an assessment of the runoff coefficient, a measure of what is termed the “flashiness” of the system, at a subwatershed scale, to track impacts of watershed development in terms hydrologic response over time.

In future, this indicator should be scored in terms of the “impervious area” per resident, with a target of maintaining the existing level of impervious area into the future by gradually reducing the impervious area per capita.

References


7. **Index: Stewardship**

Webster’s Ninth Collegiate Dictionary defines stewardship as “the individual’s responsibility to manage his life and property with proper regard to the rights of others.” Applied to a mix of private and public “properties,” including watershed resources “owned” by all (such as flow in streams, the air we breathe, and aquifers), stewardship assumes a meaning of “taking care of” and “sustainably managing” resources without compromising the ability of future generations to meet their needs.

Stewardship indicators help evaluate and track management of water resources over time, developing a line of evidence that links environmental conditions to management and stewardship activities. If environmental condition indicators tell us that we are moving away from desired conditions, and certain stewardship indicators are exhibiting no change over time, watershed managers may use this information to re-prioritize activities or implement more management practices.

For this project, we selected three indicators to represent the Stewardship Index. Under **water independence**, we examine the degree to which water needs are met by local resources. Under **water use**, we evaluate our success at conserving water as consumers. Finally, under **sustainable policy** we consider the degree to which public policies encourage stewardship. Each of these will be further explained below. In the future, additional indicators may be developed to expand this index.

**Index: Stewardship, Indicator: Water Independence**

Score: 1 (Poor)  
Trend: Up  
Period covered by this score: data are compiled from 2000 and 2010

**Introduction**

The Sonoma Valley community has expressed a desire to increase its level of water independence; that is, the degree to which the water used in Sonoma Valley comes from Sonoma Valley. This desire is driven by multiple factors. Water imports are likely to level off or diminish in the near future, according to the Sonoma County Water Agency. Some Sonoma Valley residents are uncomfortable with contributing to problems of fisheries and water quality in the water source watersheds. Some want to see less energy spent on, and less greenhouse gasses emitted by, the importation of water. Watershed residents wish to use water more carefully and find ways to re-use it, thus necessitating less importation. Better management of local water supplies will ensure that there is sufficient quantity of water for all uses.

This indicator includes two metrics: recycled water (treated wastewater) that replaces potable sources, as a percent of total water use, and local water (from inside the watershed boundary) as a percent of total water use. When these percentages are high, the level of water independence is high.
In other watersheds, such as Napa River, the amount of water stored in reservoirs, called surface storage, is a significant component of local water supplies. But in the Sonoma Creek watershed, the volume of surface storage is small enough to ignore for this analysis.

Regarding recycled water: There is one publicly owned treatment works in the Sonoma Creek watershed, the Sonoma Valley County Sanitation District, operated by the Sonoma County Water Agency. They recycle some of their treated effluent to replace potable water from local or imported sources. Currently the largest users of recycled water are vineyards in the south Sonoma Valley, where the recycled water is replacing groundwater sources. A key limiting factor to further expansion of recycled water use is the lack of appropriate storage and distribution infrastructure. Therefore, the largest portion of treated water that would theoretically be available for re-use and replacement of potable water supplies is discharged to receiving waters (streams) during the wet season and disposed of on land during the May-October period for which discharge prohibitions apply. Planning is underway to greatly increase the use of recycled water, by building a pipeline system that would reach, among other destinations, the Sonoma Golf Club and nearby vineyards.

Regarding imported water: An aqueduct operated by the Sonoma County Water Agency carries water from the Russian River near Healdsburg to many users throughout Sonoma and Marin Counties, including Sonoma Valley. Some of that water comes originally from the Eel River via the Potter Valley diversion. In Sonoma Valley, the water is sold to the Valley of the Moon Water District and the City of Sonoma, who re-sell it to residential and commercial customers.

Regarding total water use: Total water usage varies greatly from year to year, mostly corresponding to weather conditions and to irrigation practices in the agricultural sector, which is the largest consumer of water.

Data Availability

Most of the metrics associated with this indicator are regularly collected, although not readily available in useable form. Data are collected and maintained by city and county land use departments, water agencies, publicly owned treatment works, the Association of Bay Area Governments, and non-governmental organizations, such as the Local Government Commission.

For this analysis, however, data on recycled water was obtained directly from SCWA personnel. Due to time constraints, this iteration of the Scorecard uses 2000 water use data reported in the 2007 Sonoma Valley Groundwater Management Plan by USGS (http://www.scwa.ca.gov/files/docs/projects/svgw/130_Sonoma-Valley-Groundwater-Management-Plan-Dec-2007.pdf). See, particularly, Figure 2-2 in that publication. Note that these data sources are not from the same year. Although we report that all the recycled water used for agricultural irrigation is replacing potable water, this may not be strictly true, since water from some wells in the south valley may not be of potable quality.
It should be noted that groundwater wells are not metered, and exact use data for agriculture are not available. Especially in areas with persistent and unaddressed groundwater overdraft problems, the volume of groundwater unsustainably “mined” should be subtracted from the local-imported source ratio. For this round of scoring, however, we lacked the resources to estimate the volume of “mined” groundwater and did not subtract it.

Analysis, Methodology, Calculations

<table>
<thead>
<tr>
<th>Total Water Used</th>
<th>Recycled Water Produced</th>
<th>Recycled Water Replacing Potable Water</th>
<th>Imported Water</th>
<th>Groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,810 Acre-Feet</td>
<td>4,500*</td>
<td>1,500*</td>
<td>5,317</td>
<td>8,493</td>
</tr>
</tbody>
</table>

As a % of Total Water Used:
- Recycled: 7%
- Replacing: 36%
- Groundwater: 57%


Evaluation and Scoring

The target for recycled water replacing potable water is 30% of total water used. This target is based on SCWA’s target that 100% of the recycled water produced at the Sonoma Valley County Sanitation District (4500 ac-ft/year) replace potable water. The target for the proportion of local water used is 100% local water.

The current volume of recycled water replacing potable water supplies is 1500 ac-feet/year. This is 10% of total water used, and 33% of the target. The volume of imported water is 5,317 ac-feet. Local water equals total water used minus imported water, which equals 9493 ac-ft. This is 64% of total water used, and 64% of the target of 100%. Averaging these two results (33% and 64%) indicates that the Sonoma Valley has achieved 49% water independence.

No trend for these metrics was calculated from the data, because we were unable to analyze past data. However, it can be predicted that the trend for this indicator is upward, because imports are planned to be unchanged or even declining, and plans are in process to increase the volume of recycled water used.

Breaks between scores were set at 60, 80, and 100. Thus, Sonoma Valley receives a Water Independence score of 1 (poor). This comports with what seems to be community feeling on the issue. The scoring breaks are designed to set up a likely visible improvement in the next 20 years.

Missing from our analysis, for lack of time, is a quantitative statement of the uncertainty associated with the results, the score and the trend.
Discussion

The use of local water supplies depends on the natural water supply from precipitation, recharge rates to aquifers, and water use efficiency. The demand for recycled water, and its production volume, will be increasing.

There is substantial room for improvement in both the re-use of treated wastewater and the reduction of water imports.

Summary and Recommendations

Results will be improved if time series data can be analyzed for water imports, recycled water use, and total water use. The latter is most problematic, because it is only estimated on an occasional basis. Future approaches for assigning targets may need to make independent assessments of what realistic recycling targets might be.

In 2009, California relaxed the laws governing the use of greywater, or water reused onsite for non-potable uses. Homes, businesses, and possibly neighborhoods in the watershed will likely increase their use of greywater in the future, and at some level of implementation, this measure of water independence will be important to include in this indicator.

References


Index: Stewardship, Indicator: Water Conservation

Score: 2 (Fair)  Trend: no single trend observed  Period covered by score: 2007

Introduction

This indicator evaluates residential use of water, which consists of what is used in single family and multi-family residences for indoor uses (waste elimination, washing clothes and dishes, bathing, drinking) and outdoor uses (irrigation and cleaning). Residential use is the factor most directly controlled by individuals and families, whose decisions to conserve water in and around the home can collectively create large-scale benefits. More efficient use can reduce the financial and energy costs of water and wastewater treatment, transporting and storing water supplies, and developing new sources; replace ecologically harmful water diversions from rivers and streams; relieve competition for limited supplies; and reduce pollutant...
loads from irrigating lawns, gardens and crops. In short, more efficient water use can reduce the human “footprint” on the natural water balance.

The measure is gallons of water an individual uses per day (gallons per capita per day- gpcd), and compares that to the target efficient water use that could be achieved if currently available water saving devices and conservation measures were adopted by the residents of the Sonoma Creek watershed. Residential per capita use can be compared within and across watersheds while per capita use based on the total municipal use would measure, along with the residential use, different commercial, industrial, and institutional (CII) mixes by the different municipalities and thus make comparisons of what we as individuals use less meaningful.

There are two public water suppliers in the Sonoma Creek watershed – City Of Sonoma (COS) and the Valley of the Moon Water District (VOM), which serves the communities of Glen Ellen, Boyes Hot Springs, and El Verano. 1 These two districts provide water to nearly three-quarters of the more than 42,000 people living in the Sonoma Creek Watershed. 2 These water systems deliver water for residential, commercial, institutional, and public landscaping uses. They derive their supply primarily from the Russian River provided by the Sonoma County Water Agency (SCWA) with groundwater used to supplement their supply from SCWA especially in dry years and during the summer peak demand months. The residents in the watershed not served by the COS and VOM are supplied by almost exclusively by groundwater by many small water suppliers including 12 mutual companies and many individual well owners. 3

The total water supplied in 2007 by the COS and VOM is about 5.7 thousand acre-feet (TAF), with over 90% of that imported from the Russian River. At least another 1.6 TAF of groundwater is estimated to be pumped for the other domestic (non-agricultural) users in the watershed, thus a total of about 7.3 thousand acre-feet (TAF) is provided for domestic uses in the watershed. Residential use by single family and multi-family accounts is the largest sector of the domestic use, accounting for about 72% of the COS and VOM total use and presumably at least that much of the other domestic users for a total of about 5.2 TAF. 4 Groundwater pumped in the watershed for agriculture in 2000 was estimated by the USGS to be at least 6.1 AF and another 1 TAF was supplied from reclaimed wastewater. In subsequent years the Department of Water Resources estimated that the agricultural uses were much greater especially in drier years of low spring

---

1 Another public entity - the Sonoma Valley County Sanitation District- provides reclaimed water to some agricultural users.
2 USGS (2006) cites the year 2000 population at 42355 and the ser. We assume that the 2007 is greater but the proportion of watershed residents served by the public water purveyors -VOM and Sonoma- is roughly the same.
3 SCWA provides small amounts of Russian River water to a few of the private water companies (Sonoma Valley GMP 2007).
4 The other domestic users in the watershed include individual homes, small sub-divisions, mobile home parks as well as wineries, businesses and other non-residential users. The percentage of that use for residential use is unknown but is assumed to be the same as COS and VOM.
Thus it is estimated that the residential users represent about 35% or less of the water used in the Sonoma Creek watershed.

Data availability

This indicator is based upon calculating water use in gallons per person (capita), which requires measurements of current water use and population and comparing that to an estimated target efficient water use per person. Monthly or bi-monthly water use data are needed to calculate a per capita indoor and outdoor use, the calculation of which is explained in the next section. Only COS and VOM residential water use data are available for analysis.

COS and VOM measure the water use of their different customers in order to bill them based upon the volume of use. Municipal water use is separated into different sectors or types of use, often distinguished by the size and type of water meter. Residential water use is accounted for separately from commercial, industrial, institutional and dedicated landscaping use. Different types of residential customers—such as single family and multi-family dwellings—are normally also accounted for separately. Water use is often measured and billed on a bi-monthly (2 month) basis so data from an individual month may not reflect the use by all the customers.

COS and VOM report their monthly water use by the different customer classes, including single family and multi-family residential use, to the California Department of Water Resources’ (DWR) annual Public Water System Survey (PWSS). COS and VOM also report their annual water use by the different sectors to the California Urban Water Conservation Council (CUWCC), which makes the data available on-line at http://bmp.cuwcc.org/bmp/read_only/list.lasso. DWR and CUWCC do minimal checking of the agency reports so data obtained from them generally do not correct any gaps, errors or inconsistencies that may be contained in the reports.

The public water agency reports to DWR and CUWCC also provide an estimate of the population served within their water service areas, which may include small areas outside of the city limits. The reports do not explain the derivation of the population estimates and the data for the same year in the PWSS and CUWCC reports may differ a small amount because of rounding or not being updated in one of the reports. Population served data are estimated from either census projections or from the number of water connections, but the number of people served by these

---

5 DWR (Alan Aquillar, pers. com 12/18/08) estimates a much higher applied crop water demand in the 2002-2004 period based upon their agricultural water use model and it is likely that the 2007 crop water demand was also higher given that it was a dry year.

6 Some of the water agencies distinguish between single family residences, apartments, condos/townhouses, mobile home parks, etc.

7 The water use data are collected by DWR to update the California Water Plan (Bulletin 160), as well as Bulletin 166, Urban Water Use in California. It is made available on request from DWR.
connections is difficult to determine so an average number of persons per connection is used.\textsuperscript{8}

The derivation of a target or reference indoor water use relies on the data collected by different end-use studies of indoor water use, which measure the water use of the individual water-using devices in a household, including toilets, showers, dishwashers, washing machines, and faucets.\textsuperscript{9} The target outdoor use is based upon data collected in studies that examined a range of outdoor water efficiency options including landscape management practices (such as irrigation scheduling, mulching) hardware (such as ET controllers), landscape design (such as drought tolerant gardens, reduction or elimination of turf), as well as the experience of water agencies and residential users when dry conditions require mandated and voluntary reductions in water use.

Analysis, methodology, calculations

The average daily water use per person – gallons per capita per day (gpcd) – is calculated by converting the reported monthly, bi-monthly or annual residential water use data into gallons, dividing by the appropriate number of days to get a daily use and then dividing that result by the population using that water to get the gpcd. It is assumed for purposes of this calculation that only the population reported to reside within the service area of the district consumes the residential water and that visitors to the area are consuming water from non-residential accounts (i.e. commercial or institutional accounts).\textsuperscript{10}

The 2007 calendar year water use for the COS and VOM is reported to PWSS in acre-feet. The single-family and multi-family sectors are combined to calculate the residential gpcd for 2007 for each purveyor individually and the data are also aggregated to calculate a residential gpcd for the combined population of COS and VOM. The residential use is also compared to the total municipal use in order to determine the percentage of the total use that the residential sectors represent.\textsuperscript{11}

\textsuperscript{8} The California Department of Finance and Association of Bay Area Government (ABAG) make population estimates from census projections that are used by local planning departments and subsequently provided to the water departments. COS uses a standard ‘number of people per connection’ to calculate population served.

\textsuperscript{9} Some of the studies also calculated the water lost to leaks in the household. Reducing or eliminating leaks is a water efficiency measure.

\textsuperscript{10} It is possible that some of the visitors using the water in the municipalities are using residential water (e.g. bed and breakfasts) but that there is no way of determining that for this project. If visitors are using residential water in significant quantities then the gpcd will be somewhat higher.

\textsuperscript{11} Unaccounted water is the difference between the water brought into the system (and usually measured at the treatment plant and well head) and the water that is measured and thus accounted for at the customer point of use. It represents unmetered water used for fire protection, system maintenance, system leaks, as well as that used by unauthorized connections. Unaccounted-for water use can also result from meter inaccuracies and billing system errors. Unaccounted water for
Because 2007 was a dry year and water use, particularly outdoor use, can be affected by the weather, residential and total per-capita use since 2004 is also calculated. The period 2004 through 2007 includes an average year (2004), two wetter years (2005 and 2006), and a dry year (2007).

The total municipal water production for the City of Napa is available back to 1984 and total residential water use is available back to 1989. The residential use was extended back to 1984 by correlating the total production with the total residential use. A long record of water use is helpful for putting recent water use in perspective and to evaluate how the drought of 1987-1992 and plumbing code changes affected water use. Additionally the higher per-capita water use prior to the 1987-92 drought serves as the lower reference condition for scoring (see evaluation and scoring section).

The target efficient water use that the current water use is compared to is derived for indoor and outdoor use separately and thus requires separating the current total residential water use into indoor and outdoor residential use. The indoor use is calculated by the “minimum month” method, a commonly use method that assumes that the residential water use in the lowest water using months is used entirely indoors and assumes that indoor use is relatively constant throughout the year. Analysis of the monthly water use data reported to the PWSS shows that January and February and sometimes March are the lowest water using months. Since the billing is often bi-monthly the calculation sums the two lowest consecutive months, converts it to gallons and divides by the number of days in the two months to determine that indoor gpcd. The average outdoor gpcd is the difference between the annual total residential gpcd and the calculated indoor gpcd. The gpcd water use in the consecutive highest consumption months of July/August or August/September is also calculated to be able to evaluate the relative magnitude of the peak outdoor use compared to the indoor use.

The target or reference residential water use is the sum of a target indoor use and a target outdoor use. Separate indoor and outdoor use targets are derived because an indoor target can be established as a gallons per person allotment of water while the outdoor target uses a percentage reduction from the current use.

---

COS and VOM represents about 7% to 12% of the water total production.

12 The residential use record was extended by multiplying the total gpcd by 63%, the average residential to total use ratio in the 19 year period from 1989 to 2007.

13 Although some residents with automatic irrigation systems may not shut them off in the winter or some landscaping, particularly new installations, may require irrigation if there is long winter dry spell, it is assumed that those amounts are relatively small. The calculated indoor use would also include any leaks in the residential system so not all of it may actually be “consumed” by the resident. Indoor use may also increase slightly in the summer months if residents shower and wash clothes more often with increased physical activity.
The indoor use target of 40 gpcd is the average of several end use studies that measure the water use of currently available, efficient water-using appliances (toilets, showerheads, washing machines, dishwashers) and assumes that household leaks are reduced or eliminated.\textsuperscript{14} The water use by these devices is relatively constrained by current technology and plumbing codes and the main variable affecting household water use is how often the devices are used in the typical household, which is what the different studies measure. Per capita indoor use is thus relatively similar across a range of single-family and multi-family residences and lends itself to an allotment-based target. Greater indoor savings are possible with newer, more efficient devices (such as dual flush or high efficiency toilets) and through behavioral choices such as taking shorter showers and not leaving the water running. Thus the indoor target of 40 gpcd for an individual household is very achievable, while for a water agency the target assumes nearly all of the residential customers will install the devices and take care of their leaks.\textsuperscript{15} Over time most residential customers will install water efficient devices indoors but it can be achieved sooner with the proper financial incentives and regulatory mandates.

In contrast to indoor water use, outdoor water use is much more variable depending on customer behavior, weather, and the size and type of the landscaping, which might range from none (for an apartment dweller) to large expanses of turf. Because information on the size and the type of landscaping of residential customers is not readily available, it would be very difficult to establish an allotment-based target of outdoor use and it is more appropriate to express the target as percentage savings from the current outdoor use. There is a wide range of options to achieve outdoor water use savings and as previously mentioned, different studies have evaluated savings from landscape management practices (such as irrigation scheduling, mulching), hardware (such as ET controllers), landscape design (such as drought tolerant gardens, reduction or elimination of turf), and policies such as rate structures and requirements for zero footprint new development. Using recycled water from wastewater treatment plants or from on-site greywater systems for landscape irrigation can also reduce the use of potable water for outdoor water use. The percentage savings that have been achieved from these measures are highly variable. A Pacific Institute study (2003 Waste Not, Want Not: The Potential for Urban Water Conservation in California) evaluated many of the studies and estimated that outdoor water use reductions of 25% to 40% could be achieved in California. The urban water management plans for the City of Sonoma and Valley of the Moon Water District examined different measures and programs for reducing residential irrigation and estimated end-use savings ranging from 9\% (for rain sensor retrofits) to 33\% (for “cash for grass” programs). The actual savings depend on the level of participation or “penetration” of the programs and measures, which in turn depend primarily on the economic benefits and costs to the water agency and customer, although the social and environmental benefits of saving water (i.e.

\textsuperscript{14} Existing plumbing codes mandate the water use efficiency of toilets (gallons per flush- gpf- must be 1.6 gallons or less; the standard changes to 1.2 gpf in 2010 ), shower heads (2.5 gpm), and faucets (2.2 gpm).

\textsuperscript{15} 100\% participation or “penetration” of water saving devices into households may be hard to achieve but can be accelerated through financial incentives and by retrofit on resale or remodel mandates.
stewardship) may also motivate action. Another indication of the outdoor water use savings potential is the 10% to 15% summer and fall residential water savings that were achieved in 2007 by the Valley of the Moon Water District, stimulated in part by the reductions requested by the Sonoma County Water Agency and the State Water Resources Control Board to meet Russian River flow requirements. Some of this reduction was likely achieved by short-term changes in irrigation management and some may have been weather-related. Many water agencies have drought management plans that specify percentages of total and outdoor water use reductions that are to be achieved through voluntary and mandated measures (such as no-water days).

Because outdoor water use savings depend on so many variables and requires information beyond the scope of this effort, a simple but achievable outdoor water use reduction target of 20% from current outdoor use is specified for the Napa River watershed. A 20% reduction in outdoor use can be met through a wide variety of measures depending on the individual circumstances ranging from behavioral changes (such as more careful water scheduling) to investments in hardware or changes in landscape design. A 20% reduction target is consistent with policy and legal requirements to achieve 20% per-capita reductions for overall water use and has been achieved in response to short-term requirements to reduce water use during dry periods. Those users who are currently using water efficiently may not be able to achieve a 20% reduction but the users who can achieve greater than a 20% reduction outnumber them. Water agency planners that were consulted for this report (such as Carrie Pollard of Sonoma County Water Agency) felt that a 20% outdoor water use reduction target is achievable.

Evaluation and scoring

Scoring this indicator requires the following (the basic data and calculated numbers are shown in Table XXX):

1. Calculate the indoor and outdoor water gpcd for the COS and VOM in each year of the 2004 to 2007 period. Determine the average for the period.

2. Because VOM has more than twice the population of COS and the COS per-capita indoor and outdoor residential use is nearly 30% higher than VOM per-capita use, largely due to COS per-capita outdoor use being 66% higher than VOM, aggregating the two districts into one per-capita use does not create equitable efficient water use targets for the two districts. The two districts are thus scored separately.

3. For VOM reduce the average outdoor use by 20% and add that target use to the indoor target per-capita use of 40 gallons per day to get the total target residential use – 71 gpcd-, which is the upper reference value for scoring. Do the

---

16 A 20% outdoor use reduction target was also assumed for the residential water use indicator in The Bay Institute’s 2003 and 2005 Scorecard for the whole Bay region.
same for COS to get the total target residential use – 91 gpcd- and upper reference value for scoring.

4. The lower reference condition is determined by the highest per-capita use in the 1980’s prior to the 1987-92 drought and plumbing code changes that triggered reductions in water use. Records of residential water use for VOM and COS were not available for the 1980’s but a long-term record of residential water use was available for the City of Napa. Per-capita residential water use for VOM and Napa were very similar so the highest historical per-capita residential use -121 gpcd in 1987- from the long term City of Napa residential water use record is used to establish the lower reference condition for VOM. The lower reference condition for COS is established by comparing the overlapping per-capita residential water records for Napa and COS from which it is determined that COS per-capita residential use is about 30% higher than Napa and thus the lower reference condition will be for COS will be 157 gpcd or 30% higher than the 121 gpcd lower reference Napa gpcd.

5. For VOM, the difference between the 71 gpcd upper reference value and the 121 gpcd lower reference value is 50 gpcd, which can be divided up into three nearly equal tiers of 17, 17 and 16 gpcd for a 3-part scoring system. Water use between 71 and 88 gpcd is in the “good” range, between 88 and 105 gpcd is in the fair range, and between 105 and 121 gpcd in the poor range.

6. For COS, the difference between the 91 gpcd upper reference value and the 157 gpcd lower reference value is 66 gpcd, which can be divided up into three equal tiers of 22 gpcd for a 3-part scoring system. Water use between 91 and 103 gpcd is in the “good” range, between 103 and 125 gpcd is in the fair range, and between 125 and 157 gpcd in the poor range.

Results and Discussion

The 2007 per-capita residential water use in the COS is 130 gallons per day, slightly lower than the 2004-2007 average of 133 gallons per day. Both of these values are at the low end of the fair range. The VOM per-capita residential water use in 2007 was lower at 103 gallons per day, nearly 30% lower than COS primarily because of the lower outdoor use. In COS the residential water use represents 65% to 68% of the total demand for water while in VOM the residential water use represents about 75% of the total municipal demand for water, which includes commercial, institutional, and industrial uses as well as the unaccounted water from leaks and billing errors.

Outdoor residential water use in the VOM over the 2004-2007 represents was 38 gpcd or 37% of the total demand although there was a decline in 2007 that could be

___

17 Records of COS and VOM residential water use were available back to 1994 so there was over a decade to correlate with Napa water use.
18 For purposes of graphing 3 equal tiers, the lowest reference is labeled at 122 gpcd.
19 Water use less than the upper reference value of 73 gpcd would be outstanding, while water use greater than 121 gpcd would be failing.
the result of the conservation appeals made in the summer of 2007. Outdoor water use in COS was considerably higher – 63 gpcd or an average of 48% of the total demand- again the result of the larger average lot sizes. Indoor water use in COS is about 69 gpcd while in VOM it averaged about 65 gpcd. The greater indoor use in COS may be explained by the fact that its per-capita income is higher than VOM; indoor and outdoor water use is generally higher in low density communities with higher per-capita income. The residential per-capita use in VOM is similar to other suburban communities of the San Francisco Bay Area while the COS per-capita use is higher than most other communities in the Bay Area.

Annual water use will be affected by the weather - dry springs and autumns and warmer summers will increase outdoor water use. Over the longer term conservation measures including adoption of water efficient water using devices, water use awareness and landscape changes will result in significant reductions in residential water use.

Missing from our analysis, for lack of time, is a quantitative statement of the uncertainty associated with the results, the score and the trend.

Data Gaps and Recommendations

The biggest data challenge in determining per capita water use is obtaining accurate data on the population served by the water supplier especially in areas that have high tourist use like the Sonoma Valley. Both COS and VOM have good data for the number of water connections they have, but the number of people served by these connections is sometimes difficult or expensive to determine. Population served data may not be accurate and the result is possible bad per capita calculations.

Another challenge is to find more accurate ways to determine outdoor water use when that use is not directly metered, which is currently the case with most residential accounts. The minimum method used in this report and by DWR needs further refinement and validation. Other methods for comparison besides outdoor metering include remote sensing of landscape area and evapotranspiration calculations and on-the-ground mapping.

An overall recommendation is that any water use and population served data provided by a water supplier include meta data in order to assess its accuracy and to determine, for example, if per-capita calculations can be made and valid comparisons can be made over time and with other cities.

Summary and Recommendations

This indicator shows that residents in COS and VOM need to intensify their efforts to reduce their per-capita use of water and be good stewards of their water supply. Despite their embrace of many water conservation measures and their recent reductions in water use in response to drier conditions and reductions in imported
supply, the per-capita water use is at the end of the “fair” category. COS in particular needs to focus on reducing outdoor water use.

Residents are responsible for reducing their water use by adopting water saving appliances and technology and for being more water-wise, but resource managers can help residents take advantage of currently available water saving technology through financial incentives, mandated efficiency standards for new construction, mandated retrofits on resale and remodeling, and education. Reducing indoor use requires greater penetration into existing households of currently available water-efficient appliances and greater awareness of water use. There is great potential for outdoor water use reductions but it requires choices about landscaping as well technological improvements. It remains to be seen if new regulations that could potentially make it easier for residents to install greywater systems will make a significant difference in outdoor use or whether financial incentives will be needed for greater adoption. Outdoor water savings offers the added benefit of reducing use in the high water using summer months which can reduce the need to increase imported water capacity or drain reservoirs to meet peak demands. Furthermore, a significant portion of outdoor water is lost to evaporation and transpiration and is thus no longer available for capture and reuse, unlike most indoor use.

References

California Department of Water Resources (DWR) annual Public Water System Survey (PWSS)

California Urban Water Conservation Council
http://bmp.cuwcc.org/bmp/read_only/list.lasso

http://www.h2ouse.org/


EBMUD and USEPA 2003 Residential Indoor Water Conservation Study, prepared by Aquacraft


Sonoma County Water Agency 2007 Sonoma Valley Groundwater Management Plan prepared by Schlumberger Water Services

Valley of the Moon Water District 2005 Urban Water Management Plan
**Index: Stewardship, Indicator: Sustainable Policy**

Score: Not evaluated  
Trend: Not evaluated

**Introduction**

Water self-reliance can be used as an expression of the extent to which a watershed’s social, cultural, and economic needs are currently met within its own available water resources, rather than those imported from other watersheds or extracted from aquifers faster than they can be replenished. This indicator allows residents and government agencies to evaluate management trends designed to increase reliance on local water sources and mimic certain watershed functions that have been lost after large-scale landscape and hydrologic modifications took place. Through conversion of vegetation cover to intensive land uses that rapidly channel runoff from hill slopes and impervious areas, such as roads, roofs, and parking lots, a significant amount of rainfall is now no longer absorbed and slowly released throughout the long dry season but is rapidly routed to San Pablo Bay, where it is no longer available for stream flow augmentation, groundwater recharge, or other beneficial uses.

**Data availability**

Four major datasets were considered for this indicator:

- Presence of zoning or other land use provisions restricting development in groundwater recharge areas. Less groundwater recharge capacity results in lower self-reliance on local water sources.
- Presence of policies and ordinances encouraging and facilitating grey water re-use. Grey-water recycling diminishes the need for water imports and increases reliance on local water sources.
- Presence of building code provisions encouraging runoff harvesting and storage features for all land use designations. Runoff remaining for longer periods in a watershed increases the options for use before it leaves the watershed and drains into San Pablo Bay.
- Level of implementation of 14 management practices endorsed by California Urban Water Conservation Council

Most of the metrics associated with this indicator are regularly collected, although not readily available in useable form. Data sets associated with state and local policies, ordinances, and codes have not been systematically compiled and will require considerable effort to analyze.

Data are generally collected and maintained by city and county land use departments, water agencies, publicly owned treatment works, the Association of Bay Area Governments, and non-governmental organizations, such as the Local Government Commission. However, no consistent and standardized classification system exists at this point that organizes policies, guidelines, ordinances, and codes.
in a hierarchical fashion that would indicate if land use planning goals and objectives have been translated into tangible action at the implementation level. A hierarchical arrangement of stewardship data and information can be illustrated as follows: The draft 2020 update to the Sonoma County General Plan (at the highest level in the hierarchy) contains several objectives that address water self-reliance. One of them is Objective WR-4.3: “Conserve and recognize stormwater as a valuable resource.” At the next level in the hierarchy, applicable policies are expressed as: “Reduce impervious surfaces to minimize runoff and increase groundwater recharge” and “Require that development and redevelopment projects, where feasible, retain stormwater for on-site use that offsets the use of other water” and “Where consistent with water quality regulations, encourage greywater systems, roof catchment of rainwater and other methods of re-using water and minimizing the need to use potable surface water or groundwater” (http://www.sonoma-county.org/prmd/gp2020/bosdraft/wre.pdf). No steps have yet been taken, however, to enable project applicants and review staff to clearly identify if a proposed project is located in a designated groundwater recharge areas and to insure that project designs meet the objectives spelled out in the General Plan and its associated policies. In addition to the groundwater recharge protection data, those associated with grey water re-use, water harvesting will also require the development of a transparent system of data classification to insure that watersheds are comparable, and that calculations do not rely on subjective observer judgment.

Analysis, methodology, calculations

The first metric – the presence of zoning provisions restricting development in groundwater recharge areas – can be calculated based on the number of land use jurisdictions in the Sonoma Creek watershed. The Sonoma Creek watershed has only two land use jurisdictions – the City of Sonoma and the County of Sonoma. Therefore, the maximum number of land use jurisdictions that could theoretically adopt specific zoning restrictions intended to protect groundwater recharge areas is two. The draft 2020 General Plan update for Sonoma County contains a groundwater recharge protection objective, but the City of Sonoma’s General Plan does not.

However, General Plan goals by themselves do not necessarily result in development restrictions, unless they are accompanied by specific zoning or code provisions. Therefore, analysis needs to include, as outlined in the previous section, to what extent groundwater protection goals are enshrined in clear guidance to both developers and project design review and implementation oversight staff. In addition to the number of land use jurisdictions per watershed with the authority to restrict development in groundwater recharge areas, the calculation for the indicator score may need to include some kind of point system for (a) applicable municipal or county codes; and (b) compliance and implementation outcomes over time.

The second metric – the presence of policies and ordinances encouraging and facilitating grey water re-use – also resides under the jurisdictions of cities and
counties, with oversight by the California Department of Public Health. Of the two land use jurisdictions in the Sonoma Creek watershed, only the draft General Plan update contains a policy encouraging grey-water reuse systems. Since the General Plan update hasn’t been approved at the time of this writing, appropriate revisions or additions to the plumbing code have not yet been implemented. A similar need exists for the grey-water system data as for the other three policy-related datasets: In addition to counting the presence or absence of ordinances or codes that enhance water self-reliance, a transparent method of assigning points based on implementation “friendliness” and implementation outcomes needs to be developed. This is not a trivial task and requires in-depth analysis and the development of a classification system for assigning points that is outside the scope of this current Score Card project.

The third dataset required for the Sustainable Policies indicator - number of building code provisions encouraging runoff harvesting and storage features for all land use designations – also has the number of land use jurisdictions as a foundation. While the draft County General Plan update may explicitly mention the facilitation of runoff harvesting features as an objective, neither of the two land use jurisdictions in the Sonoma Creek watershed has provisions in their building codes that encourage, let alone require, water harvesting.

The fourth metric - level of implementation of 14 management practices endorsed by California Urban Water Conservation Council is relatively easy to calculate by comparing each water purveyor’s menu of practices with the Council’s list and converting it into a percent compliance score (see http://bmp.cuwcc.org/bmp/summaries/public/bmpTitles.html). However, at this time we do not have the resources to convert the existing score card developed by Public Officials for Water and Environmental Reform based on the template found in Consumer Reports (http://www.cawaterpolicy.us/scorecard.php) and incorporate an already aggregated metric into a higher-level indicator of water self-reliance. The report card on compliance with the 14 Best Management Practices for water conservation shows how well each water utility that has signed onto the Memorandum of Understanding held by the California Urban Water Conservation Council has fulfilled its commitment to implementation.

Evaluation and scoring

The datasets associated with the Sustainable Policies indicator can be compared to benchmarks associated with “desired condition.” For the four policy-related datasets, the number of policies, management practices, guidelines, and codes can be converted into a point system that includes compliance and implementation and then compared against the number of points that could theoretically be achieved.

Discussion

This indicator tells us about the level of governance and stewardship in place to promote water self-reliance and minimize the transfer of impacts in other watersheds that might otherwise experience resource extraction at the expense of
their own watershed health. The more “self-reliant” a watershed is, the more it can respond adequately to changing climate conditions or natural disturbances.

**Summary and Recommendations**

The analysis of state and local policies will require time and resources, due to the dispersed nature of the data and the lack of a standardized classification system that would allow us to assign points or scores in a transparent and objective manner. Compilation of existence and coverage/extent of implementation of water conservation best management practices in the wholesale and retail sector was not included in this report, but could be incorporated.

**8. Recommendations for Future Efforts**

Most indicator sections in this report include recommendations for improving that indicator; this section includes recommendations for the entire Scorecard project.

Since this draft of the Watershed Health Scorecard was begun, stopped, restarted, and completed, several projects have begun that should inform the next iteration of the Watershed Health Scorecard. A literature search on ecological indicator systems, especially those applied to semi-arid regions and those including human elements, should be completed to uncover recent work. Fraser Schilling at the Information Center for the Environment at UC Davis is leading the state-level effort. It is likely that a Bay Area regional scorecard will take shape. Harry Seraydarian of the North Bay Watershed Association may be contacted regarding progress toward a North Bay ecological scorecard.

Much effort was expended to choose the indices used here. Because all users of scorecards are ultimately aiming to produce a complete, well-rounded scorecard—even if the current effort only covers a few of the eventual list of topics—in future the index structure used should be that of the complete scorecard, not of the partial one (as we have used here).

We were unable to report on the uncertainties associated with data sources, analysis results, trends, targets, and scores. This aspect of reporting must be part of future efforts. Results that are not statistically defensible should not appear on the Scorecard itself.

We recommend an indicator that reports on a subwatershed-scale evaluation of “flashiness.” We attach a preliminary workflow for such an indicator as an appendix.

The process of researching, vetting, selecting, analyzing, scoring, and presenting data was very time-consuming and demanded a great deal of effort from our team members. Team facilitation was also unusually demanding. These time needs should be factored into planning future rounds of work.

**9. Acknowledgements**
We are grateful for the vote of confidence shown in this project and this team by our funders. Major funding for the 2007 Watershed Health Scorecard came from the CALFED Watershed Program (agreement 4600004706), administered by the Department of Conservation and later by the Department of Water Resources. Secondary funding was from the State Water Resources Control Board (2005 - 2006 Consolidated Grants - Proposition 50 Coastal Non Point Source Pollution Control, Agreement No. 06-346-552-0).

We thank Leigh Sharp, district manager at Napa County RCD, for helping obtain funding for the project. We thank Tina Swanson, executive director at The Bay Institute, for expert advice on the complex process of bringing a scorecard project to completion. We thank Chris Farrar at US Geological Survey for being the groundwater advisor on our technical team.