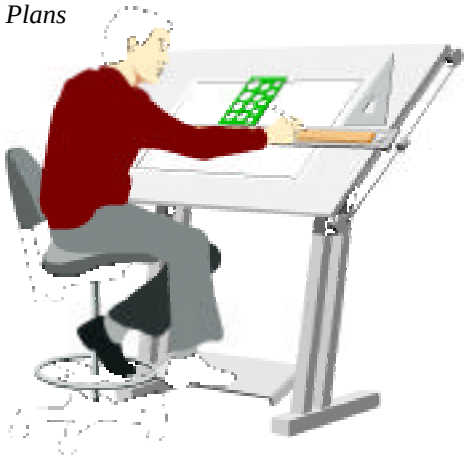
LANDSCAPE AREA MEASURING STUDY

FINAL EVALUATION REPORT

October 1999

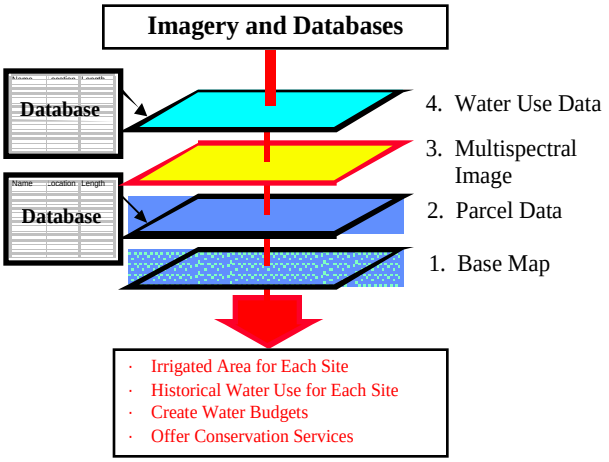
Measuring Wheel

Landscape Plans



Aerial Photography

Multispectral Imaging



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Landscape Area Measuring Study – Evaluation Report

Table of Contents

Glossary			
AQM	AquaMetrics LLC	GIS	Geographic Information System
CAD	Computer Aided Drawing/Drafting	GPS	Global Positioning System
CCWD	Contra Costa Water District	LAMS	Landscape Area Measurement System
CUWCC	California Urban Water Conservation Council	LWBD	Landscape Water Budget Database
CII	Commercial, Industrial, Institutional	MFR	Multi-Family Residential

Photo Credit: *the Measuring Wheel photo on the cover page is reproduced courtesy of the Irrigation Training and Research Center, Cal Poly San Luis Obispo.*

1. Executive Summary

Background

A Memorandum of Understanding between 160 California water utilities and interested parties such as environmental groups (signed in April 1998) requires the implementation[1] of fourteen Best Management Practices (BMP) to promote urban water conservation.

BMP #5, the Large Landscape BMP, imposes a challenging task for signatory water utilities – to develop landscape water budgets for all Commercial, Industrial and Institutional (CII), and Multi-Family Residential (MFR) sites with dedicated irrigation meters. (Note that some utilities may also choose to provide water budgets for *all mixed meter* CII and MFR sites, thereby relieving themselves of the BMP5 requirement to perform irrigation surveys at 15% of such sites over the next ten years.)

To develop a landscape water budget, utilities need two types of data: (1) weather data (available for most utilities from the CIMIS network); and (2) total landscape area at each facility. This report evaluates methods for measuring total landscape area at individual service accounts.

Project Description

This study compares four different methods for estimating landscape area at CII and MFR sites in the Contra Costa Water District (CCWD). The methods evaluated in this study include:

- **Measuring Wheel**
- **Landscape Plans**
- **Aerial Photography** (Heads-up Digitizing)
- **Multispectral Images** (Digital Image Processing)

Each method was applied at twenty test sites (CII and MFR sites with dedicated irrigation meters) in order to assess the feasibility, accuracy and cost-effectiveness of the methods. The twenty sites were selected from approximately 900 dedicated meters sites to be a representative sample of facilities and reflect a broad range of parcel sizes. Eight of the test sites could not be used for final comparison of the methods due to mismatches in the areas being measured (e.g., the multispectral method measuring the entire MFR parcel, while the wheel method measured just a few common areas).

Five different land uses were characterized for this study[2]. The first three, highlighted because of their differing needs for water, together comprise "total landscape area":

1. **Turfgrass**
2. **Other Landscaping** (groundcovers, shrubs and trees)
3. **Water Features** (such as fountains or ponds)
4. *Bare ground (and other unirrigated permeable areas such as gravel pathways)*

[1] If cost-effective for the participating utility.

[2] The measuring wheel method only measured turfgrass and other landscaping while the other methods measured all land uses.

5. *Hardscape (such as parking lots and buildings)*

Results

There are intangible but real benefits that result from any effort to learn more about a specific end use such as landscape irrigation. Benefits might include: better information about the customer, making billing information more accessible, ability to answer customer questions more easily and learning the importance of aggregating multiple accounts serving one site.

Feasibility:

Three of the methods tested – measuring wheel, aerial photos and multispectral imaging – could be performed for the entire service area. It was determined that the landscape plan method, while serving as a valuable baseline of information for this study, would be impractical to carry out for hundreds or thousands of sites. The time and trouble expended to obtain, duplicate, catalog and store even a few dozen plan sets was significant. However, an agency could require that landscape plans and landscape area data be submitted when customers apply for a new water meter service.

Accuracy:

All four methods can produce *reasonable* accuracy (defined as estimates of Total Landscape Area within 10% of the measuring wheel "reference") under *favorable* conditions (when correctly performed on a simple or well-defined site).

However, this study suggests that there is significant variability in site conditions and that each of the methods are frequently "put to the test" in real world measurements.

Table ES-1 provides the summary results of this study (for the twelve sites where reasonable comparison was possible). Using the measuring wheel as a baseline[3], landscape plans estimated 4% less, aerial photos 17% more and multispectral imaging 3% less total landscape area than was measured with the wheel.

Table ES-1: Summary Measurement Results for 12 Test Sites

	Total Landscape Area (acres)				Percent Variation from Wheel		
	Measuring Method				*Measuring Method*		
Type of Site	Wheel	Plans	Photos	Multispectral	Plans	Photos	Multispectral
Turf Dominant	22.6	21.3	27.8	18.8	-6%	23%	-17%
Tree Dominant	6.8	7.0	6.5	9.6	4%	-3%	41%
Grand Total	**29.4**	**28.3**	**34.3**	**28.4**	**-4%**	**17%**	**-3%**

[3] Note that hand measuring itself has certain weaknesses, such as underestimating tree crown area and overestimating the irrigated area of low density mulched areas

Significant differences were noted between sites that have either few or many mature trees (turf vs. tree dominant sites). The multispectral method, because it "sees" tree crown area (which the measuring wheel and landscape plan methods do not measure), will estimate *more* total landscape area than the wheel method on sites with significant tree cover over pavement. In addition, because the multispectral method does not classify unplanted mulch area between shrubs as landscaping, this method may estimate *less* total landscape area than the measuring wheel method on sites without mature trees. For example, newly planted sites with considerable space between individual plants will show only the area of the plants themselves, not the area of the surrounding mulch.

This study concludes that all four methods would be very close in their landscape area estimates for a simple rectangular park covered by turf. The differences between the methods are accentuated on sites where trees, mulched planter areas and complex, curved shapes exist (multi-family residential (MFR) sites, for example).

The differences in measurement results seen in Table ES-1 are typically due to:

1. Measuring properly but within *different* property/parcel/irrigated area boundaries.
2. Errors (omission, double counting or calculation) in tabulating areas[4]
3. The unique capabilities or limitations of each method:
   - Image-based techniques (aerial photo and multispectral) measure the visible tree canopy, which may obscure pavement (increasing "other landscaping" area while reducing hardscape area) or turfgrass (increasing "other landscaping" area while reducing turf area). The measuring wheel and landscape plan techniques typically underestimate tree area in parking lots or along pavement and sidewalks because they measure the area within the planter bed as opposed to the mature tree crown area.
   - Image-based techniques do not measure mulch areas between plants in sparsely planted shrub beds. The measuring wheel and landscape plan techniques typically overestimate actual shrub area because they measure the total area of the shrub bed.
   - Image-based techniques (aerial photo and multispectral) require a parcel "polygon" derived from a utility's facility maps or the county tax assessor's parcel maps[5]. Creating these polygons proved to be the most difficult part of the CCWD case study (see Chapter 4) because service address information was incomplete for many irrigation accounts.
   - Unless custom polygons are drawn within the boundaries of a complex site, multispectral imaging will measure privately irrigated areas in addition to common (dedicated meter) areas[6].
   - The aerial photography and multispectral imaging techniques tend to have *some* amount of misclassification (trees or groundcovers seen as turf, tree shadow seen as hardscape, etc.).
   - An out-of-date landscape plan, for example, indicated turfgrass where bareground now exists (site # 27).

The largest variations in measured area for this study occur due to different assumptions about measurement boundaries.

[4] These errors are assumed to occur to a limited degree, but are not thought to be critical for most sites.

[5] Some districts may be able to purchase a pre-existing polygon database.

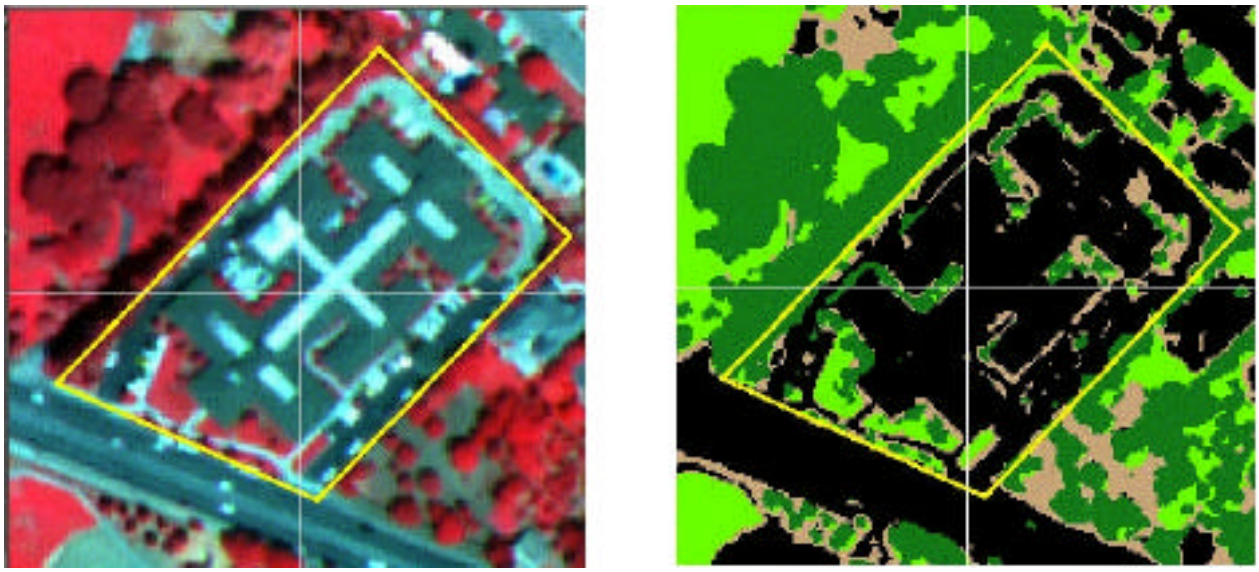
[6] The private areas can be estimated and removed from the total area: Privately Irrigated Area = (Number of housing units) x (average backyard landscape area per unit).

Eight sites[7] encountered this problem. On several sites (such as Site 28), the parcels were assumed to have different shapes by different technicians. At one MFR site (Site 4), only the common areas of the HOA were measured with the measuring wheel technique, while the other methods measured the total landscaping at the property (including private backyards irrigated with residential meters).

A significant difference in the capability of the different methods was identified because the wheel and plans methods measure the area contained by the *borders* of non-turf landscaping, while the multispectral image measures the actual planted area, which can be larger (trees) or smaller (shrubs) than the border area. Narrow parking lot medians (e.g., 4 feet wide) with overhanging trees (perhaps 20 feet in diameter) and sparsely planted shrub areas with as much as 50% mulched area are the most common examples of this discrepancy.

Figure ES-1 illustrates how a multispectral image (on the left) and the classification of this image (on the right) may differ from measuring wheel data. This figure illustrates the effect of mulch in the landscape planter areas around a building (especially at the eastern corner) – the brown areas represent wood bark mulch. The measuring wheel method would typically represent the entire planter area as "landscaping". Trees are seen as dark green while turf and lush groundcovers show as light green. The turf and tree areas at the front of the building are represented with essentially the same area as the measuring wheel.

Figure ES-1: Measuring Trees and Shrubs



Smaller discrepancies occurred in distinguishing the type of landscape. In some under-irrigated (weak) turf areas, multispectral imaging indicates other landscaping or bare ground instead of turf. In Figure ES-1, we can see that some of the tree crown area at the northern point of the property (nominally dark green) has been classified as turf (light green) because it has nearly the same "signature" as turfgrass. This area also shows that these trees are overhanging pavement, leading to a higher estimate of landscape area than the measuring wheel might indicate.

[7] 40% of the sites used for the study

Cost-effectiveness:

A significant difference between the four methods is their average cost per site, as seen in Table ES-2. This table illustrates the cost per site for the stated number of sites for a 45 square mile service area (the minimum cost method has been highlighted for each "number of sites" assumption). The per site cost for the measuring wheel and landscape plan methods are the same as there are no economies of scale for these methods.

Table ES-2: Estimated Cost per Site[8]

	Cost Per Site Based on Number of Sites					
Method	100	200	400	800	2,500	5,000
Landscape Plans	$ 126	$ 126	$ 126	$ 126	$ 126	$ 126
Measuring Wheel	**$ 106**	$ 106	$ 106	$ 106	$ 106	$ 106
Aerial Photography	$ 175	**$ 105**	**$ 69**	$ 52	$ 40	$ 37
Multispectral Imaging	$ 393	$ 198	$ 100	**$ 52**	**$ 18**	**$ 11**

Conclusions

The **Measuring Wheel** method provides good quality data but takes significant conservation staff or consultant time for each site; however, it is the preferred method when the total number of sites to be measured is small (200 sites or less). Because the final area estimate is created from simplified field measurements and area calculations for hundreds of small landscape segments, it is difficult to know if segments have been missed, double counted, or incorrectly measured or calculated. Sparsely planted areas tend to be overestimated in size and tree crown areas are under-measured.

The **Landscape Plan** method (measuring areas drawn on the plan itself as opposed to in the field) provides good quality data (because the type of area is noted on the plan), assuming the landscape plan accurately reflects the current landscape. A trained operator would typically perform this method using either a planimeter, a digitizing tablet, or by delineating a scanned image of the plan. As with the measuring wheel, sparsely planted areas tend to be overestimated in size and tree crown areas are rarely measured. A significant constraint is the difficulty of obtaining and verifying the accuracy of plans for existing sites – it is unlikely that this method would be used as the only method for a large District.

The **Aerial Photography** method (in this case, digitized aerial photos viewed "heads-up" on a computer screen) can provide reasonable estimates of landscape area, but smaller landscape features (small trees or bushes) are difficult to classify, especially if grayscale photos are used. Although this project used color aerial photographs (NB: most pre-existing aerial photography is likely to be grayscale), operators still had difficulty identifying landscaping in certain cases. Trees will overhang pavement and obscure turf areas. The measured area is defined by a parcel boundary, which may be difficult to obtain and may not reflect the boundary of the irrigated area. It is assumed that 10% of all parcels will require manual placement of parcels in GIS and conformation site visits.

[8] For a 45 square mile service area. The costs for the measuring wheel method are based on an average site of 9.5 acres with 2.2 acres of landscaping (based on the 20 study sites). The Aerial Photography and multispectral methods assume that site visits are required to 10% of the study sites

Multispectral Imagery provides estimates of landscape area using a multiple-band digital aerial camera system (three spectral bands were used for this study: red, green, and infrared). The measured area is defined by a parcel boundary, which may be difficult to obtain[9] and may not reflect the boundary of the irrigated area. It is assumed that 10% of all parcels will require manual placement of parcels in GIS and conformation site visits.

One problem observed in this study was that the multi-spectral image could not be rectified to the desired accuracy due to terrain variations across the CCWD service area. This necessitated artificially "rubber-sheeting" the parcel boundaries to the image in order to perform the area calculations.

Because an image of the entire service area must be obtained and processed, the initial cost of this method is significant. However, the cost per site can be the lowest of the four methods when at least 800 sites are measured. As with the aerial photography method, trees will overhang pavement and obscure turf areas. One unique aspect of this technique is that mulch areas in sparsely planted areas are correctly tallied as bare ground, rather than counted as planted area.

Considering its long-term advantages, CCWD approved the use of the multispectral imaging technique to develop landscape area estimates for approximately 900 dedicated meter sites and 4,530 mixed-use meter CII and MFR sites. Because the multispectral images are permanently available and accessible through GIS software, CCWD staff can create new area estimates or correct existing estimates in response to customer supplied data or staff field visits.

[9] Using the best available data sources, we were only able to create about 80% of the necessary parcel polygons during this project. The remaining polygons will be created by AQM and CCWD in a cooperative effort using manual methods.

Recommendations

1. This study considered four techniques to estimate landscape area at CII /MFR sites. Conservation coordinators are advised to obtain a copy of the BMP 5 Handbook to learn as much as possible about other landscape area measurement techniques.
2. The use of Landscape Plans to measure landscape area proved accurate but was the most expensive and least practical method reviewed in this study.
3. Measuring wheel estimates are practical and cost effective when the number of sites to be measured is approximately 200 or less. Using Landscape Plans to supplement field measurement will likely prove helpful.
4. The use of Aerial Photography can be a reasonable method of measuring landscapes when the number of sites is between 200 and 800, as this spreads the costs of obtaining the photography over a number of sites. However, under the conditions of this study, this method seemed to be less accurate than other methods.
5. If good image rectification can be assured, multispectral imaging can provide savings when the number of sites to be measured is greater than 800, and the critical resource of a parcel polygon database exists or can be readily created. This method differs from the other methods by measuring tree canopy (which the other methods typically ignore), by not measuring mulch areas (which the measuring wheel and plans methods include as planted area) and in measuring privately irrigated areas along with the dedicated meter areas (the total size of these private areas should be estimated and removed from the total).
6. Conservation coordinators are advised to obtain a copy of the BMP 5 Handbook to learn as much as possible about the variety of landscape area measurement techniques.
7. Manual methods will likely prove useful when same numbers of sites must be measured, while more automated methods are likely to provide important savings when the number of sites is large and the critical resource of a parcel polygon database exists.

2. Project Description

Background

Many California water utilities are undertaking the Best Management Practices[10] (BMP) governed by the California Urban Water Conservation Council (CUWCC).

The revised BMP #5 (April 8, 1998) requires participating water utilities to generate, within a four-year period beginning July 1999, landscape water budgets for all Commercial, Industrial and Institutional[11] (CII) and Multi-Family Residential (MFR) sites with dedicated irrigation meters[12].

BMP5 also has a requirement that utilities either perform irrigation surveys at 15% of their mixed meter CII/MFR sites (over a 10 year period beginning in July 1999) or provide water budgets for 100% of their mixed use meter CII/MFR sites by July 2003. Selection of the most cost-effective strategy will need to be done on a utility-by-utility basis.

To generate a landscape water budget, weather data must be obtained and the site's irrigated area must be measured or estimated. Weather data is readily acquired through the California Irrigation Management Information System[13] (CIMIS). However, determining the irrigated area at hundreds or thousands of CII and multi-family sites is a challenging undertaking for water utilities. Utilities must soon decide how they will obtain this landscape area data.

This Report, funded by a grant to the CCWD from the United States Bureau of Reclamation, compares four techniques to measure landscape area and assesses their advantages and disadvantages, feasibility, accuracy and costs (including fixed and labor costs).

There are more than four methods for measuring landscape area. The BMP5 Handbook[14] developed for the CUWCC and a recent study performed for the Bureau of Reclamation[15] discuss a number of other landscape area measurement techniques.

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[10] "Memorandum of Understanding Regarding Urban Water Conservation California", California Urban Water Conservation Council (CUWCC), revised September 1997.

[11] Institutional sites include schools, parks and streetscapes such as medians and parkways.

[12] The BMP5 Handbook (CUWCC, April 1999) states that landscapes at Multifamily Residential (MFR) (e.g., condominiums, apartments) sites can be addressed by BMP #5, with MFR interior uses addressed by BMP #1.

[13] CIMIS Help Line 800-922-4647; Fax 916-327-1815.

[14] BMP 5 Handbook, CUWCC; prepared by Stratus Consulting (John Whitcomb with Gary Kah and Chris Willig); April 1999.

[15] "Evaluation of Techniques to Determine Landscape Areas", December 1998, prepared for the United States Bureau of Reclamation by the Irrigation Training and Research Center. Other possible methods include Laser Rangefinder, Total Station surveying and sub-meter Global Positioning Systems (GPS).

Study Team and Data Sources

AquaMetrics LLC (AQM) assembled an experienced team of Remote Sensing, Image Processing and Geographic Information System (GIS) professionals to perform this study. Hammon, Jensen, Wallen and Associates, Inc. (HJW) provided a digital orthophoto product, color aerial photography flight services and multispectral image acquisition, processing and classification. Lynx Technologies, Inc. (Lynx) provided parcel polygon generation, landscape plan measurements and interpretation of the color aerial photography. Brighter Images, Inc. (BII) provided GIS consulting services.

Chris Dundon was the CCWD Project Manager for this study and managed the collection of data using the measuring wheel technique.

The data shown in Table 1 was provided or developed for this project.

Table 1: Data Sources

Data and Information	Provided or Developed by:
CalGrid Base Map of CCWD (CAD files)	CCWD
Customer Billing Database	CCWD
Geocoded Street Centerline Coverage	CCWD
Obtain Landscape Plans for 20 Sites	CCWD
Measuring Wheel Measurement of 20 Sites	CCWD
Landscape Plan Area Measurement of 20 Sites	Lynx Technologies
Acquire Color Aerial Photography of 20 Sites	HJW
Color Aerial Photo Area Measurement for 20 Sites (2 foot pixel)	Lynx Technologies
Creation of 4,000 Parcel Polygons from CCWD CAD files	Lynx Technologies
Digital Orthophoto of TWSA[16] (2 foot pixel)	HJW
Acquire Multispectral Image of TWSA (1 meter[17] pixel)	HJW
Classification of Landscape and other Areas for the entire TWSA[18]	HJW

[16] The Aerotopia Digital Orthophoto product (a 2-foot pixel orthophoto taken in 1996) was used for this study.

[17] 1 meter = 3.281 feet.

Types of Landscape Areas

For the purposes of this study[19], five different types of site area were defined:

- Turfgrass
- Groundcovers, shrubs and trees (a.k.a. Other Landscaping or "Other" for short)
- Water features (e.g., ponds, pools, fountains)
- Bare ground (e.g., unirrigated, natural vegetation or gravel walks)
- Hardscape (e.g., building roofs, parking lots, sidewalks)

The first two types of areas (turfgrass and other landscaping) require irrigation water in proportion to weather demands and can be used to generate detailed monthly Target Budgets for a site. Water features are included since these areas are often supplied by the same water meters as landscape areas. The sum of these three areas was called the **Total Landscape Area**; this can be used to create a "not to exceed" landscape water budget for the site based on weather data (ETo) and an ETo Adjustment Factor. Note that according to BMP5, the Adjustment Factor cannot exceed 100%.

Description of Area Measurement Methods

The four area measurement techniques considered in this report are summarized in Table 2.

Table 2: Area Measurement Methods

Technique	Description
2. Measuring Wheel	Physically measure the dimensions of landscape segments, modeled with geometric shapes such as rectangles, triangles and circles.
3. Landscape Plans	Trace the edges of landscape segments as shown in the plan, either physically using a planimeter or by digitizing the plan and measuring the segments electronically (the latter method was used in this study).
4. Aerial Photography	Trace the edges of apparent landscape and other land use segments in digitized high-resolution (2 foot pixel) color aerial photography, as viewed on a computer screen.
5. Multispectral Imaging	Use a multispectral image of the service district (represented in three separate bands of red, green and infrared), Image Analysis software (ERDAS Imagine) and a parcel boundary (polygon) to tabulate the landscape area contained within the parcel. (Note: the results obtained with classification software are based somewhat on the judgement of the computer operator.)

[18] Not all sites have parcel polygons; however, the classified data exists to support area estimates for the entire TWSA.

[19] Note that the measuring wheel method does not usually provide estimates of hardscape or bare ground areas. In some cases, however, the hardscape area may be measured and subtracted from the total parcel size to estimate landscape area.

Measuring Wheel

Sites are traditionally measured by walking the site with a measuring wheel. As described in the Landscape Water Management Auditing Handbook[20], manual measurement involves estimating the size of landscape segments by obtaining the dimensions of a series of geometric shapes which "cover" the landscape. A landscape segment is any small area of the site that can be readily measured.

Figure 1 and Table 3 provide a simple example of the use of a measuring wheel.

Figure 1: Measuring a Simple Landscape – Field Data

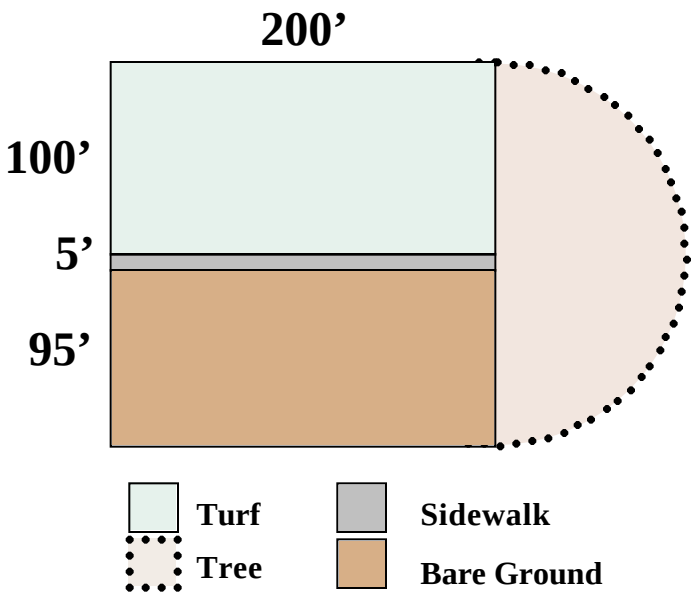


Table 3: Manual Measurement of a Simple Landscape – Calculations

Segment	Dimension 1	Dimension 2	Result (ft2)
Turf	*100*	*200*	*20,000*
Tree	*1/2 of circle*	*Radius of 100'*	*15,708*
Sidewalk	5	200	1,000
Bare Ground	95	200	19,000
		Total Site Area	55,708
		Total Landscape Area	*35,708*

[20] Landscape Water Management Auditing Handbook, Irrigation Training and Research Center, Cal Poly San Luis Obispo, 1991.

Each major dimension of the landscape segments of the site (e.g., 5', 95', 100', and 200') would be measured with a measuring wheel and recorded in the field (according to type of landscape material) in a table or with a simple sketch. In this example, we have distinguished turfgrass from trees and irrigated from unirrigated land so that a target budget could be reasonably estimated.

A typical acre of commercial landscaping might have more than 70 landscape segments requiring at least two dimensions each. These dimensions must then be entered into a spreadsheet or calculated manually and summed to provide a total site area. A few of the issues to consider when manually measuring are as follows:

- Utilizing the same person(s) to perform the measuring will improve consistency.
- Measuring personnel should have a good working knowledge of simple geometry to assist in estimating odd shapes (such as triangles, circles and areas with varying width).
- When rolling the measuring wheel over turf or groundcover areas, the measurement will be slightly different than if the wheel were rolling over paved areas. This is due to the wheel slipping on the plant material (giving a lower reading) or the surface texture being rougher (giving a higher reading).
- Confer with the property or site manager to verify the correct boundaries of the property/irrigation meter. This is also a good time to write down the meter numbers serving the site.

Landscape Plans

This technique uses large format landscape plans as the source of data. Obtaining the plan itself requires a significant effort by the utility, and plans may not be of good quality, may no longer be accurate or even exist. In many cases, a copy must be made before use, and cataloging and storing the plans adds to the expense and difficulty of this source of data.

The annotations on the landscape plan and its large format provide reasonable accuracy for delineation of areas by two distinct methods: planimetering and heads-up digitizing. With the planimetering technique, the edges of each landscape segment are traced and the planimeter indicates the area of that segment. These segment areas are then tabulated.

The technique used for this study was to digitize the plan and then to trace the edges of the landscape segments on the operator's computer screen using CAD software. Each segment was assigned a type classification and the segment data was stored in a database.

Because commercial sites are often complex, this technique resulted in the creation and classification of over 2,160 landscape segments for the 20 study sites (approximately 11 segments per acre).

Note that unless staff are well-versed in landscape plan takeoffs or have knowledge of the site itself, errors may occur due to misinterpretation of the plan. In addition, the plan may no longer reflect the actual "as-built" conditions at the site.

Aerial Photography

The Aerial Photography method employed in this study uses a computer terminal displaying a digitized aerial photo of the site. A graphics tablet or mouse is used to "draw" a polygon around each type of landscape area, a process known as "heads-up delineation." The area of the polygons is tabulated and entered into a database.

This project employed color photography scanned to a 2-foot pixel size in an effort to enhance measurement accuracy. Comments by the GIS contractor regarding the use of Color Aerial Photography were:

6. This method is much faster (as much as four times faster for some sites) but much less accurate than tracing from Landscape Plans.
7. The 2-foot pixel size of the digitized photos makes it difficult to resolve boundaries between land uses[21]. In general, setting the on-screen map scale to 1" = 1,000' is the most effective.
8. Because of tree cover, turf will be under represented.

Contrast has an effect on the confidence of the digitizing. For example, the quality of photos may vary so that some areas appear washed out while others appear too dark.

In addition, sometimes contrast is affected by adjacent features. For example, light colored groundcover and bare ground or turf tends to blend, or shadowed areas to the north of buildings are often difficult to distinguish from shrubs. The effect of these uncertainties may be misinterpretation of landuse.

Multispectral Imagery

This technique consists of taking a multispectral[22] aerial "picture" of the service area, using image analysis software to classify areas within the picture (creating a "classified" image), overlaying the classified image with a digital parcel map, and then using geographic information system (GIS) software to estimate the classified areas contained by each parcel (using the five land use classifications described earlier). Figure 2 illustrates this image analysis method.

A critical step in this process is aligning the multispectral (and thus classified) image to the parcel boundaries; good accuracy is required. The original, conventional approach selected for this project was to use a digital orthophoto[23] to align the multispectral image with streets and other geographic features -- see Figures 3 and 4 below. Since the digital parcel map had already been aligned to the orthophoto, a good match was anticipated. However, in this project the multispectral image could not be properly aligned to the orthophoto in hilly areas.

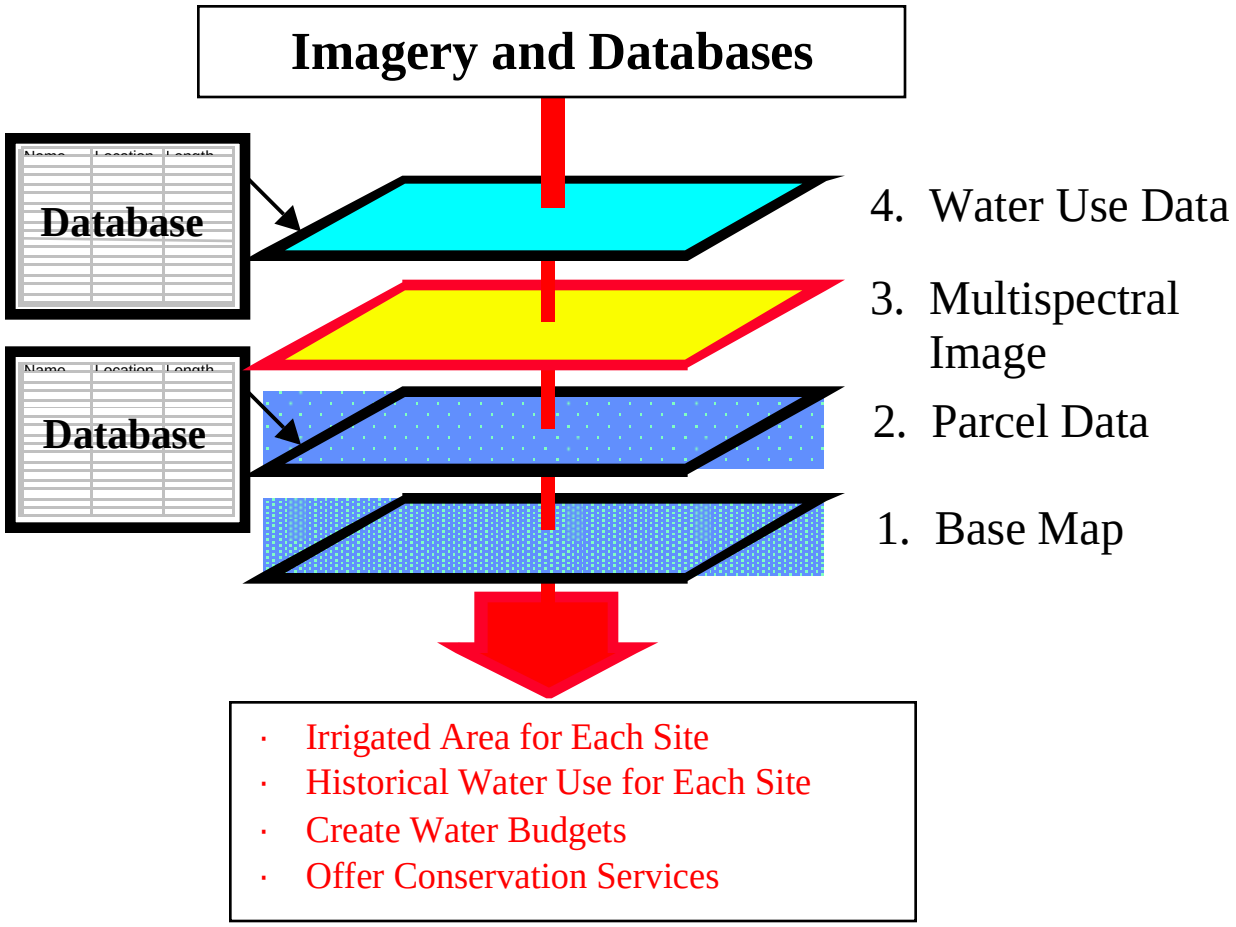
The solution was instead to align the parcel boundaries to the multispectral image, using a process called rubbersheeting (stretching the parcel boundaries to "fit" the multispectral image).

[21] Even at this modest resolution, the digital color files for just 20 sites required over one GB of data (2 CD-ROMS).

[22] The digital multispectral images used for this study include three bands: red, green and reflected infrared.

[23] An orthophoto has the appearance of a photo with the accuracy of a map.

Figure 2: Multispectral Landscape Area Measurement System (LAMS)



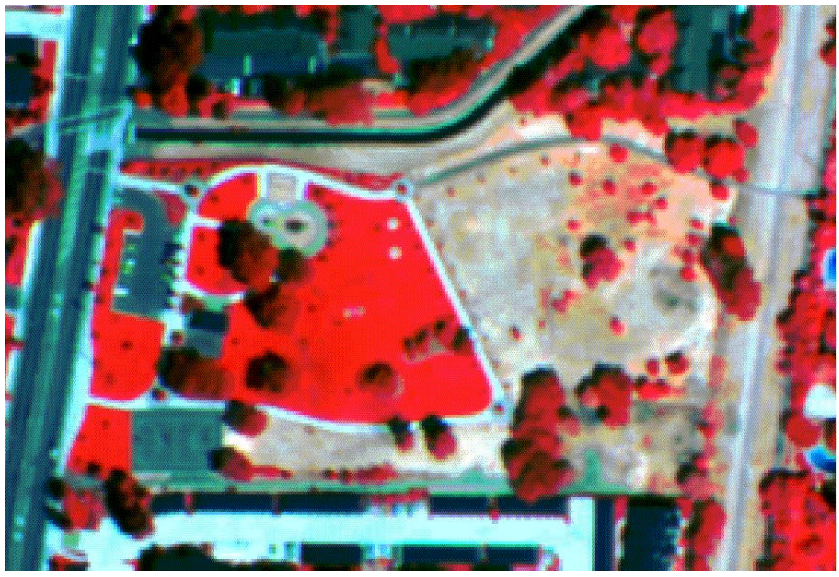
The classification of the image depends on having good quality data. In the end, it was determined that the image quality for this project was sub-standard, with air turbulence and atmospheric haze interacting to reduce pixel clarity during the acquisition of the image.

With a good quality image and an accurate match between parcel map and image, this approach can estimate the landscape size of every site (including residential) in an entire community. Note that an existing parcel map may require rectification either to an orthophoto or to the classified image itself. If the parcel map does not exist, it can often be purchased or created from other sources, as was done for this project[24].

[24] The parcels polygons were created from CAD facility maps supplied by CCWD. The CAD drawing did not indicate the parcel street address, meter number or property account number, thus additional "address matching" techniques were used.

Figure 3: Digital Orthophoto (Basemap) of Site 28

Figure 4: Multispectral Image of Site 28 (two color bands plus infrared)



Significant costs and delays were incurred in this project trying to match accounts (meters) to the parcels, as many of the target irrigation accounts did not have a service address. An additional challenge is that some parcels are in fact a mix of public (common areas) and private spaces (e.g., backyards in some condos/HOAs), thus some of the landscape area visible in the image may in fact be irrigated with individual meters rather than the large dedicated meters targeted by BMP5

For example, the polygon around site number 3, Black Diamond, surrounds all of the common areas, as well as front and back yards in the development. However, the dedicated irrigation account only provides water to the common areas and the front yards (not the back yards). Therefore the landscape area for all the back yards will need to be subtracted from the total, or the multispectral water budget would be artificially high. The "average" backyard size could be multiplied by the number of backyards to provide an estimate of the area to be subtracted from the multispectral estimate of landscape area.

A constraint of the multispectral method is that it requires sophisticated technologies for image acquisition and processing, resulting in high "fixed" or front-end costs. In addition, skilled and experienced technicians are required to guide the process to completion.

Selection of Test Sites

A sample of 20 out of approximately 900 sites served by dedicated irrigation meters in the CCWD Treated Water Service area were selected for this study. Criteria for site selection included:

- Representation of "typical" CII/MFR sites
- Broad range of parcel sizes
- Geographic distribution across the district

Because each study site required a landscape plan, letters were sent to property management companies, city maintenance departments, and to commercial sites, requesting "as-built" planting and irrigation plans. Initial response to the request for landscape plans was very poor, which necessitated numerous follow-up calls. Difficulties included:

- Most property managers for multi-family properties did not have Landscape or Irrigation plans.
- Plans for sites over 10 years old were generally not available or were no longer accurate.
- Obtaining plans often required several calls and a visit to the management office.

During the search, we learned of several sources for obtaining plans. These are:

- Owners of new properties may have plans available
- City planning departments generally have plans for city owned properties
- Site engineers at large commercial properties
- Landscape architects and architect firms

After ultimately receiving 30 plan sets, 20 were chosen to represent property types throughout CCWD. The 20 selected sites are described more fully in Tables 4 and 5.

Table 4: Summary of Study Sites

Account Type	Code	Count	Average Size (Acres)
Commercial	COM	10	3.9
Multi-Family Residential	MFR	6	19.7
Public Facilities (parks, street medians)	PUB	4	8.3
Study Sites		**20**	**9.5**
Total Area[25] of Study Sites			**190.1 acres**

[25] As determined from the irrigation plan method

Table 5: Study Sites in Detail

Site	Name[26]	Description	Code
1	American States Insurance	Commercial office building	COM
2	Pavilion Place	Condo Homeowner Association (HOA) common areas	MFR
3	Black Diamond HOA	Single Family HOA common areas and front yards	MFR
4	Elderwood Glen	Single Family HOA common area	MFR
5	Bank of the West	Commercial office building	COM
6	Taco Bell Site	Fast food restaurant and Oil Change Facility	COM
8	Concord Airport Plaza	Commercial office building	COM
9	Residence Inn	Hotel	COM
10	Stonebrook Convalescent	Convalescent Home	MFR
11	Diablo View HOA	Single Family HOA common area	MFR
12	LaTour Place	Single Family HOA common area	MFR
13	Ned Clyde Construction	Commercial/ Industrial building	COM
14	Contra Costa Food Bank	Commercial/ Industrial building	COM
15	Pike Court	Commercial/ Industrial building	COM
17	Clayton Road Medians	Road median	PUB
19	Contra Costa County Office of Education	Commercial office building	COM
22	Willow Pass Medians	Road median	PUB
25	Department of Motor Vehicles	Commercial building	COM
27	Arbolado Park	Park	PUB
28	Walden Park	Park	PUB

The four area measurement methods selected for this project were applied to each site independently, without sharing results (the measuring wheel results were retained by CCWD until the end of the project; the aerial photo and landscape plan data were developed by different sub-contractors, and the multispectral image data were developed by HJW).

[26] The original site numbers are retained for consistency.

Many of the measuring wheel results were obtained during the period of July–December 1998, although some were performed as long ago as 1993. The Landscape Plan and Aerial Photography results were obtained in the period September – November 1998. The multispectral image was acquired in August 1998; area estimates were initially generated in March 1999, but were then regenerated in May 1999 (with improved rectification of the multispectral image to the orthophoto) and September 1999 (with rubbersheeting of the parcels to the image).

Criteria for Comparing Methods

Comparison criteria included **feasibility** (suitability for expansion to district-wide coverage), **accuracy** (potential for verification and quality control, measurements in specific landscape categories[27]), and **cost** (required skill level, labor hours and costs, cost of contracted services). Estimated cost per acre and cost per site are provided.

[27] Five landuse categories were used for this study: Turfgrass, Other Landscaping, Water features (such as ponds and swimming pools), Bare ground and Hardscape. The first three categories were assumed to require water in varying proportions.

3. Results

Area Measurement Results

Tables 6, 7 and 8 provide the summary results of the test sites measured with four different methods. Each method was implemented directly by technicians, with "normal" supervision so that the results could be extrapolated to a District–wide implementation (we did not want unrealistic amounts of time spent by managers to "improve" the results). While no single method can be considered the most accurate in all cases, we have chosen to use the measuring wheel method as a basis for comparison.

Total Parcel Area -- Table 6 compares the Total Parcel Areas utilized by three methods (since the measuring wheel was only used to measure the landscape segments of the site, it is not included in this table). Landscape area discrepancies may appear arise if these results are significantly different (such entries are **outlined**). Data have been highlighted where significant discrepancies were encountered; six sites had some discrepancy in Total Site area. When these are set aside ("Grand Total Not Including…") the total site areas used by the three methods are remarkably close; these sites (and two others) are excluded from the comparison of total landscape area (Table 7) and comparison of turf area (Table 8).

Table 6: Total Parcel Areas

	Comparison		Total Parcel Area (acres)				Percent Variation from Plans	
#	Site Name	Note	Wheel (a)	Plans	Photos	MultiSpect	Photos	MultiSpect
1	American States Insurance			4.58	4.57	4.40	0%	-4%
2	Pavilion Place			5.07	5.02	5.25	-1%	3%
3	Black Diamond			34.30	35.32	34.10	3%	-1%
4	Elderwood Glen	b		30.67	27.98	31.15	-9%	2%
5	Bank of the West			5.39	5.38	5.47	0%	1%
6	Taco Bell			0.68	0.75	0.71	11%	4%
8	Concord Airport Plaza	c		11.00	9.68	11.07	-12%	1%
9	Residence Inn			3.97	3.81	4.01	-4%	1%
10	Stonebrook Convalescent			2.48	2.70	2.57	9%	4%
11	Diablo View	d		43.54	NA	43.55	NA	0%
12	La Tour Place			2.41	2.48	2.37	3%	-2%
13	Ned Clyde Construction			1.16	1.21	1.24	4%	7%
14	Contra Costa Food Bank			2.43	2.40	2.54	-1%	5%
15	4021-4041 Pike Lane	e		2.31	2.51	4.31	9%	87%
17	Clayton Road Medians	f		0.87	0.25	3.29	-71%	279%
19	CCC Office of Education			3.60	3.77	3.63	5%	1%
22	Willow Pass Medians	f		0.98	0.23	1.50	-76%	54%
25	DMV			3.52	3.58	3.58	2%	2%
27	Arbalado Park			25.02	25.56	25.68	2%	3%
28	Walden Park			6.16	6.52	6.66	6%	8%
	Grand Total			190.13	143.73	197.09	-24%	4%
	Grand Total Not Including Sites 4, 8, 11, 15 and Medians			100.76	103.09	102.21	2%	1%

Notes: (a) Total Area Not Measured with Wheel Method
(b) Parcel for Aerial Photo was in error
(c) Aerial Photo omitted parking lot at Southern End
(d) Aerial Photo not available
(e) Plans and Photos only measured 1 parcel (4021 Pike Lane)
(f) Multispectral parcels include pavement around and between median segments

Total Landscape Area -- Table 7 compares the Total Landscape Area (turf, other landscaping, water) compared to the measuring wheel method as a reference. Instances where measured results differ from the wheel data by more than 10% are described in the Notes below the table. Overall, there is a considerable amount of variance between the methods; the apparent reasons are discussed in the table. This does illustrate, however, that measuring landscapes is neither a simple nor an extremely precise task.

The sites have been grouped as to whether they have significant amounts of trees that overhang pavement or rooflines. This makes a big difference in the landscape area "seen" by the multispectral method (which measured 17% less landscape area than the wheel method for sites with small numbers of mature trees but 41% more landscape area than the wheel method for sites with many trees).

Table 7: Comparison of Total Landscape Area

	Comparison		Total Landscape Area (acres)				Percent Variation from Wheel		
	Site Name	Note	Wheel	Plans	Photos	MultiSpect	Plans	Photos	MultiSpect
#	**Turf Dominant**								
2	Pavilion Place	A	1.61	1.42	3.36	1.63	-12%	109%	1%
9	Residence Inn	B	1.15	0.94	1.09	1.17	-18%	-5%	2%
27	Arbolado Park	C	18.26	17.38	22.19	14.81	-5%	22%	-19%
14	Contra Costa Food Bank	A	0.55	0.59	0.25	0.48	7%	-54%	-14%
10	Stonebrook Convalescent	D	0.78	0.75	0.72	0.54	-4%	-8%	-31%
6	Taco Bell	E	0.23	0.18	0.16	0.18	-20%	-29%	-20%
	SubTotal		22.58	21.26	27.78	18.81	-6%	23%	-17%
#	**Tree Dominant**								
12	La Tour Place	F	0.65	0.61	1.05	1.25	-7%	61%	92%
25	DMV	F	0.51	0.60	0.57	1.00	19%	13%	97%
8	Concord Airport Plaza	F	2.60	2.80	2.33	4.28	8%	-10%	65%
5	Bank of the West	F	1.28	1.38	1.06	1.43	7%	-17%	11%
19	CCC Office of Education	F	1.37	1.33	1.19	1.22	-3%	-13%	-11%
13	Ned Clyde Construction	F	0.38	0.33	0.35	0.42	-14%	-8%	11%
	SubTotal		6.79	7.04	6.55	9.60	4%	-3%	41%
	Grand Total		29.37	28.31	34.32	28.41	-4%	17%	-3%
#	**Comparison Not Possible**								
1	American States Insurance	G	1.85	1.30	1.29	1.03	-29%	-30%	-44%
3	Black Diamond	H	7.67	7.73	7.88	9.16	1%	3%	19%
4	Elderwood Glen	H	1.50	8.27	7.83	5.47	450%	421%	264%
11	Diablo View	I	1.01	4.23	NA	14.59	320%	NA	1346%
15	4021-4041 Pike Lane	J	0.54	0.42	0.90	1.41	-23%	67%	162%
22	Willow Pass Medians	K	0.24	0.97	0.23	0.42	314%	0%	78%
17	Clayton Road Medians	K	0.21	0.87	0.25	0.15	308%	17%	-28%
28	Walden Park	L	1.61	1.96	2.30	2.41	22%	43%	50%

Notes: (A) Apparent photo misinterpretation.
(B) Plans show a building not yet built; a grass lawn now in this area.
(C) Photo method apparently treated the orchard as a large block of trees for simplicity.
(D) Multispectral did not measure mulch as landscape; dry turf near pavement classified as bare soil.
(E) Wheel measured more area than plans; photo and Multispectral did not count mulch as landscape.
(F) Significant tree canopy overhanging pavement/roofs as seen in Multispectral images; some tree shadow classified by Multispectral as landscaping; unclear why photo method showed least amount of landscaping.
(G) Wheel measured landscape all the way to street at south -- not part of parcel.
(H) Wheel, plans and photo measured only common areas; Multispectral included private yards.
(I) Wheel measured only common areas - other methods included residential open space; no photo available for this site.
(J) Wheel and Multispectral measured two parcels, other methods did not.
(K) Plans covered more medians than measured by other methods; tree overhang adds to Multispectral.

Eight sites have been excluded where direct comparison was not possible due to “apples and oranges” situations. At sites 1, 3, 4 and 11, for example, the wheel method measured only the area irrigated by the dedicated meters, while at least one of the other methods measured all landscaping (common and private) at the site. At site 15, two parcels were measured for two of the methods but only one parcel was measured for the other methods. The landscape plan areas for the medians (sites 17 and 22) suggest that different segments of the medians were measured by different methods. At site 28, multispectral used a parcel boundary that the other methods did not use (and multispectral therefore measured tree canopy that the other methods did not see).

Total Turf Area -- Table 8 compares the Turf Areas estimated by the four methods. Turf is the most intensively irrigated area and could be used (along with other landscaping and water feature area) as part of a target budget. Interestingly, both Aerial Photos and the Multispectral method are seen to be in better agreement with wheel measurements than are the landscape plans.

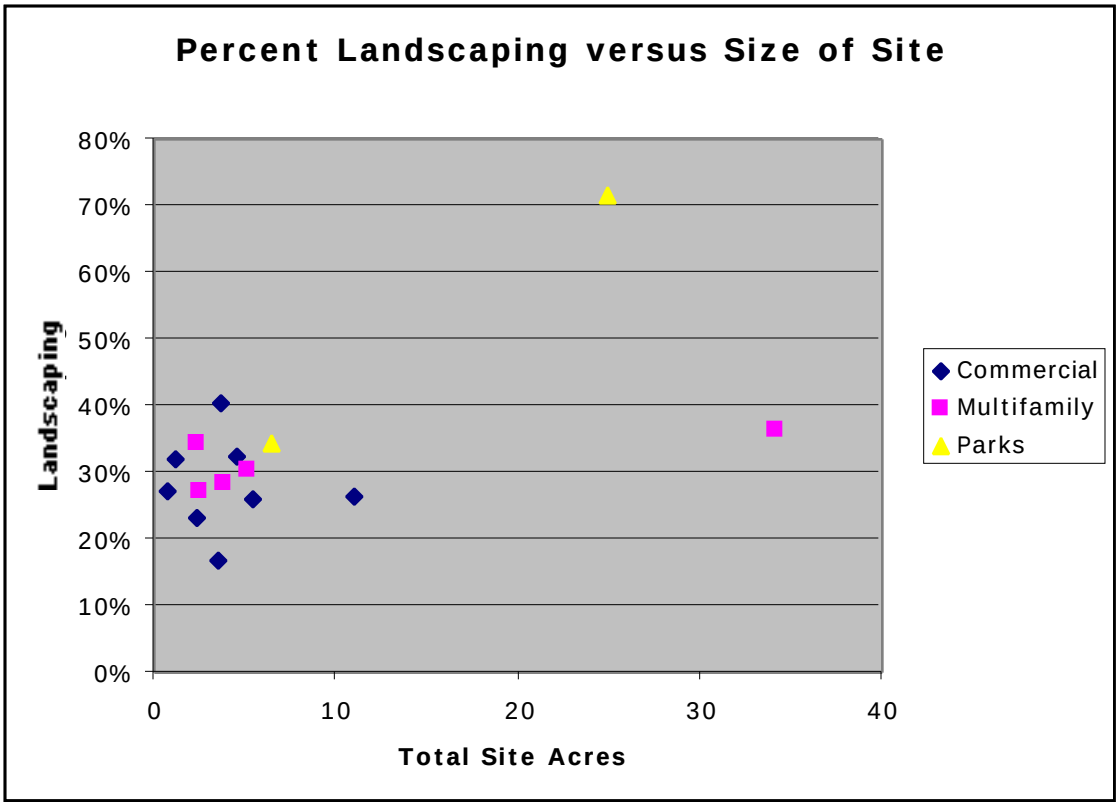
Table 8: Comparison of Turf Areas

	Comparison		Turf Area (acres)				Percent Variation from Wheel		
	Site Name	Note	Wheel	Plans	Photos	MultiSpect	Plans	Photos	MultiSpect
#	**Turf Dominant**								
2	Pavilion Place	1, 2, 3	0.37	0.57	0.09	0.70	53%	-76%	87%
9	Residence Inn	3	0.32	0.35	0.23	0.38	9%	-29%	16%
10	Stonebrook Convalescent	2	0.15	0.14	0.03	0.12	-3%	-81%	-19%
14	Contra Costa Food Bank	2	0.30	0.30	0.02	0.32	1%	-93%	8%
6	Taco Bell	2, 4	0.07	0.00	0.00	0.10	-100%	-100%	51%
27	Arbolado Park	5, 6	11.69	17.07	12.42	11.43	46%	6%	-2%
	SubTotal		12.90	18.44	12.79	13.04	43%	-1%	1%
#	**Tree Dominant**								
12	La Tour Place	2, 3	0.17	0.15	0.00	0.17	-13%	-100%	0%
5	Bank of the West	3	0.56	0.44	0.38	0.45	-22%	-32%	-20%
13	Ned Clyde Construction	2, 7	0.06	0.05	0.00	0.06	-18%	-100%	5%
25	DMV	4, 7	0.33	0.00	0.19	0.26	-100%	-43%	-21%
19	CCC Office of Education	2, 7	0.87	0.48	0.00	0.26	-45%	-100%	-70%
8	Concord Airport Plaza	2, 7	2.05	2.07	0.39	1.19	1%	-81%	-42%
	SubTotal		4.04	3.19	0.96	2.40	-21%	-76%	-41%
	Grand Total		16.94	21.62	13.75	15.44	28%	-19%	-9%
#	**Comparison Not Possible**								
1	American States Insurance	8	0.07	0.07	0.00	0.19	7%	-100%	186%
3	Black Diamond	1	1.88	2.15	0.00	2.46	14%	-100%	31%
4	Elderwood Glen	1	0.00	8.23	1.55	1.94	NA	NA	NA
11	Diablo View	9	0.04	2.00	NA	1.33	4491%	NA	2959%
15	4021-4041 Pike Lane	10	0.35	0.23	0.00	0.39	-35%	-100%	11%
22	Willow Pass Medians	3	0.00	0.00	0.00	0.17	NA	NA	NA
17	Clayton Road Medians	3	0.00	0.00	0.00	0.07	NA	NA	NA
28	Walden Park	7	1.44	1.73	2.30	1.49	21%	60%	3%

Notes: (1) Wheel measured only common areas; Multispectral included private yards.
(2) Photo misinterpretation.
(3) Multispectral misclassified the tops of some "bright" trees as turf.
(4) Plans show zero turf - thought to be an operator error.
(5) Plans show much more turf than measured by any method.
(6) Some areas of turf were dry and were classified by Multispectral as "other landscaping".
(7) Turf hidden from Multispectral view by trees.
(8) Wheel measured landscape all the way to street at south -- not part of parcel.
(9) Wheel measured only common areas; other methods included open space.
(10) Wheel and Multispectral measured two parcels, other methods did not.

It has been suggested that, given a site's total area and the type of site, it is possible to "estimate" the landscape area. While there is some "tendency" to have similar percent of landscape area, Figure 6 illustrates that the percent of landscaping can vary tremendously even for sites of the same type and total size. This seems especially true for commercial and public facilities.

Figure 6: Percent Landscaping vs. Size and Type of Site



Feasibility

The conclusion of the study team is that three of the methods – measuring wheel, aerial photos and multispectral imaging – could be applied to the entire service area. However, the landscape plan method, while providing a valuable baseline of information for this study, would be impractical to carry out for hundreds, let alone, thousands of sites. The time and trouble expended to obtain, duplicate, catalog and store even a few dozen plan sets surprised the study team.

Landscape plan analysis can serve as a useful supplement to the other methods, however. It is possible that an ordinance requiring the filing of plans with tabulated landscape areas for new or renovated sites could assist CCWD in keeping its landscape area database up-to-date.

Accuracy

Discrepancies in the areas measured with different techniques fall into three categories:

- Differences in Total Site Area
- Differences in Total Landscape Area (Turf, Other Landscaping and Water Features) vs. non-landscape areas (Bare Ground and Hardscape)
- Differences in type of Landscape Area (Turf vs. Other Landscaping)

Total Site Area

Total areas for the aerial photography and multispectral methods are based on parcel polygons provided by CCWD in a series of CAD drawings. These were converted to GIS format and used to determine the boundaries of parcels. The *apparent* parcel boundaries of the other techniques (measuring wheel and plans) may differ from this CAD-defined boundary, leading to discrepancies.

For example, the parcel polygons designate the "legal" property line. This polygon, however, may not include all of the areas watered on that site, as the parcel polygon may be "legally" located 20 feet inside of the sidewalk, while the irrigation covers the area up to the sidewalk and beyond to the curb (as was the case at Site 1). Note that CCWD's CAD drawings are based on County Parcel data sources, so this problem would occur in any parcel-based landscape measurement program.

In this study, sites 1, 3, 4, 8, 11, 15, 17, 22 and 28 ended up with different boundaries for at least one of the measurement techniques. This was due to either CAD-derived parcel boundaries that did not match the service area of the dedicated irrigation meter (sites 1, 3, 4, 11, 17, 22 and 28) or simple operator error (omitting a parking lot for site 8; selecting two parcels for site 15). Such discrepancies can be expected in any large-scale program where hundreds or thousands of sites are to be measured. Plan for the inevitable process of correcting many measurements over time, typically by working closely with customers.

(Site 8 could still be used for landscape area comparisons, as the omitted area was nearly all hardscape.)

Total Landscape Area

The operator-based methods (Measuring Wheel, Landscape Plans, and Aerial Photos) have a one-time calculation of area that is not easily checked or corrected -- the original measurement work may have to be duplicated in order to verify accuracy. For example, the measuring wheel method results in hundreds of calculations that are not easily related back to the actual areas measured at the site; working with landscape plans requires that each area be "checked off" after tabulation but no single area is easily related to a specific tabulation.

It is evident that when significant numbers of complex commercial or MFR sites are measured by human operators, there is room for errors of commission or omission. Committed errors may be of several types, the most common being calculating measurements improperly, assigning a segment to the wrong type of area, or counting the same segment more than once.

Omission errors may also occur in complex sites when a segment is omitted altogether, either by not being delineated in the field (or on a heads up digital image or planimeter), or from not being recorded.

Due to the large numbers of segments involved (one multifamily residential site had over 870 segments; the average site in this study has over 105 segments), these types of errors are both likely to occur and hard to detect. Such errors will hopefully be small for the larger sites.

The multispectral method creates a quantitative representation of the land use areas in the image delineated by the parcel polygon. By drawing supplemental polygons that define the service boundary of dedicated irrigation meters, the multispectral method can be used to analyze smaller areas of a total site.

In several cases (HOA sites 3, 4, and 11) the landscape areas being measured within the total site area were not the same. These MFR sites have common areas supplied by dedicated irrigation meters while private yards are supplied through mixed-use residential meters. The aerial photo and multispectral imaging methods use the entire parcel polygon to define the area to be measured, thus overestimating the area covered the dedicated irrigation meter(s).

Type of Landscape Area

The aerial photo and multispectral imaging methods may err in deciding whether an area is tree, turf or groundcover (however, they are less likely to mistake pavement for landscaping or water features). This confusion of land use type in unlikely to occur for the measuring wheel or landscape plan methods (assuming the plans are accurate).

Table 9 presents additional observations about the four methods tested in this study, listing advantages and disadvantages for each.

Table 9: Observations Regarding Area Measurement Methods

Method	Advantages	Disadvantages	Special Considerations
Measuring Wheel (Manual Measurement)	· Quick response for a specific site. · Capable of achieving high accuracy. · Low experience and training requirement. · "Low Tech" -- easy to add staff and expand rate of site measurement. · On site visit allows identification of water meter numbers servicing the site.	· Slow response for large numbers of sites. · Expensive to achieve high accuracy. · End product is simply a number with no other uses. · Difficult to display the area measured to the customer for verification.	· Difficult to Provide Quality Control (during fieldwork) and Quality Assurance (post-field work verification). · Requires contact with customer to gain permission to access site in some cases.
Landscape Plans (Digitized or Planimetered)	· High accuracy if plans are accurate. · Can segment total landscape area into turf and other landscaping. Easy to display area measured to customer for verification. · New accounts could be required to submit plans and area sums.	· Low accuracy when plans are not as-built. · Very difficult to obtain plans for large numbers of sites. · Difficult to organize and store plansets. · Does not include tree canopy areas in paved areas (e.g., parking lots).	· Requires large format scanner or large format planimeter.
Aerial Photography (Heads-Up Digitizing)	· Custom flight results in up-to-date information. · Can segment total landscape area into turf and other landscaping. · Consistent method for all sites. · Provide useful graphic tool when conducting a site audit. · Easy to display area measured to customer for verification. · Measures tree canopy in paved areas such as parking lots	· Old photography may be out of date. · Difficulty in overlaying parcel polygon and photo can result in errors. · Requires visit to some sites to verify meter number and parcel number are accurately connected. · Tree area may obscure pavement and turf areas. · Highly technical.	· Requires high-resolution color aerial photography (note: scanning for 2-foot pixel results in very large digital files; 50 MB per square mile). · Requires parcel polygon database.
Multispectral Imaging (Digital Imaging Processing)	· Consistent estimate of parcel areas. · Large numbers of sites measured in "batch" mode; can measure all sites in a service district if parcel data exists. · Site image useful for conducting site audits. · Customer verification of site area using site image. · Measures tree canopy in paved areas such as parking lots. · Measure shrub area but not mulch in sparsely planted areas.	· Expensive for a limited number (< 600) of sites. · Difficult to rectify ("match") parcel polygon to the image (which caused delays in this study). May benefit from rubbersheeting parcels to image. · Difficult match parcel polygon and Accounts · Requires visit to some sites to verify meter number. · Tree crown area may obscure pavement and turf areas. · Highly technical; requires training to maintain database system.	· Requires parcel polygon database. · Requires medium resolution (1 meter per pixel) multispectral imagery (33 MB per square mile). · Requires specialized image processing software. · Measures the entire area within the site parcel. Areas supplied by private residential meters need to be removed from the total to prepare the water budget.

Costs

Table 10 provides summary statistics of the cost to measure the **landscape area only** at 20 test sites using a measuring wheel, presented in a format to permit extrapolation to other water districts. Note that each of the other three methods was used to estimate **total site area**, including buildings and pavement. Total staff time was approximately 77 hours, resulting in an average productivity of about 10 sites per person per week (2 per workday).

Table 10: Costs of Measuring Wheel Method (Landscape Area Only) – 20 Sites in CCWD

Landscape Acres	Count	Average Acres	Total Acres	$/acre ($25/hr)	Total Cost	Avg. $ per Site
0-0.49	4	0.25	1.0	$ 291	$ 291	$ 73
0.5-0.99	4	0.65	2.6	$ 99	$ 257	$ 64
1-1.99	9	1.37	12.3	$ 59	$ 726	$ 81
2-3.99	1	2.60	2.6	$ 47	$ 122	$ 122
4-7.99	1	7.70	7.7	$ 70	$ 539	$ 539
>8	1	18.30	18.3	$ 10	$ 183	$ 183
Total	**20**	**2.23**	**44.5**	**$ 48**	**$2,118**	**$ 106**

Note: The most expensive site ($539) was a MFR site with 7.7 acres of complex common area; the site with the lowest cost per acre ($9/acre) was a large park.

Measuring wheel costs are proportional not only to the size of the site but to its complexity. In this set of test sites, the most complex site (a MFR site with 7.7 acres of landscaping in hundreds of small planting areas) cost $501 to measure ($70 per acre), while the largest site, a public park (twice as large as the most complex site but simple in design), only cost $183 to measure ($9 per acre).

Table 11 provides detailed estimates of the projected costs[28] to measure landscape area at significant numbers of sites using each of the four methods. Assumptions for labor cost range from $25 per hour for the measuring wheel to $75 per hour for the flight-planning specialist. Labor costs dominate the Aerial Photography method, as a skilled technician must review each site individually in order to estimate landscape areas.

The multispectral image method also requires skilled technicians, but they apply their skills to the image processing across the entire District and do not deal with each site individually.

[28] These were not the costs incurred by CCWD for this study – these are projected costs for new projects starting from scratch and include a base cost of $2 per parcel polygon for the aerial photo and multispectral image methods.

Table 11: Projected Costs of Landscape Measurement Techniques

Measuring Wheel						MW Sites	20
Phase/Activity	Setup	Data Acquisition	Data Processing	Database	Total	Hours Per Site	MW Rate
Call customers	$ 100				$ 100	0.20	$ 25
Drivetime		$ 85			$ 85	0.17	$ 25
Review of Sitemap		$ 85			$ 85	0.17	$ 25
Measurement		$ 999			$ 999	2.00	$ 25
Calculations			$ 749		$ 749	1.50	$ 25
Database				$ 100	$ 100	0.20	$ 25
				Total	**$ 2,118**		
				Per Site	**$ 106**	**4.2**	**hrs/site**

Landscape Plans						LP Sites	20
Phase/Activity	Setup	Data Acquisition	Data Processing	Database	Total	Hours Per Site	LP Rate
Obtain Plans	$ 500				$ 500	1.00	$ 25
Drivetime		$ 85			$ 85	0.17	$ 25
Review of Sitemap		$ 200			$ 200	0.25	$ 40
Measurement		$ 1,450			$ 1,450	1.81	$ 40
Calculations			$ 145		$ 145	0.18	$ 40
Database				$ 145	$ 145	0.18	$ 40
				Total	**$ 2,525**		
				Per Site	**$ 126**	**3.6**	**hrs/site**

Aerial Photography*			AP Area	45	sq.mi.	AP Sites	5,000
Phase/Activity	Setup	Data Acquisition	Data Processing	Database	Total	Hours Per Site	AP Rate
Logistics	$ 600				$ 600		$ 75
Flight		$ 4,500			$ 4,500		Flat
Process Film, Digitize			$ 2,250		$ 2,250		Flat
Measurement			$ 134,000		$ 134,000	0.67	$ 40
Calculations			$ 13,400		$ 13,400	0.07	$ 40
Confirmation Visits **			$ 5,000		$ 5,000	0.25	$ 40
Parcel Database				$ 10,000	$ 10,000		$ 2
Manually Place 10% of parcels			$ 2,000		$ 2,000	0.10	$ 40
Database				$ 13,400	$ 13,400	0.07	$ 40
*** color**				**Total**	**$ 185,150**		
**** 10% of sites, 15 min.**				**Per Site**	**$ 37**	**0.93**	**hrs/site**

Multispectral Imaging			MS Area	45	sq.mi.	MS Sites	5,000
Phase/Activity	Setup	Data Acquisition	Data Processing	Database	Total	Hours Per Site	MS Rate
Logistics	$ 750				$ 750		$ 75
Flight		$ 5,500			$ 5,500		Flat
Process Data			$ 27,045		$ 27,045	0.09	$ 60
Calculations			$ 1,352		$ 1,352	0.005	$ 60
Confirmation Visits *			$ 5,000		$ 5,000	0.25	$ 40
Parcel Database				$ 10,000	$ 10,000		$ 2
Manually Place 10% of parcels			$ 2,000		$ 2,000		
Database				$ 1,352	$ 1,352	0.005	$ 60
*** 10% of sites, 15 min.**				**Total**	**$ 53,000**		
				Per Site	**$ 11**	**0.35**	**hrs/site**

Table 12 summarizes the projected cost per site based on 5,000 target sites in a 45 square mile service area. The landscape plan and measuring wheel methods have been calculated using the 20 test sites as the site count since there are essentially no economies of scale for these methods – the per site costs are the important figure here.

Table 12: Projected Costs per Site if Applied to A District with 5,000 Target Sites

Method	Planning/ Setup	Acquisition of Data	Processing of Data	Database	Total	Site Count	Cost Per Site for TWSA
Landscape Plans	$ 500	$ 1,735	$ 145	$ 145	$ 2,525	20	$ 126.25
Measuring Wheel	$ 100	$ 1,169	$ 749	$ 100	$ 2,118	20	$ 105.90
Aerial Photography	$ 600	$ 4,500	$ 156,650	$ 23,400	$ 185,150	5,000	$ 37.03
Multispectral Imaging	$ 750	$ 5,500	$ 35,398	$ 11,352	$ 53,000	5,000	$ 10.60

Table 13 presents the least cost measurement alternatives considering the number of sites measured within a 45 square mile service area. Note that as the number of sites to be measured increases, image-based methods improve in cost effectiveness.

Table 13: Minimum Cost Per Site Depends on Number of Sites Measured (Assuming 45 square miles of Service Area)

	Cost Per Site Based on Number of Sites					
Method	100	200	400	800	2,500	5,000
Landscape Plans	$ 126	$ 126	$ 126	$ 126	$ 126	$ 126
Measuring Wheel	**$ 106**	$ 106	$ 106	$ 106	$ 106	$ 106
Aerial Photography	$ 175	**$ 105**	**$ 69**	$ 52	$ 40	$ 37
Multispectral Imaging	$ 393	$ 198	$ 100	**$ 52**	**$ 18**	**$ 11**

The economies of scale for the image-based methods are evident in Figure 7, which shows that the low labor cost of the image-based methods eventually overcomes the high fixed cost nature of these methods as more sites are measured.

Figure 7: Costs of Landscape Measurement Techniques
(Assuming 45 square miles of Service Area)

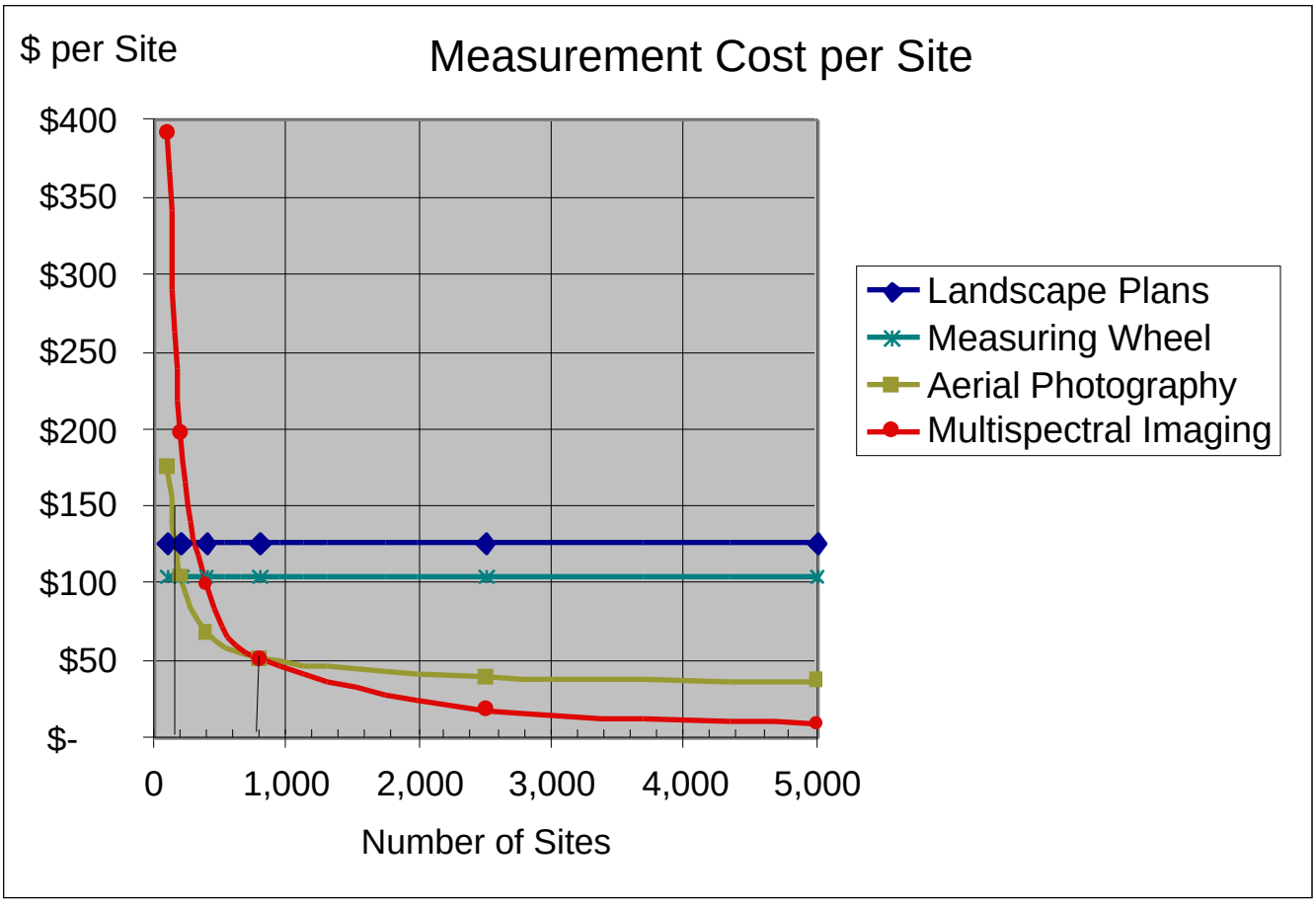


Table 13 presents basic, qualitative statements about each of the methods to help the reader become comfortable with the characteristics of each method.

Table 13: Qualitative Assessment of Landscape Measurement Techniques

Criteria	Measuring Wheel	Landscape Plans	Aerial Photos	Multispectral Imaging
Skill Level/Training Requirement	Low	Medium	Medium	High
Startup Costs	Low	Medium	Medium	High
Equipment Costs	Low	Medium	Medium	High
Labor Cost as a portion of total cost	High	High	Medium	Low
Cost per Site[29]:				
1-200 sites	**Lowest**	High	Medium	**Highest**
200-800 sites	**Highest**	*Not practical*	**Lowest**	Medium
> 800 sites	**Highest**	*Not practical*	Medium	**Lowest**

[29] See Figure 7 above.

4. Case Study: CCWD Water Budget Program

As an extension of the Landscape Area Measuring Study, CCWD decided to measure the remainder of the dedicated meter irrigation sites (approximately 900 sites) as well as all commercial, industrial, institutional and multi-family sites (an additional 4,530 sites; 5,430 total), and to create a database program for calculating Landscape Water Budgets. The multispectral image method was selected due to the large number of sites and the desire to have the images available for use in a geographic information system (GIS).

District Description

CCWD (located 15 miles East of San Francisco Bay) provides treated water to Concord, Clayton, Clyde, Pacheco and parts of Pleasant Hill and Walnut Creek. Property types include commercial, industrial park, multi-family complexes, and public agencies. As illustrated in Table 14, there are approximately 1,267 dedicated irrigation accounts supplying an estimated 900 sites. An additional 5,847 mixed meter accounts serve the same service categories.

CCWD's billing system categorizes dedicated irrigation accounts into three distinct groups (revenue codes 14, 24 and 44) listed in Table 14. (RevCode 99 was assigned to the special group of canal accounts found along CCWD's transfer canal.)

Table 14: CII/MFR Customer Accounts

RevCode	Customer	Total	%
11	Multifamily Residential	2,468	35%
14	MFR Irrigation	576	8%
20	Commercial	2,842	40%
24	Commercial Irrigation	317	4%
30	Industrial	6	0%
40	Public	233	3%
44	Public Irrigation	374	5%
99	Canal Accounts	298	4%
	Mixed Use	5,847	82%
	Irrigation	1,267	18%
	Grand Total	7,114	100%

A parcel polygon database was created in GIS format based on a CAD file supplied by CCWD (CalGrid map system). The CAD file did not have address or meter number labels associated with the parcel shapes. Therefore, the CCWD billing database "service address" field was used to locate accounts in the GIS work file (using a TIGER street centerline database[30]), but more than 50% of the dedicated irrigation meter accounts did not have a specific service address. The plan was to use "nearest neighbor" techniques to locate accounts without addresses[31].

The GIS contractor was able to create approximately 84% of the necessary parcel polygons and associate accounts with these polygons. Unfortunately, many of the dedicated irrigation accounts will have to be assigned manually by AQM and CCWD staff; this is estimated to take approximately 6 minutes per account (137 hours total). A detailed description of the GIS procedures employed is found in Table 15.

Table 15: GIS Procedures for Accounts and Parcels

The site polygon shapes were digitized from the CCWD landbase in NAD27 coordinates and then re-projected to NAD83 based on a reference point from the Aerotopia digital orthophotographs. The polygons were snapped to the landbase using AutoCAD Map. ArcCAD was used to create the resulting coverage. Label points and User-IDs were system generated when possible.
Account points were digitized using three methods:
First, accounts were matched to corresponding parcels based on a visual scan of the CCWD map book; locations were matched on the site address.
Second, accounts were geocoded using CCWD supplied TIGER centerline data. The TIGER streets and CCWD accounts shape file was imported into AutoCAD Map with attributes captured as object data. The accounts (points) were spliced with the TIGER centerlines into the CCWD landbase to locate their position to a specific parcel.
A total of 5,749 accounts (out of 7,114) were located and digitized with their associated attributes linked to parcels in ArcView 3.1 using these two methods.
Third, an attempt was made to digitize the remaining non-address matched accounts by sorting on water meter route sequence number. This helped with location because some accounts could be bracketed by other address-matched points. These new points were digitized using AutoCAD's BLOCK definition with a single attribute (route sequence number). The resulting point data set was exported to a shape file – but 732 of these could not be assigned to a specific parcel.
Although 91% of CII and MFR accounts were placed using these three techniques (6,480 out of 7,114), 634 accounts (many of them target "dedicated irrigation meter" accounts with no service addresses) and an estimated 720 parcel polygons could not be located using these methods.
CCWD and AquaMetrics staff will locate these unfound accounts and parcels using manual techniques.

[30] The positional accuracy of the street centerline file was only +/- 200 feet in many areas.

[31] Only commercial accounts were made available to AQM for route sequence matching. In retrospect, the residential accounts would have improved address matching.

Landscape Water Budget Database and GIS Software

In order to facilitate management of the BMP5 requirements (create water budgets, provide bi-monthly reports of water application amounts relative to budget), a database system was designed and developed in Microsoft ACCESS which permits the printing of water budget reports (a sample report is included in Appendix C).

These reports are based on parcels or groups of parcels and provide the total area measured for the parcel as well as monthly weather data, target budgets and actual water use. The actual use and budget are also graphed for easy recognition of over-budget, under-budget problems.

Because the data used for multispectral imaging and the parcel polygons are geographic in nature, GIS software was provided (ESRI ArcView Version 3.1) so that CCWD staff could perform geographic queries on the irrigation accounts and parcels. For example, all multifamily irrigation accounts within the City of Concord could be selected and analyzed separately from all other accounts.

Expected future uses of this system include customer interaction (telephone calls or personal visits), analysis of over-budgets accounts, targeting of conservation services such as irrigation audits and meeting BMP5 reporting requirements.

By linking the database and GIS software, thousands of pages of reports can be produced without user input, as may occur on an annual basis when “water budgets” are sent out to irrigation customers. Patterns of overuse (during rainy months or within certain customer groups) can be analyzed to permit specific program response. Because the imagery permits recalculation of landscape area, corrections of original estimates or recalculation due to changing conditions can be performed without leaving the office and with the same accuracy as the original calculations.

5. Conclusions and Recommendations

Conclusions

This study was performed to test the feasibility, accuracy and cost of four readily available landscape area measurement methods.

- The **Measuring Wheel** method provides good quality data but takes significant conservation staff or consultant time for each site; however, it is the preferred method when the total number of sites to be measured is small (200 sites or less). Because the final area estimate is created from simplified field measurements and area calculations for hundreds of small landscape segments, it is difficult to know if segments have been missed, double counted, or incorrectly measured or calculated. Sparsely planted areas tend to be overestimated in size and tree crown areas are under-measured.
- The **Landscape Plan** method (measuring areas drawn on the plan itself as opposed to in the field) provides good quality data (because the type of area is noted on the plan), assuming the landscape plan accurately reflects the current landscape. A trained operator would typically perform this method using either a planimeter, a digitizing tablet, or by delineating a scanned image of the plan. As with the measuring wheel, sparsely planted areas tend to be overestimated in size and tree crown areas are rarely measured. A significant constraint is the difficulty of obtaining and verifying the accuracy of plans for existing sites – it is unlikely that this method would be used as the only method for a large District.
- The **Aerial Photography** method (in this case, digitized aerial photos viewed "heads-up" on a computer screen) can provide reasonable estimates of landscape area, but smaller landscape features (small trees or bushes) are difficult to classify, especially if grayscale photos are used. Although this project used color aerial photographs (NB: most pre-existing aerial photography is likely to be grayscale), operators still had difficulty identifying landscaping in certain cases. Trees will overhang pavement and obscure turf areas. The measured area is defined by a parcel boundary, which may be difficult to obtain and may not reflect the boundary of the irrigated area. It is assumed that 10% of all parcels will require manual placement of parcels in GIS and conformation site visits.
- **Multispectral Imagery** provides estimates of landscape area using a multiple-band digital aerial camera system (three spectral bands were used for this study: red, green, and infrared). The measured area is defined by a parcel boundary, which may be difficult to obtain[32] and may not reflect the boundary of the irrigated area. It is assumed that 10% of all parcels will require manual placement of parcels in GIS and conformation site visits.

[32] Using the best available data sources, we were only able to create about 80% of the necessary parcel polygons during this project. The remaining polygons will be created by AQM and CCWD in a cooperative effort using manual methods.

One problem observed in this study was that the multi-spectral image could not be rectified to the desired accuracy due to terrain variations across the CCWD service area. This necessitated artificially "rubber-sheeting" the parcel boundaries to the image in order to perform the area calculations.

Because an image of the entire service area must be obtained and processed, the initial cost of this method is significant. However, the cost per site can be the lowest of the four methods when at least 800 sites are measured. As with the aerial photography method, trees will overhang pavement and obscure turf areas. One unique aspect of this technique is that mulch areas in sparsely planted areas are correctly tallied as bare ground, rather than counted as planted area.

Considering its long-term advantages, CCWD approved the use of the multispectral imaging technique to develop landscape area estimates for approximately 900 dedicated meter sites and 4,530 mixed-use meter CII and MFR sites. Because the multispectral images are permanently available and accessible through GIS software, CCWD staff can create new area estimates or correct existing estimates in response to customer supplied data or staff field visits.

To a large degree, the landscape area method (or methods) selected by a utility will depend on the number of sites that need to be measured. When the number of sites is small, methods with low startup costs may be preferred (manual measurement or heads-up delineation of existing aerial photography), although per site costs are high (e.g., $106 per measuring wheel site). However, when the number of sites is large or when time is short, an image classification method with low per site costs (as low as $9 per site) such as multispectral imaging may be preferred (if the necessary parcel polygon database is available).

There are always discrepancies in areas measured with different techniques. These fall into three categories:

1. Differences in Total Area
2. Differences in Landscape Total Area vs. Non-landscape Areas
3. Differences in type of Landscape Areas

Differences in Total Area may appear due to the parcel polygon not matching the apparent parcel provided in the landscape plan and/or the apparent parcel boundaries encountered in manual measuring. The color aerial photography and the multispectral image methods use the parcel polygon to define the edge of the measured area, although at many sites this does not exactly match the irrigated area. Eight out of 20 test sites had this problem.

Differences in Total Landscape vs. Non-Landscape area may occur due to human judgement (estimating or simplification techniques employed when using a measuring wheel, such as measuring the outer boundary of a shrub bed rather than the crown area of the shrubs), differing interpretations of aerial photos or the limitations of the method itself (out of date landscape plans, areas hidden from aerial view [e.g., close to buildings or under trees]).

Differences in type of Landscape Areas may occur due to misclassification of areas with the aerial photo or multispectral image methods.

When applied to the twelve sites with comparable boundaries, the Total Landscape Area measured by the Landscape Plan, Aerial Photo and Multispectral Imaging techniques differed from the Measuring Wheel method by –4%, 17% and -3%, respectively.

Because any chosen method will have difficulties, measurement of landscape area for CII/MFR customer sites should be viewed as a *process*, not one-time product. Perhaps 80% of the desired data will be obtained in short order, but the remaining sites will have to be addressed over a longer period.

It should be mentioned that the technology for multispectral imaging is advancing rapidly – new cameras and rectification technologies were introduced during the performance of this study. And the potential success of high altitude, unmanned, solar powered reconnaissance airplanes (which could dramatically lower the cost of image products) is just one of many indications that some form of remote sensing may become standardized in the landscape water conservation domain.

Recommendations

1. This study considered four techniques to estimate landscape area at CII /MFR sites. Conservation coordinators are advised to obtain a copy of the BMP 5 Handbook to learn as much as possible about other landscape area measurement techniques.
2. The use of Landscape Plans to measure landscape area proved accurate but was the most expensive and least practical method reviewed in this study.
3. Measuring wheel estimates are practical and cost effective when the number of sites to be measured is approximately 200 or less. Using Landscape Plans to supplement field measurement will likely prove helpful.
4. The use of Aerial Photography can be a reasonable method of measuring landscapes when the number of sites is between 200 and 800, as this spreads the costs of obtaining the photography over a number of sites. However, under the conditions of this study, this method seemed to be less accurate than other methods.
5. If good image rectification can be assured, multispectral imaging can provide savings when the number of sites to be measured is greater than 800, and the critical resource of a parcel polygon database exists or can be readily created. This method differs from the other methods by measuring tree canopy (which the other methods typically ignore), by not measuring mulch areas (which the measuring wheel and plans methods include as planted area) and in measuring privately irrigated areas along with the dedicated meter areas (the total size of these private areas should be estimated and removed from the total).
6. Conservation coordinators are advised to obtain a copy of the BMP 5 Handbook to learn as much as possible about the variety of landscape area measurement techniques.
7. Manual methods will likely prove useful when small numbers of sites must be measured, while more automated methods are likely to provide important savings when the number of sites is large and the critical resource of a parcel polygon database exists.

Appendix A: Area Measurements For Each Method

1. Measuring Wheel

#	Site Name	Measuring Wheel LAND USE (Square Feet) Turf	Other Landscape	Water Features *	Bare Ground *	Hardscape *	Grand Total		Total Landscape Area
1	American States Insurance	2,929	77,549				80,478		80,478
2	Pavilion Place	16,259	53,921				70,180		70,180
3	Black Diamond	81,753	252,462				334,215		334,215
4	Elderwood Glen	0	65,484				65,484		65,484
5	Bank of the West	24,315	31,471				55,786		55,786
6	Taco Bell	2,977	6,990				9,967		9,967
8	Concord Airport Plaza	89,084	24,030				113,114		113,114
9	Residence Inn	14,080	35,897				49,977		49,977
10	Stonebrook Convalescent	6,447	27,578				34,025		34,025
11	Diablo View	1,894	42,053				43,947		43,947
12	La Tour Place	7,338	21,056				28,394		28,394
13	Ned Clyde Construction	2,568	13,872				16,440		16,440
14	Contra Costa Food Bank	12,911	11,129				24,040		24,040
15	4021-4041 Pike Lane	15,163	8,224				23,387		23,387
17	Clayton Road Medians	0	9,290				9,290		9,290
19	CCC Office of Education	38,014	21,667				59,681		59,681
22	Willow Pass Medians	0	10,250				10,250		10,250
25	DMV	14,453	7,705				22,158		22,158
27	Arbolado Park	509,303	286,158				795,461		795,461
28	Walden Park	62,583	7,472				70,055		70,055
	Grand Total	902,071	1,014,258				1,916,329		1,916,329

* Not Measured

#	Site Name	Measuring Wheel LAND USE (Acres) Turf	Other Landscape	Water Features *	Bare Ground *	Hardscape *	Grand Total		Total Landscape Area
1	American States Insurance	0.07	1.78				1.85		1.85
2	Pavilion Place	0.37	1.24				1.61		1.61
3	Black Diamond	1.88	5.80				7.67		7.67
4	Elderwood Glen	0.00	1.50				1.50		1.50
5	Bank of the West	0.56	0.72				1.28		1.28
6	Taco Bell	0.07	0.16				0.23		0.23
8	Concord Airport Plaza	2.05	0.55				2.60		2.60
9	Residence Inn	0.32	0.82				1.15		1.15
10	Stonebrook Convalescent	0.15	0.63				0.78		0.78
11	Diablo View	0.04	0.97				1.01		1.01
12	La Tour Place	0.17	0.48				0.65		0.65
13	Ned Clyde Construction	0.06	0.32				0.38		0.38
14	Contra Costa Food Bank	0.30	0.26				0.55		0.55
15	4021-4041 Pike Lane	0.35	0.19				0.54		0.54
17	Clayton Road Medians	0.00	0.21				0.21		0.21
19	CCC Office of Education	0.87	0.50				1.37		1.37
22	Willow Pass Medians	0.00	0.24				0.24		0.24
25	DMV	0.33	0.18				0.51		0.51
27	Arbolado Park	11.69	6.57				18.26		18.26
28	Walden Park	1.44	0.17				1.61		1.61
	Grand Total	20.71	23.28				43.99		43.99

2. Landscape Plans

#	Landscape Plans	LAND USE (Square Feet)							
	Site Name	Turf	Other Landscape	Water Features	Bare Ground	Hardscape	Grand Total	Total Landscape Area	Homeowner*
1	American States Insurance	3,144	52,470	1,212	15,979	126,590	199,394	56,826	
2	Pavilion Place	24,835	37,127		5,786	109,729	177,477	61,962	43,390
3	Black Diamond	93,592	243,062			785,514	1,122,169	336,654	371,815
4	Elderwood Glen	358,622	1,750		314,366	321,536	996,273	360,372	339,728
5	Bank of the West	19,078	40,877		6,134	168,873	234,961	59,954	
6	Taco Bell		7,950		631	20,826	29,407	7,950	
8	Concord Airport Plaza	90,378	31,424			357,404	479,205	121,802	
9	Residence Inn	15,300	24,979	707	5,665	126,290	172,941	40,987	
10	Stonebrook Convalescent	6,247	26,349			75,376	107,972	32,596	
11	Diablo View	86,947	97,487		674,271	658,648	1,517,353	184,433	379,374
12	La Tour Place	6,402	19,456	597	9,258	69,170	104,883	26,455	
13	Ned Clyde Construction	2,105	12,103			36,386	50,593	14,207	
14	Contra Costa Food Bank	13,054	12,561		248	80,115	105,978	25,616	
15	4021-4041 Pike Lane	9,905	8,215			82,319	100,439	18,120	
17	Clayton Road Medians		37,857				37,857	37,857	
19	CCC Office of Education	20,873	37,175			98,705	156,753	58,047	
22	Willow Pass Medians		42,455				42,455	42,455	
25	DMV		26,323			127,042	153,365	26,323	
27	Arbolado Park	743,593	13,522		218,216	114,381	1,089,712	757,115	
28	Walden Park	75,547	9,911		156,524	26,549	268,531	85,459	
	Grand Total	1,569,622	783,052	2,516	1,407,077	3,385,453	7,147,718	2,355,189	1,134,307

* This area was deemed to be irrigated privately

#	Landscape Plans	LAND USE (Acres)							
	Site Name	Turf	Other Landscape	Water Features	Bare Ground	Hardscape	Grand Total	Total Landscape Area	Homeowner*
1	American States Insurance	0.07	1.20	0.03	0.37	2.91	4.58	1.30	
2	Pavilion Place	0.57	0.85		0.13	2.52	4.07	1.42	1.00
3	Black Diamond	2.15	5.58			18.03	25.76	7.73	8.54
4	Elderwood Glen	8.23	0.04		7.22	7.38	22.87	8.27	7.80
5	Bank of the West	0.44	0.94		0.14	3.88	5.39	1.38	
6	Taco Bell		0.18		0.01	0.48	0.68	0.18	
8	Concord Airport Plaza	2.07	0.72			8.20	11.00	2.80	
9	Residence Inn	0.35	0.57	0.02	0.13	2.90	3.97	0.94	
10	Stonebrook Convalescent	0.14	0.60			1.73	2.48	0.75	
11	Diablo View	2.00	2.24		15.48	15.12	34.83	4.23	8.71
12	La Tour Place	0.15	0.45	0.01	0.21	1.59	2.41	0.61	
13	Ned Clyde Construction	0.05	0.28			0.84	1.16	0.33	
14	Contra Costa Food Bank	0.30	0.29		0.01	1.84	2.43	0.59	
15	4021-4041 Pike Lane	0.23	0.19			1.89	2.31	0.42	
17	Clayton Road Medians		0.87				0.87	0.87	
19	CCC Office of Education	0.48	0.85			2.27	3.60	1.33	
22	Willow Pass Medians		0.97				0.97	0.97	
25	DMV		0.60			2.92	3.52	0.60	
27	Arbolado Park	17.07	0.31		5.01	2.63	25.02	17.38	
28	Walden Park	1.73	0.23		3.59	0.61	6.16	1.96	
	Grand Total	36.03	17.98	0.06	32.30	77.72	164.09	54.07	26.04

* This area was deemed to be irrigated privately

3. Color Aerial Photography

#	Color Aerial Photography / Site Name	LAND USE (Square Feet) Turf	Other Landscape	Water Features	Bare Ground	Hardscape	Grand Total	Total Landscape Area
1	American States Insurance		56,032		45,112	97,868	199,012	56,032
2	Pavilion Place	3,969	142,444			72,196	218,610	146,414
3	Black Diamond		343,200		246,426	948,848	1,538,475	343,200
4	Elderwood Glen	67,312	273,829		516,836	360,819	1,218,796	341,140
5	Bank of the West	16,608	29,516			188,397	234,521	46,124
6	Taco Bell		7,052			25,560	32,611	7,052
8	Concord Airport Plaza	17,205	84,284			319,991	421,479	101,488
9	Residence Inn	10,050	35,986	1,289		118,660	165,985	47,325
10	Stonebrook Convalescent	1,210	30,239			86,249	117,698	31,449
11	Diablo View							
12	La Tour Place		44,313	1,364		62,551	108,227	45,676
13	Ned Clyde Construction		15,160			37,515	52,676	15,160
14	Contra Costa Food Bank	954	9,991			93,629	104,574	10,945
15	4021-4041 Pike Lane		39,081			70,239	109,320	39,081
17	Clayton Road Medians		10,857				10,857	10,857
19	CCC Office of Education		51,826			112,596	164,422	51,826
22	Willow Pass Medians		10,234				10,234	10,234
25	DMV	8,175	16,831			130,945	155,950	25,005
27	Arbolado Park	540,894	425,825			146,709	1,113,428	966,719
28	Walden Park	100,268			154,010	29,925	284,202	100,268
	Grand Total	766,644	1,626,699	2,652	962,385	2,902,698	6,261,077	2,395,995

* Photo not available

#	Color Aerial Photography / Site Name	LAND USE (Acres) Turf	Other Landscape	Water Features	Bare Ground	Hardscape	Grand Total	Total Landscape Area
1	American States Insurance		1.29		1.04	2.25	4.57	1.29
2	Pavilion Place	0.09	3.27			1.66	5.02	3.36
3	Black Diamond		7.88		5.66	21.78	35.32	7.88
4	Elderwood Glen	1.55	6.29		11.86	8.28	27.98	7.83
5	Bank of the West	0.38	0.68			4.33	5.38	1.06
6	Taco Bell		0.16			0.59	0.75	0.16
8	Concord Airport Plaza	0.39	1.93			7.35	9.68	2.33
9	Residence Inn	0.23	0.83	0.03		2.72	3.81	1.09
10	Stonebrook Convalescent	0.03	0.69			1.98	2.70	0.72
11	Diablo View			7	5		12	7
12	La Tour Place		1.02	0.03		1.44	2.48	1.05
13	Ned Clyde Construction		0.35			0.86	1.21	0.35
14	Contra Costa Food Bank	0.02	0.23			2.15	2.40	0.25
15	4021-4041 Pike Lane		0.90			1.61	2.51	0.90
17	Clayton Road Medians		0.25				0.25	0.25
19	CCC Office of Education		1.19			2.58	3.77	1.19
22	Willow Pass Medians		0.23				0.23	0.23
25	DMV	0.19	0.39			3.01	3.58	0.57
27	Arbolado Park	12.42	9.78			3.37	25.56	22.19
28	Walden Park	2.30			3.54	0.69	6.52	2.30
	Grand Total	17.60	37.34	7.06	27.09	66.64	155.73	62.00

* Photo not available

4. Multispectral Image

#	Multispectral Image Site Name	LAND USE (Square Feet) Turf	Other Landscape	Water Features	Bare Ground	Hardscape	Grand Total		Total Landscape Area
1	American States Insurance	8,371	36,507	0	54,484	92,503	191,865		44,878
2	Pavilion Place	30,400	40,586	0	12,094	145,417	228,497		70,986
3	Black Diamond	107,316	290,957	799	158,650	927,577	1,485,299		399,072
4	Elderwood Glen	84,335	151,537	2,608	649,088	469,390	1,356,958		238,480
5	Bank of the West	19,529	42,545	0	5,060	171,243	238,377		62,074
6	Taco Bell	4,498	3,516	0	390	22,311	30,715		8,014
8	Concord Airport Plaza	51,822	134,466	0	7,508	288,406	482,202		186,288
9	Residence Inn	16,401	33,431	1,280	8,031	115,580	174,723		51,112
10	Stonebrook Convalescent	5,202	18,108	0	2,851	85,787	111,948		23,310
11	Diablo View	57,933	576,650	897	655,791	605,853	1,897,124		635,480
12	La Tour Place	7,365	46,817	325	4,362	44,399	103,268		54,507
13	Ned Clyde Construction	2,695	15,592	0	1,434	34,259	53,980		18,287
14	Contra Costa Food Bank	13,952	6,556	188	3,508	86,615	110,819		20,696
15	4021-4041 Pike Lane	16,893	44,425	0	2,114	124,379	187,811		61,318
17	Clayton Road Medians	2,913	3,798	0	3,408	133,291	143,410		6,711
19	CCC Office of Education	11,461	41,889	0	5,369	99,574	158,293		53,350
22	Willow Pass Medians	7,422	10,848	0	435	46,617	65,322		18,270
25	DMV	11,469	32,111	0	886	111,597	156,063		43,580
27	Arbolado Park	497,680	147,399	136	295,971	177,336	1,118,522		645,215
28	Walden Park	64,747	40,116	0	138,725	46,354	289,942		104,863
	Grand Total	1,022,404	1,717,854	6,233	2,010,159	3,828,488	8,585,138		2,746,491

#	Multispectral Image Site Name	LAND USE (Acres) Turf	Other Landscape	Water Features	Bare Ground	Hardscape	Grand Total		Total Landscape Area
1	American States Insurance	0.19	0.84	0.00	1.25	2.12	4.40		1.03
2	Pavilion Place	0.70	0.93	0.00	0.28	3.34	5.25		1.63
3	Black Diamond	2.46	6.68	0.02	3.64	21.29	34.10		9.16
4	Elderwood Glen	1.94	3.48	0.06	14.90	10.78	31.15		5.47
5	Bank of the West	0.45	0.98	0.00	0.12	3.93	5.47		1.43
6	Taco Bell	0.10	0.08	0.00	0.01	0.51	0.71		0.18
8	Concord Airport Plaza	1.19	3.09	0.00	0.17	6.62	11.07		4.28
9	Residence Inn	0.38	0.77	0.03	0.18	2.65	4.01		1.17
10	Stonebrook Convalescent	0.12	0.42	0.00	0.07	1.97	2.57		0.54
11	Diablo View	1.33	13.24	0.02	15.05	13.91	43.55		14.59
12	La Tour Place	0.17	1.07	0.01	0.10	1.02	2.37		1.25
13	Ned Clyde Construction	0.06	0.36	0.00	0.03	0.79	1.24		0.42
14	Contra Costa Food Bank	0.32	0.15	0.00	0.08	1.99	2.54		0.48
15	4021-4041 Pike Lane	0.39	1.02	0.00	0.05	2.86	4.31		1.41
17	Clayton Road Medians	0.07	0.09	0.00	0.08	3.06	3.29		0.15
19	CCC Office of Education	0.26	0.96	0.00	0.12	2.29	3.63		1.22
22	Willow Pass Medians	0.17	0.25	0.00	0.01	1.07	1.50		0.42
25	DMV	0.26	0.74	0.00	0.02	2.56	3.58		1.00
27	Arbolado Park	11.43	3.38	0.00	6.79	4.07	25.68		14.81
28	Walden Park	1.49	0.92	0.00	3.18	1.06	6.66		2.41
	Grand Total	23.47	39.44	0.14	46.15	87.89	197.09		63.05