APPENDIX C

Evaluation of the Potential of San Timoteo Creek for Revegetation with Native Riparian Species, June 2004

REVEGETATION
&
WILDLIFE MANAGEMENT
CENTER, INCORPORATED

EVALUATION OF THE POTENTIAL OF SAN TIMOTEO CREEK FOR REVEGETATION WITH NATIVE RIPARIAN SPECIES

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EVALUATION OF THE POTENTIAL OF SAN TIMOTEO CREEK FOR REVEGETATION WITH NATIVE RIPARIAN SPECIES

By Bertin W. Anderson and Victor R. Vasquez

16 June 2004

SUITABILITY OF THE SAN TIMOTEO CREEK FRINGE FOR REVEGETATION

ABSTRACT

In early June 2004, 56 soil sample were collected along San Timoteo Creek in an effort to evaluate the area relative to suitability for revegetation with riparian species. The data set included information on surface and subsurface soil texture, surface and subsurface salinity estimates, depth to the water table, and soil moisture levels 3 to 4 feet below the surface. In addition we recorded the vegetation present near the sample points. These variables were selected because they have been found to be relevant to growth of a variety of riparian plant species. The sample points were distributed according to a systematic design.

Data analysis revealed that overall the soil is biased toward the sandy end of the spectrum, although it is not totally devoid of clay content. Surface and subsurface soil texture were about the same. Common riparian species such as cottonwood and willow are usually associated with soils with high sand content. The soil found in the area is generally quite suitable for riparian plant species.

The salinity level, as indicated by measures of soil electrical conductivity, was found to be slightly higher on the surface than at 3-4 feet below the surface. This is common as salt is often brought to the surface by capillary action. Most of the area was found to have salinity levels below the upper tolerance limit of typical riparian species such as cottonwood and willow—a positive finding.

Sandy soil moisture levels must have a minimum level of 2-3% of dry soil weight before plants can pull water from it. The moisture content must be higher as the amount of clay in it increases. The more clay the greater the difficulty plants have in extracting water. The soil found in the study area must have moisture of 3-5% of dry soil weight for plants to draw the water out because of the presence of some clay. Most of the soil samples had soil moisture levels in this narrow range indicating that the soil contains a few days supply of water available to plants. Without being recharged in the very near future, plants planted in this soil would begin t0. show signs of stress eventually becoming stunted and decadent or they might simply die suggesting that the revegetation with riparian species should be accompanied by permanent irrigation.

The water table was estimated to be 20-40 feet below the surface. Where willow thrive, the water table is not more than about 6 feet deep and not more than 8 feet where cottonwood are typically found in peak condition. This fact, in conjunction with information in the preceding paragraph, leads us inexorably to conclude that a planting effort would have to be accompanied by irrigation in perpetuity. More about irrigation below.

Analysis showed there were 2 major trends across the study area involving the variables for which data were collected. The first trend, accounting for about half of the variance in the data set, is for salinity and soil moisture to increase from upstream to downstream while depth to the water table decreases. This means that more soil moisture is found in the downstream direction, but this observation, favorable for riparian vegetation, is to some extent cancelled by the fact that salinity levels increase in the same direction and this is a negative feature. The soil salinity level could be rectified by addition of sulfuric acid in conjunction with sprinkle application of several feet of water. The precise amount of acid and water to add per acre is determined by a soil analysis to determine the proportions of calcium, magnesium, potassium, and sodium in the soil and by soil texture analyses, respectively.

The second trend in the data set, one accounting for about 25% of the variance, was for clay content of the soil to increase as lateral distance from the stream increases. Species such as cottonwood and willow are best adapted to sandier soils.

Both of the trends found in this data set are fairly common in river systems in the arid Southwest. At times of runoff, as water runs into the system, it carries both fine and coarse material. Close to the stream where flow is often swift, especially during floods, and fine materials and dissolved salt are flushed out of the soil and re-deposited in the downstream direction. In the floodplain, since rivers flow downstream, it is not surprising that depth to the water table often decreases in the same direction and this is often associated with higher soil moisture levels because the water in the capillary fringe of the water table is closer to the surface. At times of heavy runoff there may be considerable soil moisture all the way to the surface at the downstream end of a stream.

The extent of annual irrigation required would vary with the extent of winter precipitation. We have developed a potentially applicable model to predict the amount of irrigation required for trees to make it to the end of a growing season.

Prior to planting additional soil sampling should be done in order to confirm findings in this analysis. This should be done for subsurface electrical conductivity and soil moisture. Surface soil texture and electrical conductivity can be calculated from equations provided in appendix. 2.

INTRODUCTION

We collected 56 systematically distributed samples along the fringe of San Timoteo Creek in early June 2004. All points are shown in Figure 1. At each point we collected surface and subsurface soil for determination of soil texture, surface and subsurface electrical conductivity (expressed as millimhos/cm), subsurface soil moisture (expressed as % of dry soil weight), and an estimate of depth to the water table. We also recorded the condition, height, and species of plants occurring at the sample point. If the point was in an area of bare ground we simply recorded this observation.

The purpose of this report is twofold: First, to present results of an analysis of soil and vegetation along San Timoteo Creek and, second, to briefly describe plans for follow-up revegetation and some potential constraints associated with the effort.

RESULTS

Soil Texture. We assign numeric values to represent soil textures. Details of this procedure are presented by Anderson, Russell and Ohmart (2004). To quickly summarize the procedure, sand is assigned negative values with pure sand being -3 and gravelly sand -4. A loamy soil is assigned a value of 0 and positive value are assigned as the clay contingent increases, until pure clay, with a value of 3, is reached.

The soil in the San Timoteo Creek survey area tended to be predominantly sandy with surface and subsurface values ranging from 0 to -3 (Table 1). The median values (the point dividing the sample into halves) at the surface and subsurface was -1. That the averages are lower indicates an asymmetrical distribution with more values falling on the sandy end and only a few at the clay end of the distribution

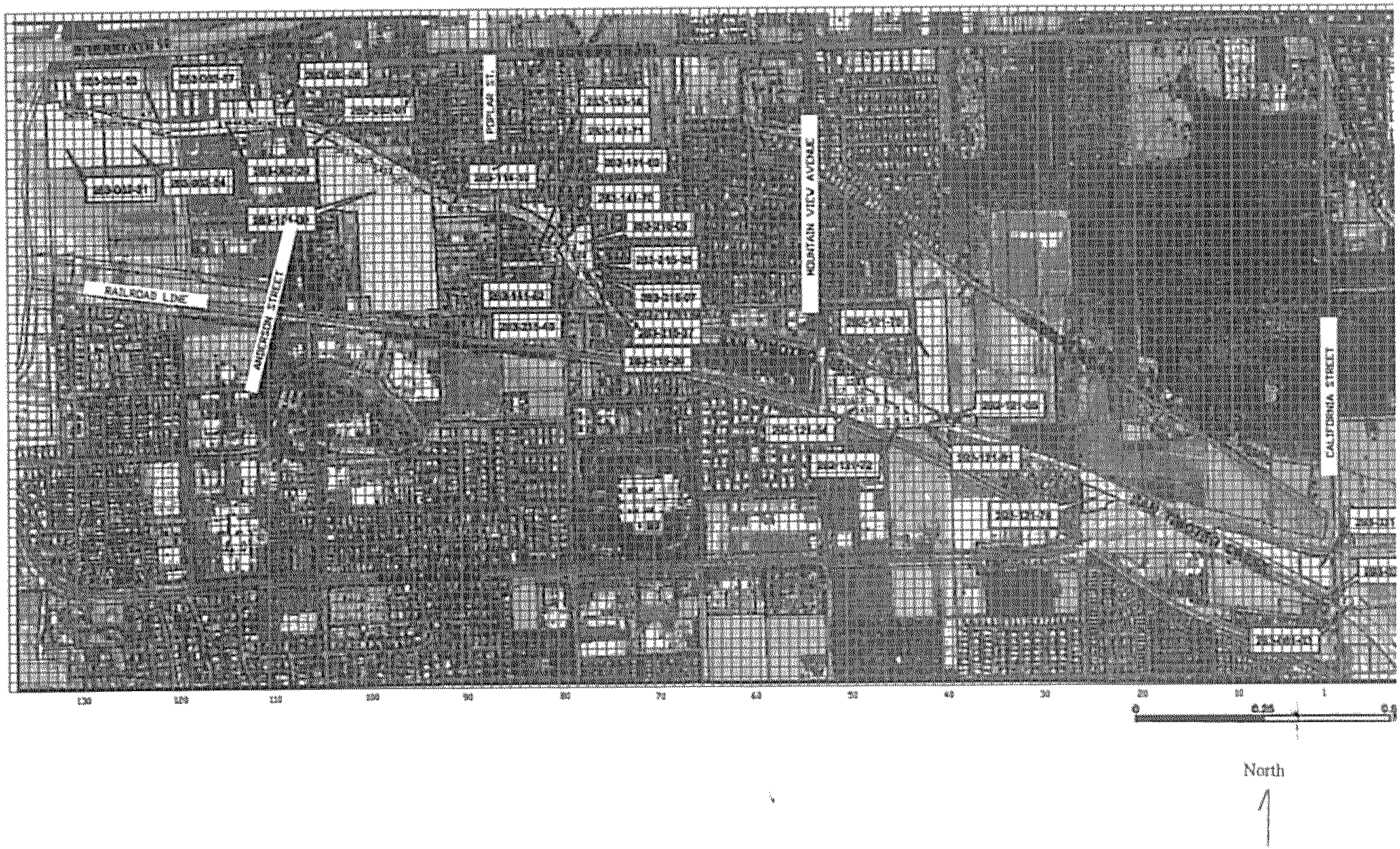
Table 1. Summary of data for variables on the San Timoteo Creek in June 2004. S1 and S4 indicate the soil types found on the surface and subsurface, respectively; EC1 and EC4 refer to surface and subsurface electrical conductivity levels expressed as millimhos/cm; pctsm, soil moisture expressed as percent of dry soil weight; DWT, depth from the surface to the water table in feet; lg10 = base 10 logarithm of EC1, EC4, and pct. N refers to sample size.

Case Summaries

	s1	s4	ec1	ec4	dwt	pctsm	lg10e1	lg10e4	lg10pct
N	56	56	56	56	56	56	56	56	56
Mean	-1.4464	-1.4643	1.6193	1.3896	34.1429	6.3317	.0902	.0288	.7002
Median	-1.0000	-1.0000	1.0700	.8900	35.0000	4.2437	.0294	-.0506	.6277
Std. Error of Mean	.11084	.14407	.17849	.14967	.49768	.75203	.04200	.04182	.03584
Std. Deviation	.82945	1.07812	1.33569	1.12004	3.72426	5.62769	.31430	.31296	.26819
Minimum	-3.00	-3.00	.37	.31	20.00	2.48	-.43	-.51	.39
Maximum	.00	1.00	6.17	6.35	40.00	26.94	.79	.80	1.43

Figure 1. Location of sampling points on the San Timoteo Creek in Loma Linda. At each point we collected data relevant to determining the suitability of the area for revegetation with native riparian species. The grid represents 100 foot by 100 foot units. The rows of units were numbered sequentially beginning with the first sample point.

Figure 1

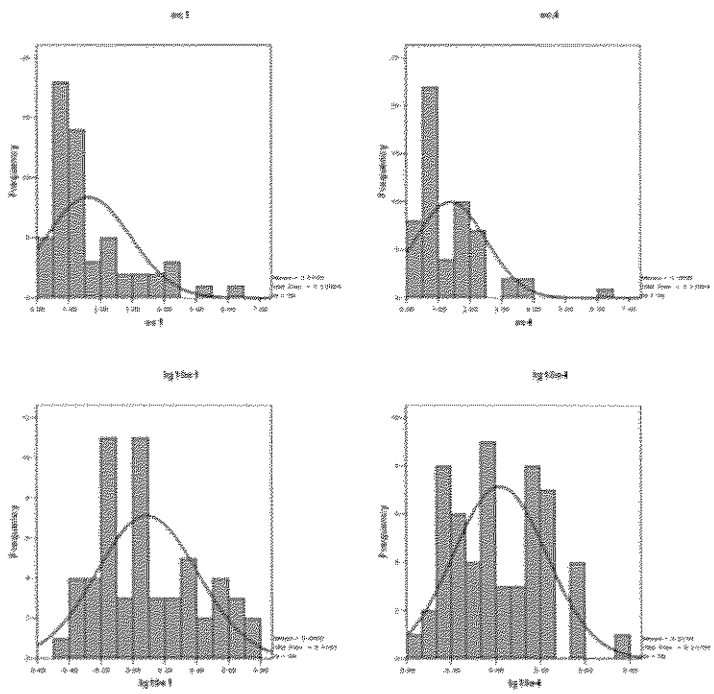

POPLAR ST.
MOUNTAIN VIEW AVENUE
CALIFORNIA STREET
RAILROAD LINE
ANDERSON STREET
North

Soil Electrical Conductivity. Soil electrical conductivity (EC) provides an indication of the amount of dissolved material, mostly salts, in the soil. The values are given in units called millimhos/centimeter (mmhos/cm). The way that plants respond to soil salts varies from species to species. Generally responses are grouped as highly salt sensitive for those that do best when EC levels are less than 3 millimhos per centimeter; moderately salt tolerant for plants that do well up to 8 mmhos/cm; and salt tolerant when they grow where EC levels are in excess of 8 mmhos/cm, but even most of these plants begin to fail when levels exceed 12 mmhos/cm. In the area under investigation EC values were roughly the same (Table 1) for the surface and subsurface samples and ranged from 0.3 mmhos/cm to 6.4 mmhos/cm. As with soil textures the median EC values were lower than the means indicating distributions skewed to the right as a result of a relatively few large values. The EC data in general indicate that the entire area is suitable in combination for salt sensitive or moderately salt tolerant species. Because of the skewed nature of the EC data, they were transformed to a new series of values by converting the original values to the base 10 logarithm of the original values. A transformation such as this has the advantage of bringing outlying values closer to the middle. For example, consider the values 10, 100, and 1000. By transforming them with log 10 we get a new series with values of 1, 2, and 3. The difference between the largest and smallest values was 990 in the original set, but in the transformed set this is reduced to 2. This sort of transformation is required in order to meet assumptions associated with many statistical analyses, specifically, narrowing the range is often important in meeting assumptions

The original and transformed EC values are shown in Fig. 1. The original data show that 9 (16%) of the surface samples have EC values too high for salt sensitive species such as cottonwood and willow. Deep in the soil profile 5 (9%) of the sample were above this important level. At neither the surface nor the subsurface were values in excess of tolerance levels for moderately salt tolerant species such as seep willow (*Baccharis* sp) and, possibly, elderberry (*Sambuchus* sp).

The log 10 transformations normalized the distributions sufficiently for the data to be used in a follow-up analysis discussed below.

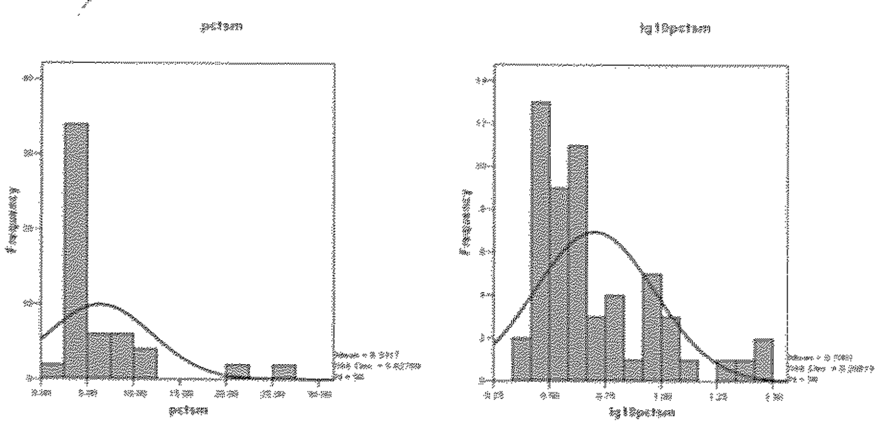
Figure 2. Electrical conductivity levels (millimhos/cm) in surface and subsurface soil (top) and the same data transformed with log 10 transformations in order to produce more normal distributions required for many statistical analyses.



Soil Moisture Levels. Soil moisture must be 2-3% in sandy soil—perhaps somewhat more than that in the soil encountered in the assessment area—before plants can pull water from it. At sample values of, say, 3% to 6%, there is perhaps enough water to last plants for only a few days. After that, if no additional water becomes available, the plants will begin wilting and dying. With short periods of depravation trees tend to be stunted and decadent. While most of the soil samples in this investigation have soil moisture levels greater than 3% it can be seen in Fig. 3 that most of them fall between 3% and 5%. Soil moisture levels are low enough to predict that trees planted in this situation would struggle for existence thus we strongly recommend that planted vegetation be irrigated in perpetuity to insure long term survival.

The log 10 transformation of soil moisture data was less successful (right graph, Fig. 3) than for the EC data, but it was deemed adequate for use in the follow-up principal components analysis discussed below.

Figure 3. Soil moisture expressed as a percent of dry soil weight. Samples were taken at 3-4 feet below the surface. The graph on the left is the raw data and that on the right was transformed with log 10 of the data on the left in an effort to develop a more normal distribution.



Depth to the Water Table (DWT). Most riparian plant species grow in areas where it is 10 feet or less to the water table or at least to soil that is more or less permanently moist. We just saw that soil moisture levels are quite low, now the DWT data show that the water table is very far below the surface (Table 1). DWT data contribute further to the notion that planting in these areas would have to be associated with long term irrigation.

We now know that, in general, the area sampled is at best marginal for typical riparian species because of great depth to the water, low soil moisture, and, at least to some degree, soil salinity levels that are too high for typical riparian species. But we have not determined whether some portions of the area might be better than others. We now turn to a different kind of analysis in order to discern any trends that might be running through the data set. This analysis will tell us what, if anything, is "going on" in the data set—a data set that was systematically collected to reveal any trends that might exist. This analysis encompasses a few distinct steps that we will take the reader through in order to facilitate comprehension of what we believe is "going on".

Intercorrelations among Variables. The first step is to determine the extent to which the variables in the data set are intercorrelated. If there are in fact things going on, by definition, there must be interplay between the variables studied. We won't, of course, discover any trends that involve variables for which we collected no data. We're primarily interested in finding trends significant to the growth of riparian vegetation and experience over the past 3 decades has taught us what to look for in a relatively short period of time at reasonable cost that will lead us to that end.

The extent of intercorrelations between pairs of variables is given in Table 2. There are 2 matrices in the table. The one above the middle show the extent to which the variable in the left row correlates with the variable at the top of a column. The nearer this value is to 1.0 the higher the correlation. This shows some quite high correlations, for example, 0.810 for log 10 of surface soil EC and log 10 of subsurface soil EC. There was also a high negative correlation (-0.699) for soil moisture and depth to the water table. This should get an observer's attention, because it suggests that as soil moisture increases depth to the water table decreases—a potentially important trend in the data set. However, for this and several other correlations that are more or less intermediate between 0 and 1.0, these correlations tell us nothing about how seriously we should take them. Such information is, however, given in the matrix below the middle horizontal line. In this matrix values indicate the proportion of the time the observed correlations from the upper matrix could be expected by chance. It is more or less standard procedure to take a value seriously if this proportion is 0.05 or less, meaning that the observed correlation could be expected to occur only 5 times in 100 by simple luck. A value of 0.001 means that the observed correlation could be expected to occur only once per 1000 trials by luck. If the value given is 0.000 it means that the chances of the observed correlation being due to chance are some unspecified value less than 1 in 1000 trials. The total number of pair wise comparisons is equal to N X (N-1)/2 where N is the number of variables (8). Thus the number of comparisons is 28. Among them 20 (71%) should, by statistical convention, be taken seriously. Among these 20 correlations 11of them had values less than 0.01. Overall this is encouraging if we are, in fact, hopeful that something is going on in the data set—there probably are things going on. This makes potentially meaningful a subsequent effort to try to define these trends.

Table 2. Intercorrelations between pairs of variables for which data were collected along San Timoteo Creek in June 2004. Variables are defined as in Table 1.

Correlation Matrix

		latd	disu	s1	s4	dwt	lg10e1	lg10e4	lg10pct
Correlation	latd		-0.444	0.238	0.190	0.102	-0.439	-0.370	-0.307
	disu			0.130	0.160	-0.225	0.520	0.630	0.413
	s1				0.516	-0.185	0.172	0.254	0.285
	s4					-0.395	0.006	0.185	0.406
	dwt						-0.488	-0.407	-0.699
	lg10e1							0.810	0.687
	lg10e4								0.666
	lg10pct								
Sig. (1-tailed)	latd		0.000	0.039	0.080	0.228	0.000	0.002	0.011
	disu			0.170	0.119	0.048	0.000	0.000	0.001
	s1				0.000	0.086	0.103	0.030	0.017
	s4					0.001	0.483	0.086	0.001
	dwt						0.000	0.001	0.000
	lg10e1							0.000	0.000
	lg10e4								0.000
	lg10pct								

Principal Components Analysis. Principal components analysis is a multivariate analytical technique (one that considers several variables simultaneously) designed to provide a mathematical description of any trends that occur in the data set. If there are trends the variance associated with the variables included in the analysis that are associated with a trend will "explained" these trend. The proportion of the variance explained for a given variable is referred to in technical terms as the communality.

Communalities. In a perfect world, where all of the variance associated with all of the variables is explained the communalities, would be 1.0 for each variable. In this analysis the variance associated with DWT least well explained (0.54, Table 3). The greatest amount of the variance explained was 0.784 for log 10 of the soil moisture. These data reveal that at least half, and for 4 variables, 72% or more, of the variance for the variables was explained (attributable to trends) by the analysis. Now we will spend some time defining these trends.

Table 3. Communalities of variables used in a principal components analysis of the San Timoteo soil data set. The values under the "Extraction" column represents the proportion of the variance accounted for in the analysis. The analysis is optimal if the explained variance, that is, the communality, is 1.0, but this virtually never happens. Latd refers to lateral distance from the stream; disu, distance from the upstream end of the area investigated; s1 and s4, surface and subsurface soil texture, respectively; dwt, depth to the water table; lg10e1 and lg10e4, the base 10 logarithm of surface and subsurface electrical conductivity values, respectively; lg10pct, base 10 logarithm of soil moisture expressed as percent of dry soil weight.

Communalities

	Extraction
latd	.665
disu	.537
s1	.597
s4	.716
dwt	.536
lg10e1	.795
lg10e4	.780
lg10pct	.784

Extraction Method: Principal Component Analysis.

The Trends. The analysis determined that there were 2 major trends in the data set. The extent to which each variable is associated with a trend or component is given by a value from 0 to 1.0 where the former means no relationship and the latter means a perfect relationship. The component is defined by the variables that are most associated with it. Thus on the first component we see that log 10 of the soil moisture scores (lg10pct) is highest at 0.875, while log 10 of surface and subsurface EC are close behind (0.872 and 0.852), respectively. Distance from the upstream end (disu) is, at 0.685, quite high as is depth to the water table at -0.679. We interpret this as a trend for the surface and subsurface salinity to increase as soil moisture increases and that both of these tend to increase at further distances from the upstream end of the site and where depth to the water table is least. There is, at the same time, a tendency for DWT to decrease in the downstream direction.

To rephrase, it means that soil moisture is greatest where depth to the water table is least but that at these places soil salinity is greatest and that these conditions are most likely to occur in the downstream direction. Thus, if one is looking for relatively great soil moisture it will be found in the downstream direction and will be associated with the highest soil salinity levels.
But how important is this trend?

The total variance in the data set is equal to the number of variables in the data set, thus, 8. The proportion of the total variance explained by a given component is determined by squaring the values of each variable associated with a given component in Table 4. The sum of these squared values yields a number equal to the proportion of the total variance that is accounted for by this component. In the present analysis the squared values summed for the first component comes to 3.64 or 45.6% of the total variance in the data set (Table 5). This trend, therefore, is large enough to account for nearly half of the variance in the data set—a proportion large enough to warrant serious attention in evaluating the area for revegetation.

The second component indicates that surface and subsurface soil tend to have greater clay content at greater distances lateral to the stream (Table 4). This component accounts for an additional 22% of the variance in the data set (Table 5), and tells us that sandier soil, generally more suitable for riparian vegetation, was found at points closer to the channel. Thus the 2 trends in the data account for about 68% of the variance. The second component informs us that the soil is most appropriate for riparian species at points closer to the channel.

Table 4. Statistical description of 2 principal components found in the San Timoteo Creek study area. With a perfect association with the component the values would be 1.0 or 0 with no association. If the values under each component are squared and summed the total equals the variance explained by the principal component. The total variance is equal to the number of variables (8). The sum of the squared values are given in Table 5. latd refers to lateral distance from stream; disu, distance from the upstream end of the area investigated; s1 and s4, surface and subsurface soil texture, respectively; dwt, depth to the water table; lg10e1 and lg10e4, the base 10 logarithm of surface and subsurface electrical conductivity values, respectively; lg10pct, base 10 logarithm of soil moisture expressed as percent of dry soil weight.

Component Matrix[a]

	Component	
	1	2
latd	-.448	.681
disu	.685	-.260
s1	.347	.690
s4	.376	.758
dwt	-.679	-.274
lg10e1	.852	-.261
lg10e4	.872	-.143
lg10pct	.875	.137

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Table 5. Sum of the proportions squared for each variable on each of 2 principal components (Table 4) for data collected on the San Timoteo Creek study area.

Total Variance Exp

Initial Eigenvalues			Extraction Sums of Squa	
Total	% of Variance	Cumulative %	Total	% of Variance
3.64	45.55	45.55	3.64	45.55
1.77	22.06	67.62	1.77	22.06

The Vegetation. Actually, it is the absence of vegetation that is the most obvious characteristic of this study area (Figs. 4-9). Bare ground accounted for 86% of the entire area encompassed by the study. The absence of vegetation reflects disturbance more than general unsuitability of the area for vegetation. In places some species are thriving.

The most numerous plants are those falling into the category of annuals—those species that complete their life cycle and die within a single year, often a single season. Annuals are present in nearly every photograph in Figs. 4-9. There were several species of annuals, including Russian thistle (*Salsola iberica*). Collectively annuals accounted for about 15% of the ground cover in the area investigated.

Perennials, those plant species that live for more than a single year, were few in variety and number. There were 2 kinds of shrubs, California buckwheat (*Eriogonum fasciculatum*), common along the fence in the area where samples 30-44 were taken (Fig. 7, top), and brittle bush, (*Encelia farinosa*) an example of a plant tolerant of harsh, dry conditions (Fig. 7, middle).

The enormous cottonwood shown in the bottom photograph in Fig. 8, the area where samples 45-56 were taken, provides unequivocal evidence that it is possible for this species to live in the area. We must keep in mind, though, that conditions when this tree got started, some 60-80 years ago, could have been, and probably were, substantially different than now. Non-native pepper trees (*Schinu molle*), an import from South America, were also observed (Fig. 4, bottom)

Figure 4. Soil collection site for samples 1 and 2. Both photographs were taken 3 June 2004 looking NW from south of Barton Road and California Street intersection. Note the prevalence of bare ground and dead or dying annuals. The tree in the upper left of the lower photograph is a pepper tree.

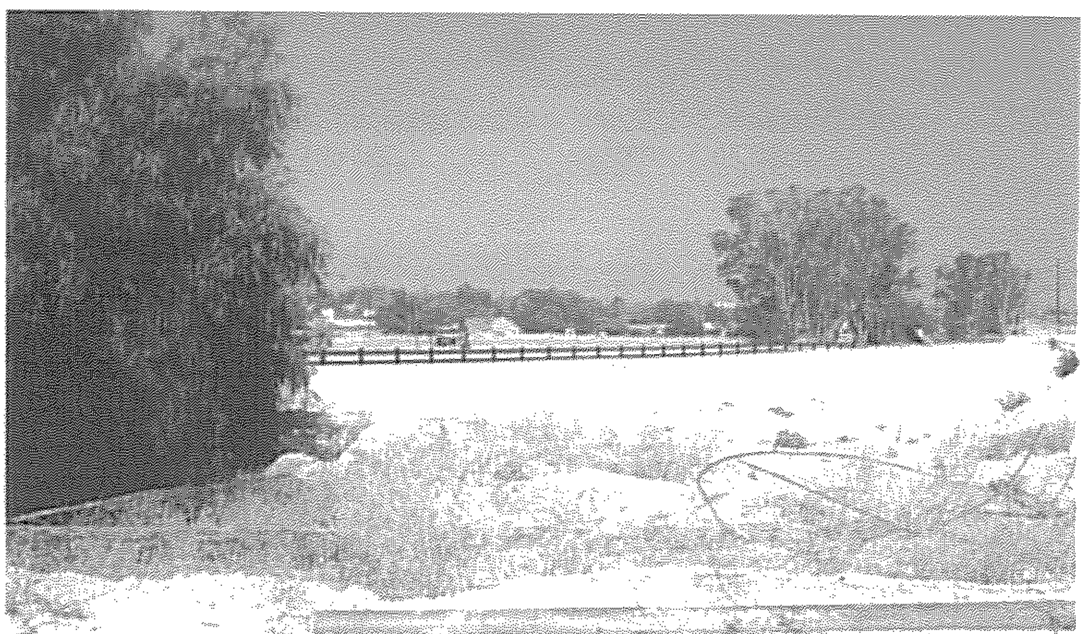


Figure 5. Soil collection site for sample 3-20. Top, looking north from the middle of the south end of the site, just east of Mountain View. Bottom, Looking NE from the middle of the south end of the site, also just east of Mountain View. The tree, top photograph, is eucalyptus (*Eucalyptus* sp). The bottom photograph is an agricultural field; the tall trees in the upper right are eucalyptus.

Figure 6 . Soil collection site for samples 26-38 taken 3 June 2004, looking west from Poplar Street. on the south side of the creek. This photograph shows prominently the extent of bare ground (agricultural field) and the presence of annuals.

Figure 7. Soil collection site for samples39-44 taken 3 June 2004. Top, looking west from Anderson St. on the north side of San Timoteo Creek. Middle, close-up of a shrub, brittlebush (*Encelia farinosa*), common to the area. Bottom, close-up of another shrub, California buckwheat (*Erigonium fasciculatum*), growing along the fence in the top photograph.

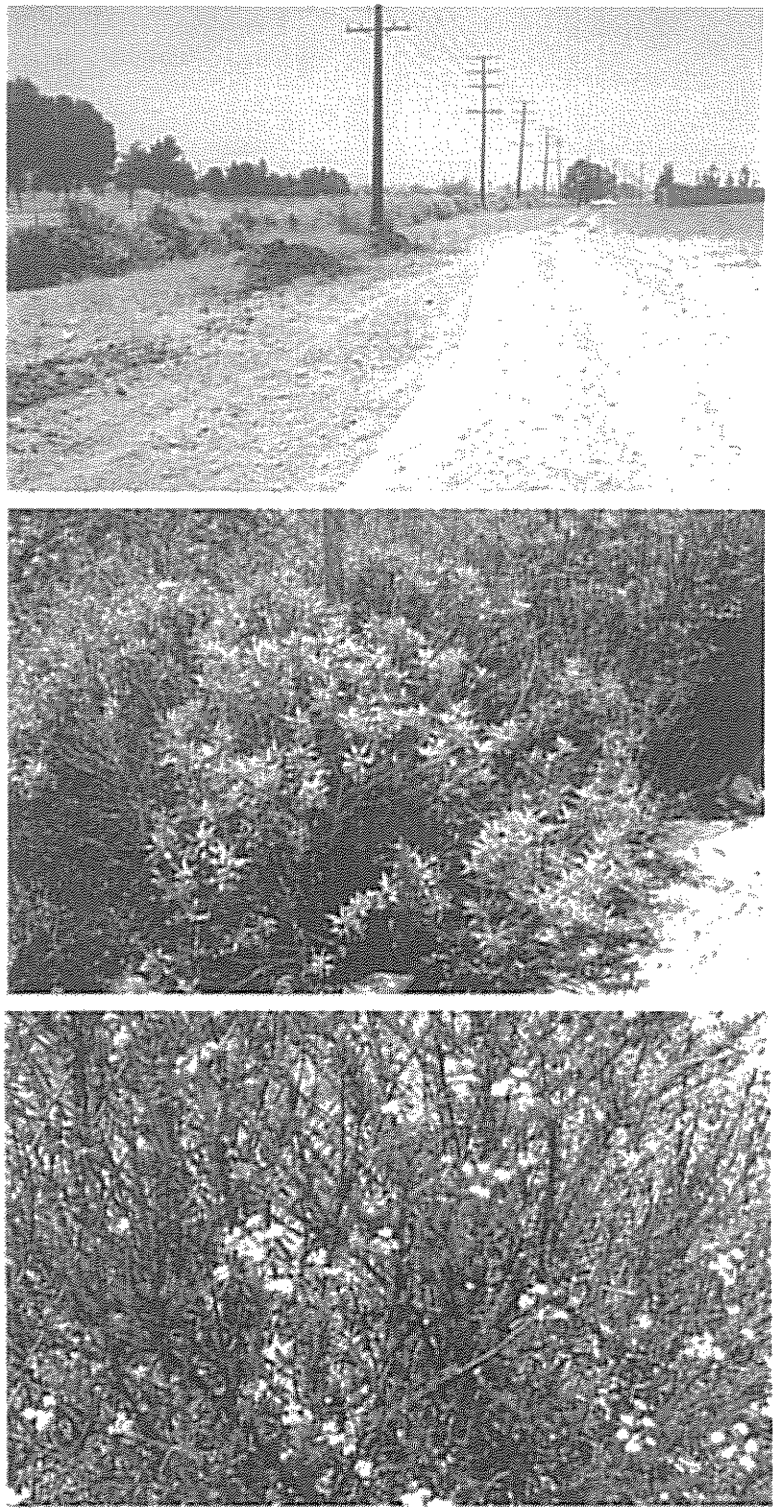
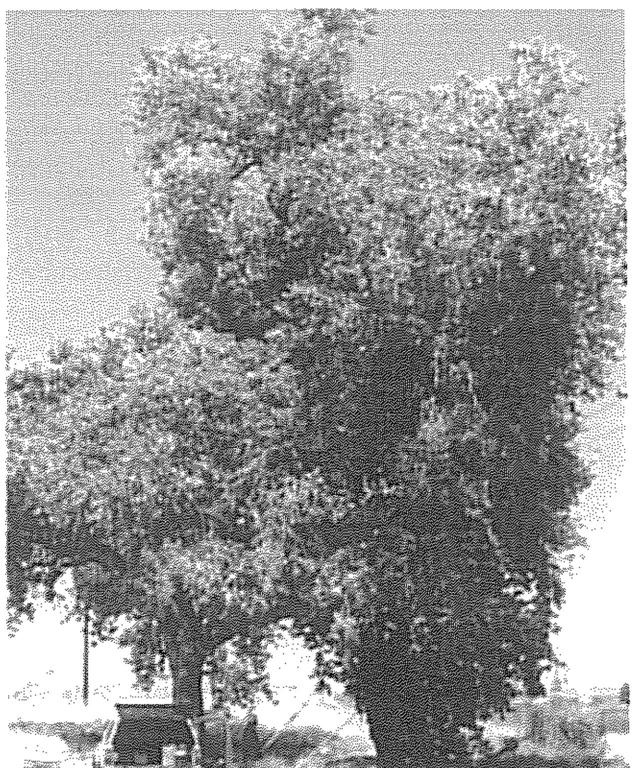


Figure 8. Soil collection site for samples 45, 46, 48, 49, 51-56 taken 3 June 2004. Top, looking west from Anderson Street on the south side of San Timoteo Creek. Bottom, mature cottonwood trees (*Populus fremontii*) in the vicinity of sample sites 54 and 55.



REVEGETATING THE SAN TIMOTEO STRIP

The most serious difficulty associated with revegetating this area is the prevalence of dry soil. In general the soil texture is suitable for revegetation with almost any species, although it is dense enough that irrigation should be done with care. Salinity levels are not serious but about 15 points, accounting for 27% of the area, are marginally suitable or unsuitable for salt sensitive species. One of these relatively saline areas is concentrated in the area where samples 30-38 were collected (APN 283-101-09, 283-092-01), another where samples 46-53 (APN 283-062-30, 283-062-34) were collected. In the first of these there are other positive points that partially offset the salinity levels, including a water table being somewhat closer to the surface and soil with greater moisture levels than in any other stretch of the sample area.

If it were deemed imperative to plant nothing but salt sensitive species in this area the land could be easily reclaimed by adding sulfuric acid (the precise amount determined by the amount of potassium, calcium, magnesium, and sodium in the soil) followed by slow application of about 3-4 feet of water with sprinklers. This procedure would reduce salinity levels by 50% at moderate cost and would need to be done only in the areas cited in the preceding paragraph. With irrigation in perpetuity, careful irrigation procedures in the initial years might, alone, be adequate for planting salt sensitive species, but we emphasize that this irrigation water must be very attentively applied.

The irrigation necessary will vary from year to year and will be related to rainfall. The amount of water that will be required and the period over which it should be added is related to the extent of winter precipitation. We have developed a model that will be useful in making these determination in the most appropriate and least expensive way (Anderson, Russell, and Vasquez 2000).

It should be emphasized that all plants to be planted should be derived from seeds or cuttings from local genetic stock. This will help better insure planting individuals that are best adapted to the local suite of conditions. This means that one cannot decide on one day to revegetate an area and then buy trees for the effort on the next day. There must be a lead time encompassing 2 or 3 months for collection of material and development of saplings and that this must begin in winter/early spring.

Before any final planting designs are developed a more intensive soil sampling effort should be conducted. While the present sampling effort is sufficient to provide the precision necessary to make a sound decision about what species should be planted there is the possibility that conditions will change by the time the planting will actually take place. At least 15 additional points should be systematically distributed across the planting area to corroborate findings presented here. In this sampling effort it would be necessary to obtain data for subsurface EC and soil moisture. The other variables can be predicted within a reasonable range of confidence with the equations in Appendix 2, thus reducing time and cost required for the effort.

The general approach to revegetation that we have developed over the past 2 decades or so is presented in Appendix 1.

Table 6. Plant species that may be appropriate for includion in revegetation efforts along San Timoteo Creek.

Species	Salt tolerance	Planting density
Trees		
Cottonwood (*Populus fremontii*)	sensitive	18 ft =134/ac
Black willow (*Salix goodingi*)	sensitive	18 ft =134/ac
Arroyo willow (*Salix lasiolepis*)	sensitive	18 ft =134/ac
Sycamore (*Platanus racimosa*)	unknown	18 ft =134/ac
California white oak (Quercus lobata)	unknown	18 ft =134/ac
Shrubs		
Mule fat (*Baccharis salicifolia*)	moderately toelrant	15 ft=194/ac
Sandbar willow (*Silix exigua*)	sensitive	15 ft=194/ac
Elderberry (*Sambuchus mexicana*)	unknown	15 ft=194/ac
Blue elderberry (*S. cerulea*)	unknown	15 ft=194/ac
Quailbush (*Atriplex cannescens*)	tolerant	15 ft=194/ac

LITERATURE CITED

Anderson, B. W., P. E. Russell, and R. D. Ohmart. 2004. Riparian revegetation: an account of 2 decades of experience in the arid Southwest. Avvar Books, Blythe, California.

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Appendix 1. The nine step revegetation plan, from Anderson, Russell, and Ohmart (2004, pp 39-53).

Introduction

The Nine-Step Plan was developed as a paradigm in which research would be superimposed on revegetation efforts (Anderson 1989, Anderson and Laymon 1989). The goal was to develop a revegetation method that would integrate site conditions and field methods to growth and survival of species planted, thus insuring overall success of the project. Knowledge obtained from previous projects was used to determine which species to plant and where to plant them in subsequent projects, as well as the management methods to use.

Step 1: Preliminary Analysis

Preliminary data from a prospective site are invaluable in prudent development of plans that can be successfully executed. Preliminary sampling will usually lower costs and reduce frustration (Green 1979). The preliminary analysis phase of the Nine-Step Plan involves collecting soil at 15 (or enough to inexpensively facilitate a reasonable estimate of variation) systematically selected sample points per 10 ha. At each sample point 2 soil samples are taken, 1 near the surface, and the other just above the water table, or at 2 m if the water table is more than 2–2.5 m below the surface. For each of these samples soil textures, electrical conductivity (EC), soil moisture, and surface-to-water-table depth are determined. If possible a water sample is taken and the EC is determined for it. Preliminary analysis also usually includes a vegetation analysis that provides at least a partial list of plants occurring in the area as well as revealing the soil conditions in which they are found. This information provides clues about the potential for competition from weeds and reveals health of extant vegetation. This is a fact-finding step where climate, geologic features other than soil, development of roads, and any other ancillary items or actions that would be relevant to the outcome of the project are taken into consideration.

Electrical conductivity is a measure of total soluble material extracted from a water saturated soil paste. EC values obtained are highly correlated with the amount of salt in the soil.

Salinity and texture of surface samples are important variables related to germination and long-term persistence of vegetation types planted. Low salinity and medium-to-fine textures such as sandy loam or silty clay promote germination and survival of seedlings. Such soils retain moisture for longer periods than sand after rainfall, thus allowing time for germination. High salinity means water is less available for plants to use. Water diffuses from areas that are low in salinity to areas of higher salinity. If the salt concentration in the soil is less than in the plant's vascular system, water will move from the soil into the plant roots. As the salinity of the soil increases and approaches that of the plant vascular tissues, the ability for the plant to extract water decreases. It is therefore harder for plants to extract water from saline soils. Similarly, clay soils hold water so tightly that much of the water present is unavailable for plant use. Finer soils do not readily absorb moisture and thus much of the water from storms is lost to runoff and evaporation from temporary ponds formed on the surface. We routinely determine soil moisture levels of the various soil types associated with a specific project site.

Salinity and texture of subsurface soils are also important. Our findings indicate that subsurface EC is an important factor for growth of cottonwood Populus fremontii, willow Salix spp. and mesquite Prosopis spp. Samples collected deep in the soil profile are used to determine which species could be expected to survive and, therefore, which species to plant. Salinity and drought tolerance of candidate species are primary considerations.

Data obtained from preliminary analysis is not extensive enough to permit accurate mapping of the distribution of a variable across a site. It is sometimes tempting to delineate acceptable portions of the site and create a planting design on the basis of this marginal analysis. It would be a serious error to extend this inadequate sampling effort to that extent. To circumvent this temptation we show unnumbered sampling points on a map of the site and put the data in a table (Table 3.1). Neither the points on the map nor the data in the table are numbered. This effectively precludes misuse. Final determination of what should be planted should not be made until the preliminary analysis is complete. Any guarantees relative to success should not be made until this crucial information is available. This is the step that puts wishful thinking in line with reality.

Data for a preliminary sampling effort are presented in Table 3.1. In this case the project sponsors wanted to plant exclusively cottonwood and willow. The subsurface soil had high EC values, with 80% of them being in excess of 3.0 mmhos/cm, the value considered to be the threshold beyond which cottonwood and willow go into significant decline. EC levels indicating high soil salt concentrations were also apparent in the surface soil and in water from the water table. Subsurface soil values indicated much sand except in 1 sample, representing about 7% of the site, where clay predominated. High subsurface EC levels alone and all variables in combination suggested the unsuitability of this site for the intended plant species. The plant species present in the preliminary analysis indicated that the site was at that time dominated by saltcedar Tamarix ramosissima and arrowweed Pluchea sericea, but that screwbean Prosopis pubescens was also present on perhaps 10% of the site. This information tells us that the potential for competition from saltcedar is moderately high to high. We reported that not more than 20% of this site was suitable for the intended species. On the basis of the findings of the preliminary analysis, plans for the site were drastically altered.

Skipping this preliminary analysis to save time often results in loss of time and money. The preliminary analysis is the way to determine if the site is suitable for intended purposes, evaluate potential problems, and determine actions to take before investing time and effort into the other steps of the Nine-Step Plan. The major aspect of the sampling design that can be determined from the preliminary analysis is the amount of intensive sampling that needs to be done once the actual revegetation effort begins. In general, the greater the variation in preliminary data, the larger the sample size required to develop valid maps of the variation associated with autecological variables across a site.

Step 2: Propagation

Cuttings and seeds are taken from local genetic stock. It is most desirable to collect the cuttings or seeds from stock growing as close as possible to the revegetation site. Such propagules are more likely to develop into plants that are adapted to the conditions of the site than if collected elsewhere.

Cottonwood and willow are generally propagated from stem cuttings, while mesquite, palo verde Cercidium spp., and several species of shrubs are propagated from seeds. Cottonwood and willow cuttings are made from branches containing lateral or terminal buds before new shoots emerge during winter or early spring. Pods or seeds of Palo verde and mesquite are collected from or below trees; mesquite seeds are also collected from coyote or herbivore scats.

Cuttings of cottonwood and willow are rooted in 264-ml pots. Before they are inserted they are generally treated with a growth hormone such as indolebutyric acid to promote root development. Potting soil includes a mixture of equal portions of sandy soil from habitats in the area (to encourage micorrhizal fungi), vermiculite, and peat moss. Micorrhizal fungi help in the uptake of nutrients from the soil assuming nutrients are present above certain minimal levels. Saplings are then watered daily and require 8–12 weeks to develop to a stage adequate for planting.

Mesquite, palo verde, and saltbush seeds are sown in 264-ml pots, and watered daily until the seedlings reach planting height. Mesquite and palo verde require more time to reach planting size than cottonwood and willow cuttings.

When planted, the seedlings or saplings should be at least 30 cm tall and be in good-to-excellent condition. Those that are planted when they are much less than 30 cm tall or are in poor-to-fair condition tend to become stunted or die, never attaining a height suitable to attract much wildlife. We overproduce seedlings and saplings by 30% or more. This ensures that sufficient plants of high quality will be available at planting.

Step 3: Site Preparation

Site preparation ordinarily involves clearing and leveling the area with a bulldozer over as much of the area as deemed necessary. This clearing is done selectively, thus saving any extant vegetation deemed valuable to wildlife. Surface soils in many of the floodplains are not "natural" now that salt and debris have built up since construction of major dams. Sporadic stream flooding formerly checked salt accumulation. Leaving this surface salt in place is detrimental to plant growth and survival and renders success of revegetation projects doubtful and reduces prospects for germination.

The procedure that has been used by agencies trying to save money, while being environmentally "friendly," is to clear only the top vegetation while leaving the soil relatively undisturbed. The consequences of such a procedure threatens the possibility of having successful projects. If saltcedar is present, the root crowns are left intact, and the saltcedar trees re-sprout and grow vigorously and rapidly. The only effective way to kill the remaining saltcedar is by herbicide application or by digging out the roots. Both ways are expensive and can delay planting. Herbicide can damage any plants that may already have been planted, even when carefully applied. Furthermore, crowns and roots left intact would occupy planting positions, impeding tillage or making tillage useless— roots of surviving saltcedar would quickly grow into adjacent augered holes after irrigation starts.

Stumps that remain also cause damage to equipment such as backhoes and trucks used for augering and/or planting. We have been involved with projects where saltcedar was cleared at the surface. Stumps were sprayed with herbicide. The stumps, protruded from the ground and punctured tractor and backhoe tires. A single tire can cost as much as $1,000 to replace not including added labor costs and delays. Seldom is the funding agency willing to cover these unplanned costs. Another consequence is that salts that have accumulated on the surface remain there to inhibit growth and survival of propagated plants and prevent germination.

The alternative procedure is to scrape the top 10 cm or so from the surface and to cut the saltcedar crowns at least 0.3 m below the surface. With this procedure saltcedar are killed while topsoil and accumulated surface salts are pushed to the site periphery or into berms where salts are less likely to interfere with development of any planted vegetation. This also saves time and money in that the amount of weeding required would be greatly reduced, and equipment damaged less frequently. Fewer obstacles to plant growth permit more growth and survival. This method is, in the long run, more environmentally "friendly" than the other alternative.

Step 4: Intensive Soil Analysis

Intensive sampling involves taking soil samples at 10–30% of all planting points on 6 m centers (roughly 250/ha). A minimum of 30 sample points are typically planned for each species, but it is unlikely that the variation in variables across the site can be adequately represented with only 30 individuals of each species--80 or 100 would be more realistic. It must also be born in mind that for small (1 or 2 ha) projects the need for relatively large samples of monitored plants does not diminish just because area decreases. On small projects we often measure all or at least half of the trees planted. Sampling, done with a sufficient quantity of points appropriately distributed over the site allows accurate mapping of the distribution of salts, nutrients, soil texture and moisture, and depth to the water table across the site. For each autecological factor, we determine suitability for species to be planted. As can be seen on a site in the lower Colorado River (Fig. 3.1), autecological variables (particularly soil EC and texture) are highly variable. High variability is expected with EC but often occurs in soil texture and depth to water table as well, and these often vary independently. Suitability is determined by considering all autecological conditions for which data were collected. A species is considered to be suitable for planting at a given point only if none of the autecological factors considered is limiting. For areas suitable for more than 1 species, the suitable species to be planted would be the one with the greater wildlife value (for example cottonwood in areas suitable for both cottonwood and mesquite). With this information a planting design is developed in such a way that, with the exception of the experimental holes, planting will occur only at points where growth can be expected to be at or near maximum for each species. Each set of experimental holes is planted with the same sequence of each species to be monitored.

It is almost a natural desire to have a detailed planting design based on preliminary soil sampling. A moment's reflection will suggest the folly associated with this desire. If the preliminary analysis indicates that a site is worthwhile for revegetation, the intensive soil sampling can be done after clearing. It is often too costly (and inappropriate) to be practical prior to initiation of the project because heavy vegetation hinders locating sampling points and gets in the way of sampling equipment. Subsequent clearing would eliminate the sampling holes and make it difficult to place experimental plants into the sampling holes. Without intensive soil sampling data, a planting design would be based on guessing and wishful thinking. These, of course, have no place in a scientific approach to revegetation. Such procedures leave the outcome to chance—growth and survival become matters of luck.

Sampling points are arranged in groups of 3 to 5 consecutive augured holes. There are 2 major reasons for using this procedure. First, sets of 5 are useful in outlining borders and transitions from areas of high EC, or transitions involving EC and soil type. Second, sets of 5 are easy to find in the years following planting, especially when they consist of a consistent sequence such as cottonwood, willow, honey mesquite Prosopis glandulosa, screwbean, quailbush Atriplex lentiformis. For the first several months after planting plants to be monitored are easy to find, but from the second year on they can be difficult or impossible to locate—especially if the irrigation system has been removed (a problem overcome with GPS units). A distinctive sequence of plants can often be spotted at a distance or can be readily identified as a particular group. Planting trees for monitoring singly can pose problems. Even in the first year measuring randomly distributed single trees is an excruciatingly slow process. If they are systematically distributed finding them is marginally faster in the first year, but finding monitored plants becomes nearly impossible for some plants by the time the trees are 2 or more years old.

Step 5: Tillage

Tillage for trees is accomplished by auguring holes with a minimum diameter of 40 cm to a depth of 2.5 m or to the water table. This method, sometimes called vertical tillage, allows for rapid root penetration to the water table. See Chapter 3 for more information concerning the importance of tillage.

We accomplish tillage by mounting a power head on the right side of the front bucket on a backhoe. We use a 40-cm diameter auger with rebar welded to the edges in order to reduce the rate of wear. A 1-m extension is hooked directly to the power head and the auger is connected to the extension. The front bucket can be raised just high enough to move from point to point without dragging the auger. We use a C-500 series John Deere backhoe or equivalent. The power available is sufficient to auger a hole in about 1 minute when the soil is sandy or fine sand to a depth of 2.5 m. Drilling rate slows significantly as the amount of clay, especially dry clay, in the soil increases, requiring up to 15 min to drill to a depth of 1.5 m. Often the power is inadequate to drill deeper.

When clay soils are involved and the profile of the soil is relatively dry the spinning auger often polishes the sides of the hole. In essence we create a large "pot" 1.5 m deep and 40 cm in diameter. It seems that such "pots" would create an environment in which trees would not survive or would be stunted. This is true for cottonwood and willow, but honey mesquite Prosopis glandulosa and quailbush planted in such "pots" have thrived when provided with water during the growing season.. Salt levels in these situations must be below 8 mmhos/cm for survival of mesquite and below 12 mmhos/cm for survival of quailbush.

Step 6: Irrigation System Design and Installation

We generally use an irrigation system consisting of 13 mm black polyethylene drip tubing emanating from black polyethylene mainline 5 cm in diameter. Each lateral drip tube line is supplied with a screen filter and ball shut-off valve. Laterals are spaced about 4.5–6 m apart, while 500-ml/h pressure compensating emitters are installed in each lateral every 4.5–6 m. Water is ordinarily pumped from existing wells or from the stream channel, but it can also be delivered to drip systems from water trucks. Details of the irrigation system design cannot be made until the intensive sampling design is complete.

Drip irrigation systems are desirable because they are efficient and promote minimal weed growth. Of all the possible irrigation systems to consider, drip irrigation delivers water most efficiently. Less efficiency means more fuel costs to run pumps since more water would need to be delivered to compensate for that lost to evaporation or percolation away from the planted plants. Sprinkle and flood irrigation promote excessive weed germination and growth by wetting most of the soil surface between trees, creating mobility problems as a result of dense, tall weeds and mud, rendering weed control difficult or impossible. Dense weedy growth can out-compete planted seedlings and saplings and promote high rodent populations. If rodent and rabbit populations attracted to the dense cover become high in the first year after planting, they sometimes do significant damage by girdling trees.

Step 7: Planting

If beavers Castor canadensis, burros, cattle or rabbits are common on or adjacent to the site, fencing should be installed before planting. Beaver fencing should be about 1 m high and the bottom buried. It is important that it be located where soil will not slough or wash out from under the fence. Burro fencing should be sturdy and at least 1.5 m high. If deer are numerous, cottonwood and willow trees should be fenced individually with fencing at least 2 m high.

Trees appropriately distributed on a site are ordinarily planted in densities of roughly 250–320/ha. This may vary somewhat depending on species and locations. Soil moisture levels should also receive careful consideration when determining planting densities. If soil moisture levels are likely to be low in years following planting, soil moisture availability may be a serious problem. Reducing plant density probably insures greater vigor albeit for fewer trees per unit area. At this density, the tree canopy should reach 100% ground coverage within 4 years (Anderson 1987, Anderson and Vasquez 1991). Denser plantings require more initial water per area and more cost, but within 4 years the coverage would be the same as with trees planted at 250–320/ha. Occasionally one sees plans drawn up or demands made by those who sponsor projects that call for 2 or 3 times this number of trees per hectare. Ordinarily planting trees in such densities is unwise because within 4 years they will provide no better habitat for wildlife than trees planted at 250–320/ha. Wildlife responds to most mixed habitats maximally when the vegetation is planted 3–6 m apart (Anderson and Ohmart 1984, 1985). Shrubs such as mulefat Baccharis spp., coyote willow Salix exigua, and quailbush are sometimes planted at 3 m spacing along irrigation lines. It is also important for those planning revegetation projects to allow sufficient lead time for development of seedlings and saplings. This consideration is often neglected. If the project contracting procedure is delayed, getting the plants started will also be delayed. It normally requires at least 2 months to develop plants of appropriate stature for planting. Thus if a project is delayed from 1 April to 1 June planting could not reasonably take place until August, thus most of the first-growing season would be lost. If it is a 3–5 year mitigation project about 20% of the growing time available to meet requirements would be lost. Obviously the potential is there for those responsible for the effort to be faced with doing part of the project over—at significant additional cost.

Often we start plants even if we suspect that delays are likely. Even this will not necessarily avert problems, because if the plants must sit in the greenhouse for an additional 2 months or so they can become root bound, a condition sometimes resulting in reduced plant vigor. About 1/3 of the projects we have been associated with were affected by delayed starts—to the detriment of the project in most of these situations.

Detrimental impacts due to a delay become manifest in a variety of ways. Two of them—lost growing time and reduced vitality, were mentioned above. In areas such as those where winter rains are extensive (250–600 mm) damage to trees comes as the result of floods. Trees planted in spring often attain sufficient stature to resist flood flows by fall, but when planting is delayed until July or later, many, perhaps most, planted trees get washed out by winter floods. Another common project impact due to delayed planting is that desired species are not available in the quantities needed. Additional plants of these species must be planted a full year late. Such trees, of course, have 1 less year to attain heights required by the mitigation dictate.

Fertilizer is added if soil sampling indicates the need (Anderson and Vasquez 1991). If fertilizer is used, it is applied in such a way that competition from weeds will be reduced by burying fertilizer tablets beside the root balls at planting.

Planting is usually done in the spring or early summer. At this time potted plants are usually about 400–500 mm tall. In addition, Tubex®, a protective tubing, can be used to protect young plants. This tubing is touted as having beneficial actions of slowing competitor growth, deterring browsing, and increasing water use efficiency. If honey or velvet mesquite *Prosopis velutina* are to be planted, protective covering or rabbit fencing is a must. Timing of planting is important. These species are frequently attacked by sucking insects called psyllids. These insects are usually a problem in spring, with severity declining in the hottest months and re-occurring in September or October on the lower Colorado River. To circumvent early attacks we grew honey mesquite in our greenhouse in Valencia, California, where honey mesquite are not indigenous and therefore there are no psyllid problems. With the onset of hot weather (highs of 40 °C) on the lower Colorado River we delivered trees from Valencia for planting. As saplings mature they are less likely to die from these insect attacks. Psyllid attacks in late summer and early fall may result in halting growth. Death is usually not an outcome, but stunting that remains apparent for years is common.

Step 8: Irrigation and Weeding

In the desert Southwest irrigation is essential for revegetation. Trees planted without irrigation usually die quickly because soil moisture levels are insufficient for newly planted riparian plants. Some areas near streams or backwaters are moist for long periods, but such areas are few and small and likely to have surface salt accumulation or are subject to flooding.

Some have argued that planted saplings should thrive if naturally occurring mature trees or seedlings are found to be growing in the area. The problem is that most of the seeds that the mature trees produce do not germinate and most of those that do germinate die soon thereafter. Only a few are successful and only when conditions are favorable. Such conditions occur rarely and occurrence is unpredictable.

To make soil moisture conditions suitable for trees and/or shrubs at each planting point, irrigation is a practical necessity. Irrigation is usually done in the morning at a basic rate of 30 L/day through 8 L/h pressure-compensating emitters. This requires 4 h of irrigation per day. Irrigating later in the day may result in death or damage to young plants near the ends of laterals, particularly during hot weather. During the hottest time of year in the lower Colorado River valley, water near the ends of lines can become hot enough to scald plants by 10:30 AM, even while running continuously since sunrise. Ponding can also result in scalding.

Excessive irrigation can create a large wetted area that serves only to promote shallow lateral roots and weed growth. It is also more expensive, but in coarse soils with low soil moisture, we have found more irrigation to be beneficial, at least for a short term. It can promote lateral root development. Lateral roots may not have enough time to reach depths where soil moisture is sufficient to sustain the trees after irrigation is discontinued. In poorly drained soils, irrigation can be done intermittently to allow time for water to percolate deep into the soil profile. Irrigating at less than 30 L/day is inadequate except in wet areas where drainage and soil aeration are limited.

Irrigation is usually done 5 days each week for 18–24 weeks in the first season. This allows time for roots to reach the water table. We have found that many trees are damaged during hot periods if they are not irrigated for 2 consecutive days. Therefore, irrigation is extended to 6 or 7 days per week during such conditions. In October, irrigation frequency is decreased and eventually discontinued to promote dormancy. We have observed considerable freeze damage in October on tender growth of mesquite and palo verde on a site on the lower Colorado River where we prolonged irrigation and plant growth well into the fall.

Adhering to irrigation schedules is very important for the success of a revegetation project. Underwatering and overwatering achieve the same outcome—failure of the trees to survive.

Cottonwood and willow trees are never planted where the depth to the water table, perched water table, or permanently wet soil exceeds 2.5 m unless adequate irrigation can be supplied on a permanent basis. Irrigation during the second year is done 5 days per week from May through September on an as-needed basis to ensure survival and reasonable growth rates. Monitoring reveals the need for irrigation modifications.

Weeding to prevent competition is done as needed during the irrigation period. This involves hand weeding planting points and disking between rows or digging out saltcedar with a backhoe. We have used herbicide after planting on some sites, but because of negative affects to planted trees and shrubs this practice has been discontinued.

Step 9: Monitoring and Report

Monitoring. Monitoring begins soon after planting and continues for 18 weeks during the year of planting. Plants selected for monitoring are those planted in the systematically selected sample holes used for the intensive sampling. Practical statistical estimates of height and growth are ensured by creating the monitoring design in such a way that a minimum of at least 30 individuals (but see STEP 4, above) of each species are monitored. Height of each tree is determined by measuring the distance from the base to the top of the tallest up-stretched leaf. Condition or quality of each tree is quantified on a scale of 1 (poor) to 4 (excellent). Height and quality index data are entered on the computer the day they are taken. We then analyze growth in the context of the variation in autecological factors on the site determined from the intensive sampling. For example, if growth of cottonwood or willow is less than expected (expected growth being 0.013 m/d, varying somewhat with area, soil factors, and species) we take immediate steps to improve the growth rate. We take into consideration the autecological conditions where trees are performing better than expected, as well as where trees are under performing. Growth is often associated with an autecological factor. Poor growth may be found to be associated with coarse soil texture, a deep water table, or high salinity levels. In such cases the hypothesis is that soil moisture is inadequate or salinity is excessive, so irrigation would be promptly increased to increase soil moisture to dilute and leach salts. If growth is found to be inadequate where the water table is closer than 1 m but more than adequate elsewhere, we decrease irrigation or irrigate in frequent short intervals (punctuate). In such situations soil aeration may not be sufficient. Decreasing or punctuating irrigation allows time for soil aeration. Often several factors need to be considered simultaneously. We monitor on a weekly basis to prevent serious damage. Weekly monitoring allows us to detect potential problems while they are still subtle; that is, at such an early stage procedures can be altered before significant damage occurs. Routine problems with slowing growth rates can usually be reversed, often quickly and dramatically, by alteration of the irrigation rates or duration. Thorough familiarity of conditions on the site is often indispensable to solving problems effectively.

Models of relationships of crown diameter (D) to height (h) have been developed for major riparian species and presented in Anderson and Ohmart (1982, 1984). For cottonwood and willow, crown diameter (D) may be calculated by

$$D = 0.44 + 0.84h \qquad \text{Eq. 3.1}$$

For a stand of trees with crowns that have not closed, the volume of space occupied by a tree (V) can be estimated by

Eq. 3.2

Substituting for D from the first equation into the second equation yields

$$V = 0.81h(1 + 1.91h)2 \qquad \text{Eq. 3.3}$$

The relationship between height and space occupied by a tree, as expressed in Eq. 3.3, is such that an increase in height of larger trees results in a greater increase in occupied space than an equal change in height of smaller trees (Fig. 3.2).

Occasionally it is desirable to have data concerning foliage volume or percent ground cover. Use of these equations greatly reduces costs that would otherwise accrue if data concerning foliage volume and percent ground cover were to be directly measured in the field. We are convinced, after many years of checking, that these calculated values are as accurate and as useful as direct measurements.

Monitoring in the second growing season is done May through October from the original sample. We also assess available soil moisture. Measurements at these times will reveal the extent to which the project may be in jeopardy. It is reasonable to expect that as time passes mortality will increase cumulatively until in 50 or 60 years (the natural life expectancy of cottonwood and willow) the majority of the original trees will be dead, even with the most intensive care. At the end of 3 growing seasons, assuming irrigation continues for at least 2 seasons, , mortality should be small, not exceeding 5%. Frequency of monitoring is substantially decreased in follow-up years. Small increments in mortality can perhaps be expected to be compensated for by natural germination on some revegetation sites.

In addition to subtle problems that develop as a result of autecological conditions on the site, other problems can be observed. For example, if emitters are becoming clogged with algae this may be detected during a monitoring session, in the form of reduced flow, or total lack of flow. Although this problem would ordinarily be detected by the irrigator, the highly systematic procedure associated with weekly monitoring serves as a check and from carefully taken notes it can also reveal the extent of the problem. Other problems such as damage by deer, rabbits, psyllids, or other insects can be merely noted or quantified. The incursion of weeds can also often be quantified. Weekly monitoring is indispensable and can often lead to the avoidance of problems that are potentially project threatening.

Reports

Substantive reports with quantified data (ecological conditions, monitoring, growth rates) should be provided. Items such as irrigation and planting designs and results of weekly monitoring are made available on an "as requested" basis. Reports keep everyone involved abreast of project developments.

Benefits Gained from Using the Nine-Step Plan

Over the years we have developed what has come to be known as the Nine-Step Revegetation Plan as discussed above. Among other things, this plan includes fairly extensive soil testing and tillage to a depth of about 2.5 m. The objective is to plant as few plants as possible at points where, because of unsuitable autecological conditions such as soil type or soil EC levels, plants will not grow. Of course the soil testing adds costs to a project, but in the long run including all steps of the Nine-Step Plan insures maximum success while still keeping costs relatively low. Seldom have we had an opportunity to demonstrate directly how our approach compares with the outcome of projects where the decision is made to alter or eliminate all soil testing. We have had one very good opportunity to make such an evaluation. In the project being compared to ours the soil and salinity levels were virtually identical to those on our sites. We sampled extensively to the west, east, and south of the project being compared. Directors of the project being compared elected to do no soil testing or tillage (pers. comm., Anderson with project director). The difference between the shortcut approach and ours is that decisions about where to plant what, using our methods, is based on soil sampling and use of vertical tillage.

On the site using the shortcut methodology, "honey mesquite" height of live trees after 5 years averaged 2.67 m (SD = 0.76 m, N = 38) with space occupied by leaves and limbs using Eq. 3.3 on average being about 46.4 m3. In contrast honey mesquite of about the same age that we planted on 3 different projects in the same area averaged 4.2 m (SD = 0.74 m, N = 59) tall with foliage volume of the average tree occupying 152 m3. Thus our trees averaged 57% taller and occupied 328% more space. For screwbean the shortcut approach led to live trees with a mean height of 3.5 m (SD = 0.76 m, N = 78) and the average tree occupied 104 m3. In contrast screwbean of about the same age that we planted on 3 different projects in the same area averaged 4 m (SD = 0.71 m, N = 129) tall with foliage volume of the average tree occupying 150 m3. Thus our trees averaged 114% taller with 147% more foliage volume. In 2003 the differences between projects involving the Nine-Step Plan showed further increases and the differences between projects employing the Nine-Step Plan and those discussed above using the short-cut methodology increased even more (B. W. Anderson and P. S. Russell, Unpublished data).

Did our more intensive approach yield results that warranted the additional effort? (We know nothing about costs on the project using the shortcut methodology.) The answer involves a nonscientific value judgment that we will leave up to others to make. Is it our methodology that accounts for the observed differences? Our data for the comparison constitute results from a reasonably (if accidentally) well designed means of comparison. Therefore we would tentatively conclude that it is the methodology that accounted for the difference. Any of the 3 projects using our intensive methodology significantly outdistanced results obtained with the shortcut methodology.

Relative to use by wildlife, suffice it to say that we have published many papers (for example, Anderson, Ohmart, and Rice 1983, Rice, Anderson, and Ohmart 1984) documenting the association between increasing bird densities with increasing foliage volume for any given trees species. The same was shown to be the case for wildlife in general in a report summarizing a decade of our fieldwork on the lower Colorado River (Anderson and Ohmart 1984).

Occasionally other workers have claimed to have used the Nine-Step Plan in their revegetation efforts when, in fact, they took shortcuts that negated such claims. For example in at least one instance trees to be monitored were not planted at the points where soil data were collected. This alone negates a claim to have implemented the project with the Nine-Step Plan. It also means that the weekly monitoring during the initial season cannot realistically be related to conditions on the site and this shortcoming affects any report (STEP 9) resulting from the effort. Similarly, in another complex project the sample of monitored trees was too small (<30 individuals of each species) to be useful in any meaningful way, either for evaluating the progress on the site or for reporting relationships between growth, survival and site conditions. These 2 examples illustrate failure to fully implement at least 2 steps each thus negating any claim for having implemented the Nine-Step Plan. It is unfortunate that these claims are made and these projects fail—an outcome predicted to be likely when the Nine-Step Plan is not fully implemented—they might, nonetheless be associated with the Nine-Step Plan because of the sponsors irresponsible and perhaps unethical claims. We suggest that unless all 9 steps are followed in detail it is inappropriate to claim that the Nine-Step Plan was used.

Summary

The Nine-Step Plan for revegetation is a paradigm for revegetation projects and includes research. Combining the practical aspect of doing revegetation projects with research concerning the needs of various riparian plant species allowed us to gradually develop, with reasonable confidence, a set of circumstances under which at least the major riparian plant species should be planted. The data collection period has spanned more than 20 years. The results of this work are spread over the next several chapters of this book. The Nine-Step Plan, in chronological order, includes a preliminary analysis of a site to determine site suitability for revegetation, propagation of plants to be planted, site preparation, including clearing unwanted vegetation, intensive soil sampling to allow mapping the distribution of salts and other factors across the site, irrigation system design and installation, planting, irrigation and weeding, monitoring, and report.

APPENDIX 2. Equations for calculating surface soil texture and EC.

Surface Soil Texture. The surface soil texture can be calculated as:

$$S1 = -0.865 + 0.397S4$$

Where S1 refers to subsurface soil texture, 0.865 is a constant, and s4 is the subsurface soil texture. All elements of the equation are statistically significant at $P = <0.001$. The standard error of estimate is 0.72 indicating that the true value could vary, plus or minus, this amount. This is sufficiently accurate for current needs.

Surface Electrical Conductivity. Surface electrical conductivity can be calculated from the following equation:

$$EC1 = 10^{(-0.145 + 0.637lg10EC4 + 0.310lg10PCT)}$$

EC4 = surface soil electrical conductivity, EC4 = lg10EC4 = log 10 of subsurface soil electrical conductivity, lg10PCT = log 10 of the soil moisture 3-4 feet below the surface. In the equation R = 0.834, adjusted R2 = 0.684 and overall equation is statistically significant at $P = <0.001$. The probability associated with the constant was 0.085; lg10EC4, <0.001, and lg10PCT, 0.012. The standard error of the estimate was 1.5 mmhos/cm meaning that the equation generated estimate is accurate to plus or minus 1.5 mmhos/cm, which is satisfactory for our purposes.