Applicability of Remote Sensing Data to Rapidly Assess River Restoration Sites in the Palo Verde Valley

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ABSTRACT

Identifying sites for river restoration is a complex process, drawing from many fields of science. Field data is often collected to assess if a site is suitable for restoration. Because field data collection can be time and resource intensive, using remote sensing data could potentially speed up the process. I used remote sensing data to assess restoration potential in 106 sites in the Palo Verde Valley on the Colorado River. I identified sites for restoration and determined how the remotely sensed data matched with field data. Each site was classified as LEV, STB or IRR. LEV sites consisted of small buffers of land surrounding the river channel. STB sites were large sites that were setback from the river. IRR sites contained irrigation channels inside them. In ArcGIS, I created layers for water features, the sites, elevation and land use, and assigned weights to each of these features. Using suitability analysis, I created a model to quantify the restorability of each site. Overall, 65 sites were very promising for restoration. I found that LEV sites had the best restoration potential, with a mean score of 0.5, while IRR sites had the least potential with a mean score of 2.3. In addition, I found that remote sensing data did not vary much from field data. However, the results were not statistically significant. Remote sensing can be used as a preliminary process in assessing restoration sites. Future studies may want to look into this relationship more closely.

KEYWORDS

Suitability analysis, Colorado River, DEM analysis, Lower Colorado River Restoration Project, Restoration Type Comparison

INTRODUCTION

Identifying sites in large rivers for restoration is a complex process, combining knowledge from across fields of science. Each step in the process, such as selecting a restoration method, accounting for scientific uncertainty, and managing the scale of a project adds complexity and increases difficulty. In matching restoration approaches to the goals of the project, projects are classified into three categories: projects that create new habitat, projects that restore habitat to a previous historical state, or projects that alter habitat based on theoretical models (Wheaton et al. 2008). Uncertainty, which arises from many sources, such as lack of ecological scientific understanding or fluctuations in water quality resulting from human management, can result in restoration failure if not properly managed (Lemons and Victor 2008). The project scale also affects complexity. As river systems and restoration sites increase in size, more biological, geological and chemical processes need to be accounted for (Beechie et al. 2010). As additional factors are considered, the complexity of choosing a site increases as each new variable could allow a restoration to be a success or failure. This complexity necessitates the creation of simplified metrics to estimate potential of restoration success.

The wide variety of specific metrics currently used to estimate restoration potential of sites in large rivers demonstrates the need for universal metrics. Some effective measurements are with respect to ecosystems, such as habitat change (Parasiewicz et al. 2013, Gilyear et al. 2013). By quantifying the lack of habitat, how habitat has been altered and the duration of time that organisms are stressed, the success of a restoration can be predicted in several sites (Parasiewicz et al. 2013). Other physical variables related to the complexity of a channel, such as cross section shape, complexity, historical changes, and structures of the channel (such as braiding) have also been used in planning restoration of several sites (Tompkins 2006). The difference in metrics used may be explained by a difference in restoration goals. Depending on the site, a method that restores to either a historical or resilient state may be more applicable (Vasey and Holl 2007). Because site/project-specific variables measured in one river system may not transfer to another ecosystem, fundamental variables need to be found (Birks et al 2013). General, broad variables that can be applied across a wide range of different ecosystem types would make restoration planning more straightforward.

Measuring restoration variables using remotely sensed data has the potential to speed up the identification of sites compared to variables measured in the field. Remote sensing involves collecting data using aerial photography or satellite imagery, and analyzing the data. Metrics of river change, such as height of channel incision, changes in flood patterns, historical land-use change and the structure of the river can be measured using remote data from maps, historical photos, and other sources (Schmidt and Wilcock 2007, Tompkins 2006). Some of these metrics have been successfully used in restoration policy planning (Tompkins 2006), yet some proposed variables with respect to ecosystem services, such as biodiversity, conservation of fisheries, and human culture may be harder to measure using remote sensing (Gilyear et al. 2013). Other potentially useful variables, such as land area and type of habitat alteration, have not been tested using remote sensing (Parasiewicz et al 2013). Remote sensing data has rarely been used to rapidly assess restoration sites. I plan to use remote sensing to rapidly assess over 100 sites in the lower Colorado River. In order for remote sensing to become a valid method to assess restoration sites, a clear correlation between remote sensing and field data needs to be established.

The goal of this study is to rapidly assess 106 potential restoration sites in the Palo Verde valley. I am comparing basic metrics, using variables that should be applicable across a broad range of river and project types. Using this data I seek to determine which sites and parts of the valley show the most promise for restoration. I examined DEM elevation data as well as current satellite data. I analyzed each site using suitability analysis modeling. I then compared the output of DEM modeling with field data acquired from my lab group.

METHODS

Site description

This study focuses on restoration sites in the Palo Verde Valley, which is part of the greater Lower Colorado River basin. The valley surrounds the Colorado River and small towns such as Parker and Blythe on the California/Arizona border. A large area in the Palo Verde Valley was historically desert flood plains, parts of which are now agricultural. This farmland consists of a patchwork of in-use and abandoned agricultural land. Irrigation channels surround abandoned and in-use farmland, taking water from the river and later returning it to the river (Z. Rubin, *personal* *communication*). Multiple restoration projects are occurring on the Lower Colorado River, however very few are occurring in the Palo Verde Valley itself (BLM 2012). A large portion of the valley is also on the Colorado River Indian Tribe Reservation, shared by the Mohave, Navajo, Hopi and Chemehuevi tribes (Z. Rubin, *personal communication*).

Data sources

To analyze restoration potential, I acquired several datasets for GIS analysis (Table 1). I acquired satellite maps using the ArcMaps online database. I downloaded elevation data from the USGS and acquired elevation cross section data from the Kondolf lab group (M. Kondolf, unpublished data). I visually identified potential restoration sites in the Palo Verde Valley and then confirmed this with an expert, Zan Rubin, a Ph.D. student in Landscape Architecture and Planning. We selected 106 sites.

Table 1. Description of each data source, date of data collection and type.

Description	Source	URL	Dates	Type
Elevation Data	USGS	ned.usgs.gov/	2013	Raster
Cross Section	Kondolf Lab	landscape.ced.berkeley.edu/%7ekondolf/	2012	Points
Satellite Imagery	ESRI/ ArcGIS Online	esri.com/software/arcgis/arcgisonline/maps/maps-and-map-layers	2013	Image[1]

[1] consists of many images over space.

Restoration approaches

To analyze restoration potential, I considered three potential restoration site types. The first type, LEV, restores area along the channel between the channel levees and service roads. Service roads hug the levees, creating a thin patch of land between the levees and the road. This area can be restored with very little political opposition. The second type, STB, sets back channels into areas of historical flood plain. Historically, the Colorado River floodplain was very large compared to the channel that contains it now (Z. Rubin, *personal communication*). This restoration method would evaluate restoring the river to areas of its historical floodplain, allowing the river to inundate these areas. The third type, IRR, restores areas between the river channel and irrigation canals.

Irrigation channels propagate through the Palo Verde Valley and surround historical floodplains. Using both irrigation channels and the river channel, the river could be more easily reconnected to its floodplain (Z. Rubin, *personal communication*). For each site, I selected a restoration method that matched the sites characteristics and confirmed with Rubin.

GIS data collection

To measure restoration potential variables from the raw datasets, I used ArcGIS 10.1 (ESRI 2012). I used the ArcGIS editor tool and the field calculator included in the student edition to measure variables in the metric system. I measured site area (m^2) and elevation (m). These variables are descriptive of the site and some will be used in the final analysis.

I created a restoration sites layer in ArcGIS. Using the ArcGIS trace function, I traced each site based on its purposed restoration method. For LEV sites, I traced the area between levees and the surrounding road. For STB sites, I traced the abandoned floodplain area. For IRR sites I traced the area surrounded by river and irrigation canals. These shapes were saved to the sites layer to find the area of the site and allow for further manipulation. Into each site layer polygon, I added two other variables, state location (California or Arizona) and a dummy variable of 1 for each site. This dummy variable can be used to give all sites the same score.

To quantify the river channel, I traced the river channel, creating a polygon using ArcGIS. I also created a points layer on the river for later comparison of the elevation of the river to the site. I visually traced abandoned canals as well, using a separate canal polygon layer. For each water feature I created a buffer of 61 m, because certain insects can only live within that range of water (Z. Rubin, *personal communication*). To each buffer layer, I also added a dummy variable of 1. Using satellite imagery, I visually categorized land use (farm, residential, abandoned, natural) and assigned this variable to each site. Land use was assigned in two ways. For sites with multiple land uses, I traced individual polygons of each land use type and assigned the variable to each polygon. For sites with only one land use type, I assigned the land use variable directly to the site layer, using the dummy variable.

Finding differences in elevation

In order to quantify the differences in site elevation from the river elevation, I combined data from the sites polygons, river points layer and elevation data. First, I combined multiple elevation data sets into a single raster. Combining the sites polygon layer and elevation raster, I extracted the elevation data using the sites layer. This gave me a raster with only the elevation data inside my sites. Next I used the "extract data to points" tool to extract the elevation to the points on the river (ESRI 2013). I found the nearest point to each site and added the elevation value into the attributes table of the sites layer for each site polygon. I used the "convert polygon to raster" tool to create a raster for each site that had the value of the nearby river elevation for each site (ESRI 2013). Using the raster calculator, I subtracted the site elevation raster from the river elevation raster. This raster gave the difference in elevation as it changes in space for each site (Eq. 1).

$$D = \text{Elevation at point in site} - \text{Elevation of nearby river} \qquad \text{(Eq. 1)}$$

Suitability analysis

To determine site's potential for restoration, I used suitability analysis. Suitability analysis applies weights to variables that are determined to be beneficial or detrimental to quantify how well a space can be restored (Malczewski 2004). Aspects that increase potential for restoration are called opportunities while aspects of a site that reduce potential for restoration are called constraints (Malczewski 2004). Since the change in elevation, D, was the base layer (where lower differences in elevation signified greater restoration potential), I decided to keep the scores within this frame of reference. Sites that were within 0 to 6 m of the river level were considered possible candidates for restoration (Z. Rubin, *personal communication*). This means, opportunities necessitate a negative score (as a way of artificially lowering the elevation difference in the site), while constraints represent a positive score (artificially increasing the difference). I modified a model given to me by my mentor (Z. Rubin, *personal communication*). Using the river channel and irrigation canal layers with the buffer, areas that were within the buffer were assigned a beneficial score of -2, because these areas had easy access to water for insects and for restoration

(Z. Rubin, *personal communication*). The state the site was located in was not included in the original model, so I assigned a weight of -1 for California and +1 for Arizona, due to differences in politics. I assigned a score of +5 to any developed area, to heavily restrict these sites from being choosen (Z. Rubin, *personal communication*). I added a score of -1 for undeveloped sites as this was also not included in the original model. Finally I added a score of +3 to agricultural areas, as a modification of the original model (Z. Rubin, *personal communication*).

Table 2. Suitability analysis Scoring. Table displaying the score give for each feature of the suitability analysis.

Variable	Score
Land use	Agricultural (+3), Undeveloped (-1), Developed (+5)
Distance to Channel/Canals	(- 2) if within 61 m
State	CA (-1) AZ (+1)
Channel/Canal Buffer	(- 2) if within 61 m

Using suitability analysis, I applied the model to each site. The equations below adds up each numerical score given for each opportunity or constraint (Eq. 2, Table 2). To perform this calculation over space, I merged the polygon layers together for both positive and negative aspects. This allowed me to compute most of the model together. I then clipped this polygon to the original sites layer, in order to remove excess data. Using the field calculator, I added up each variable over the site. Then, using the "convert polygon to raster" tool, I created a raster (15 m cell size) of the opportunities and constraints. I then used the raster calculator to add the differences in elevation to the score raster and created a color coded map of restoration suitability over space. Finally, I used the "Zonal Statistics" tool in order to get the statistics, like the average score of each site (ESRI 2013). This allowed to assess if a site was suitable for restoration.

$$S = D + (\text{State}) + (\text{Channel Score}) + (\text{River Buffer Score}) + (\text{Land Use}) \qquad \text{(Eq. 2)}$$

Field validation

To verify methods evaluated from remotes sensing data, I used field measurements. I acquired two field elevation cross sections from my lab group. A site map shows the locations of the surveys below (Figure 1). I used the "Profile Graph" function of ArcGIS to extract the same cross section from the DEM (ESRI 2013). I then took this extracted data and analyzed cross section data using Excel to make a two dimensional graph of the land surface (Microsoft 2013). Due to the small number of sites, I compared each field cross section to DEM cross sections qualitatively.

Figure 1. Locations of sites. Field sites are located as the two red points, while remote sensing sites are shown as green polygons.

RESULTS

Remote sensing data

LEV sites averaged the lowest suitability analysis scores while IRR sites averaged the highest (lower scores signify better restoration potential). Overall, site scores ranged from -6.8 to 6.8 (Table 3). The average overall site score was 1.4 (Table 3). Site 13 is an example of a low scoring site, with an average score of 0.87 (Figure 2). Elevation was below or within one meter of the river level (Figure 2). Much of the site was unused and accessible to water (Figure 2). Site 71 received a high score. A large difference between river and site elevation was typical of these sites

(Figure 3). Land use may also be agricultural, however, in this site it was not (Figure 3). Water was also inaccessible to the high scoring portions of the site.

For the LEV method, 28 sites scored below 2, and 6 sites scored between 2 and 6 (Table 4). The median score of the suitability analysis was – 0.2 and a mean of 0.5 (Table 3). On average, LEV sites had a lower elevation difference from the river and lower land use scores than the other methods. The LEV method had less spread than the other methods, with a standard deviation of 1.5 (Table 3). The minimum score was -2.3 while the max score was 3.7, corresponding to a total range of 6.0 (Table 3). Most LEV sites were located in the Lower Palo Verde Valley.

For the STB restoration method, I found 21 sites scored lower than 2, 17 sites scored between 2 and 6, and 3 sites scored greater than 6 (Table 4). The median suitability analysis score was 1.9 with a mean of 1.4 (Table 3). STB sites scored on average with all sites (Table 3). The STB method had the greatest spread of all methods, with a standard deviation of 3.1 (Table 3). The minimum score was -6.8 while the maximum score was 6.8. This corresponded to a range of 13.6 (Table 3). STB sites were located throughout the Palo Verde Valley.

For the IRR restoration method, I found that 16 sites scored below 2, 12 sites scored between 2 and 6, and 3 sites scored above 6 (Table 4). The median of the suitability analysis score was 2.0, with a mean of 2.3 and a standard deviation of 2.6 (Table 3). On average, IRR sites scored higher than the other methods (Table 3). IRR sites had a wider distribution than LEV sites, but a smaller distribution range than STB sites, with a standard deviation of 2.6 (Table 3). The minimum score was -1.9 and the maximum score was 6.8, corresponding to a range of 8.7 (Table 3). IRR sites were located throughout the Palo Verde Valley.

Table 3. Statistics of suitability analysis scores. I computed statistics of the suitability analysis scores to gain more insight into the distribution.

	Median	**Mean**	**SD**	**Range**	**Min**	**Max**
LEV	-0.2	0.5	1.5	6.0	-2.3	3.7
STB	1.9	1.4	3.1	13.6	-6.8	6.8
IRR	2.0	2.3	2.6	8.7	-1.9	6.8
All	1.1	1.4	2.6	13.6	-6.8	6.8

Table 4. Distribution of suitability analysis scores.

	S < 2	2< S <6	6 < S	Total
LEV	28	6	0	34
STB	21	17	3	41
IRR	16	12	3	31
Total	65	35	6	106

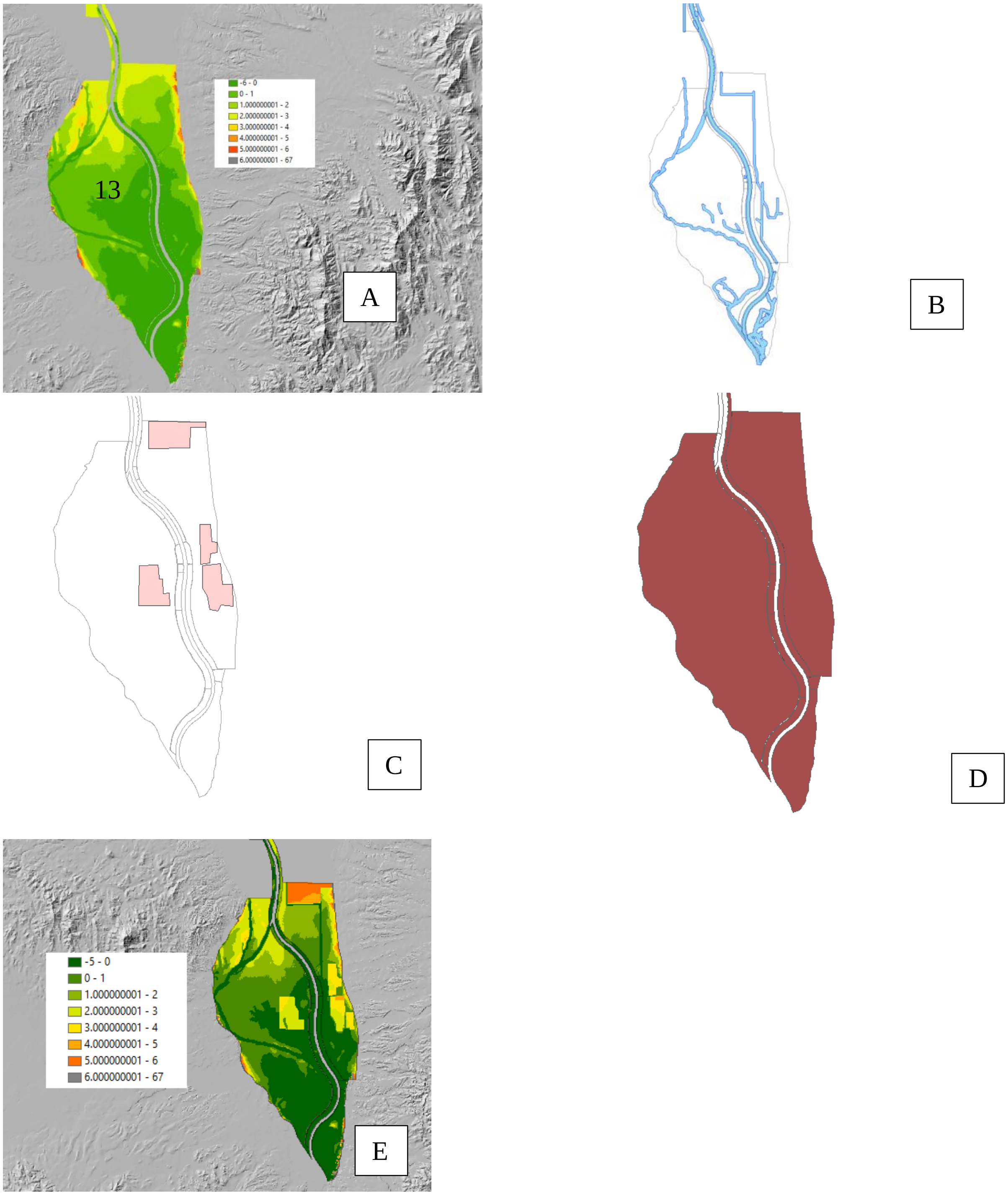

Figure 2. Layer of suitability analysis for low scoring sites. An analysis of sites 2, 13, 19, 20, 21, 27, 28, 29, 30, 105. Pay attention to site 13, had a mean score of 0.87. The difference in elevation comprises the base layer (A). Layer B consists of a buffer for the river channel and water features (an opportunity). Layer C shows land use (agricultural), which represents a constraint. All other land use was classified as “unused” and weighted in the sites layer. Layer D shows the location (state). All sites in this section are located in Arizona (a constraint). E shows the final results.

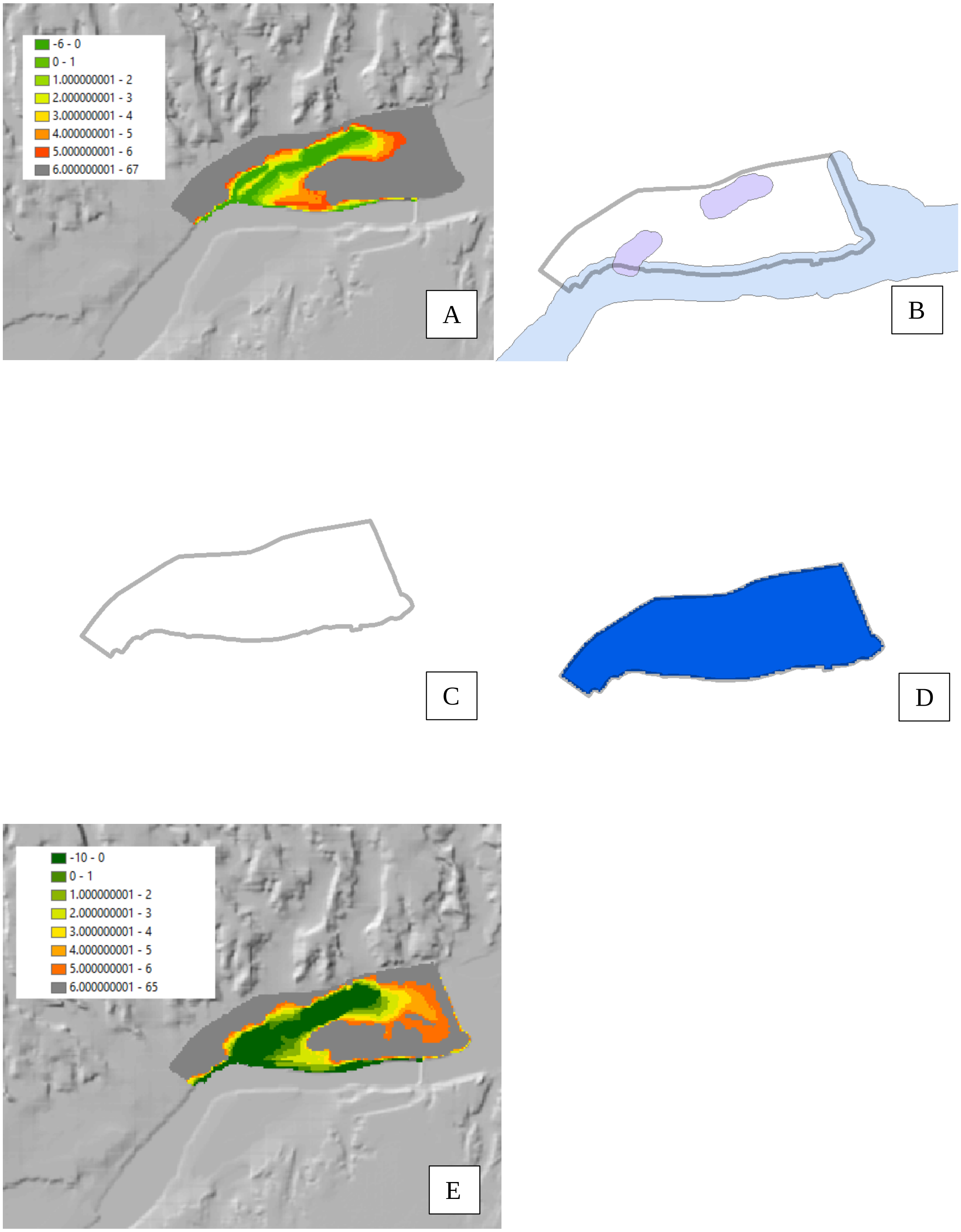

Figure 3. Suitability analysis layers for high scoring sites. An analysis of site 73, which had a mean score of 6.77. The difference in elevation comprises the base layer (A). Layer B consists of a buffer for the river channel and water features (an opportunity). Layer C shows land use (unused), which represents an opportunity. Layer D shows the location (state) of this site. It is located in California (an opportunity). E shows the final results.

Upper Palo Verde Valley

Middle Palo Verde Valley

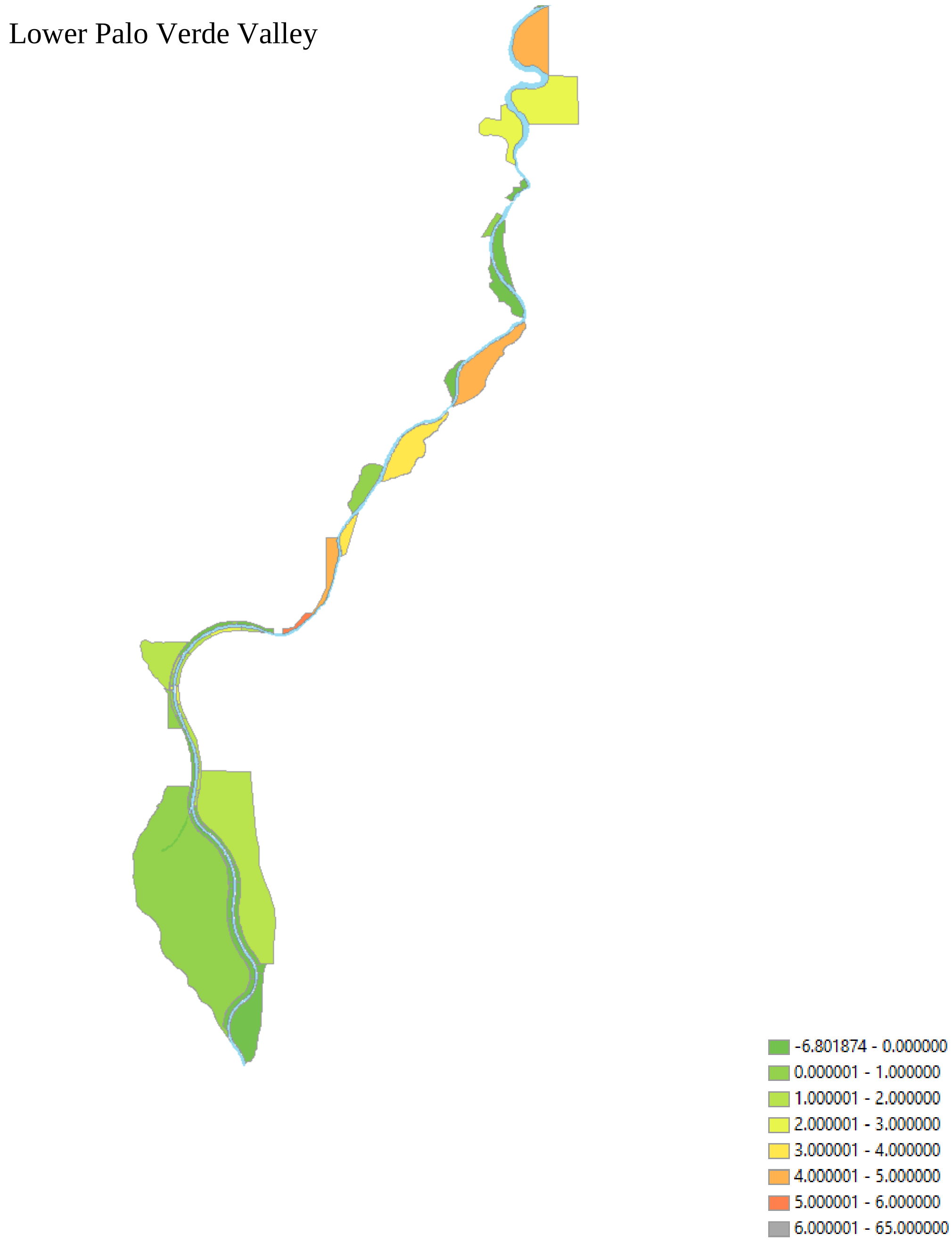

Figure 4. Site maps of the Palo Verde Valley. This map includes all sites, with some overlap in order to give spatial perspective. Sites that scored low are in green. Sites that scored high are in red and grey.

Comparison of field data with remote sensing data

Using field data, I analyzed two field data sites, sites 71 and 35 (Figure 6, Figure 7). Site 35 was an LEV site located in the lower Palo Verde Valley. This site follows the river with a small amount of land extending back from the river. This site mostly consisted of a levee system holding back the river, with adjacent fields that were below the river level (Z. Rubin, *personal communication*). At Site 35, the largest deviation between the remote sensing data and field data about 5.1 meters (Figure 6). Site 71 was an IRR site located in the upper Palo Verde Valley. This site consisted of an area with a water feature in the middle of the site. The largest deviation between the field and remote sensing data was estimated to be 1.5 m (Figure 7).

Figure 5. Site map of sites analyzed using field data. Marker 1 shows site 35 while maker 2 shows site 71.

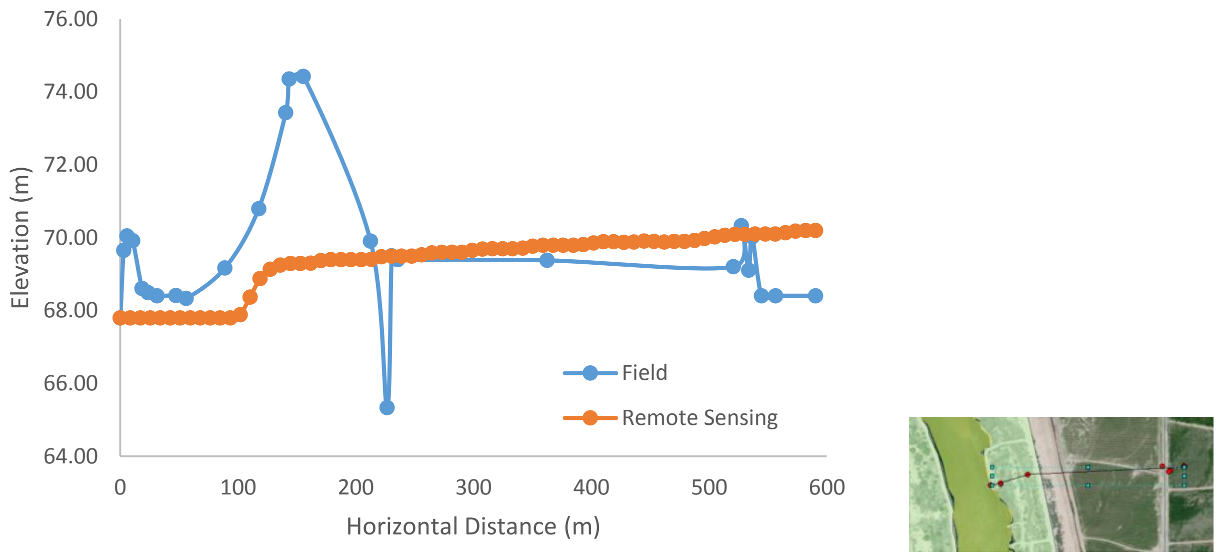

Figure 6. Comparison of elevation cross sections for site 35. On the right is a picture of the site. Both field and remote sensing results are included.

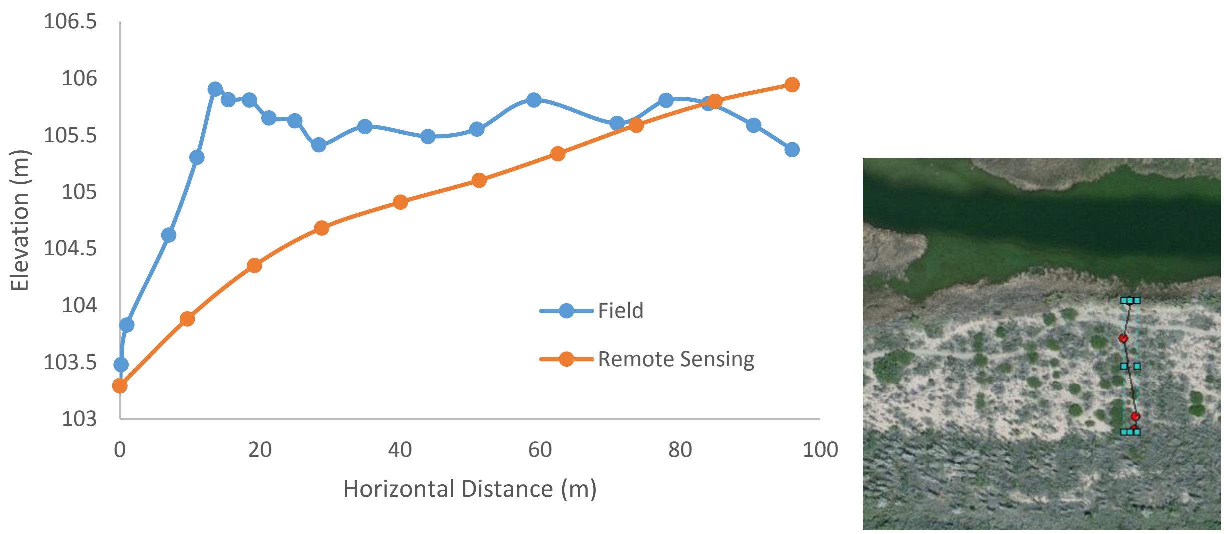

Figure 7. Comparison of elevation cross section for site 71. On the right is a picture of the site. Both field and remote sensing results are included.

DISCUSSION

The Palo Verde Valley is a promising location for future restoration projects. Out of 106 sites, 65 scored very well for restoration (below 2). Among all sites, the mean suitability analysis score of 1.38 signified that many sites are potentially good for restoration. These sites spanned California and Arizona, although California has a more favorable political climate for restoration.

Only 6 sites scored very poorly (higher than 6). LEV sites demonstrated the best restoration potential while IRR sites exhibited the worst potential. Field data compared favorably with conclusions reached from remote sensing, however I surveyed too few field data sites to draw statically significant conclusions. Remote sensing data appeared to capture the general elevation trends while missing some of the nuances. This remote sensing method will allow for pre-restorations to occur in a much faster, cheaper and efficient manner. In the Palo Verde Valley, restoration on the Colorado River will need to address the changing climate and increasing water needs of the population.

Restoration approaches

The LEV method

LEV sites demonstrated good restoration potential as a result of being close to the river with low elevation. LEV sites did not extend away from the river enough to experience sharp elevation increases. LEV sites perform well with a little variation as suggested by a mean suitability analysis score of 0.5 and a standard deviation of 1.5 (Table 3). This is also supported by the range of 6.0 (Table 3). The difference between the mean and median is caused by a few larger positive outliers skewing the data. This may have been because many of these sites were located in the lower Palo Verde valley while a few poor performing sites may have been located elsewhere. Based on the conclusions for site #35, it appears that remote sensing can predict restoration. The site had an overall low elevation, which was captured in the DEM. However, the DEM failed to capture a tall levee that held back the river channel. Instead, it portrays an elevation increase, as if the site had been smoothed over (Figure 6).

The STB method

STB sites demonstrated average restoration potential as a result of high variation. The mean suitability analysis score of 1.4, standard deviation of 3.1 and range of 13.6 demonstrated the wide range of variability in STB sites (Table 3). STB sites included both the highest and lowest scoring sites. The large range in scores for STB sites was caused by a diversity of STB site geography.

STB sites included small sites that were located near the river, as well as large sites, that were set back extremely far from the river. High performing STB sites were located in the middle and upper Palo Verde Valley. These were small sites that hugged the river or may have had water features located inside. Poor performing sites were located in the upper Palo Verde Valley, marked with high elevation differences from the river.

The IRR method

IRR sites demonstrated below average restoration potential as a result of high elevation differences with the river. The mean suitability analysis score of 2.3 and a standard deviation of 2.6 suggest that IRR sites are not as suitable for restoration as the other site types (Table 3). In general, IRR sites that performed well were located in the lower Palo Verde Valley. High performing IRR sites in the lower Palo Verde Valley had low elevation differences with the river. Poor performing sites were located in the Upper Palo Verde Valley. IRR sites showed high variability due to the wide range of shapes and geography of each site. Based on site 71, it appears that the remote sensing data was a reasonable approximate for field conditions. The remote sensing data did not perfectly capture the elevation, and instead seemed to represent general trends in elevation change, with the nuances smoothed over. Because the largest deviation between the two was only about 1.5 m, remote sensing data can be used in order to predict site elevation (Figure 7).

Comparing findings to literature

Combining current restoration approaches in the literature with these suitability analysis results may lead to more successful restorations. Each LEV, STB or IRR method could be successful depending on the physical characteristics of the site. In some parts of the river, STB sites were very successful, while in other parts of the river, LEV sites were successful. According to other studies, the most successful restoration methods vary depending on the morphology of each site (Freeman et al. 2003). While I did find that LEV sites generally scored well, this data conflicted with some literature findings. Using small buffer strips of land is a common way restoration technique (Teels et al. 2006). However, this method of restoration is only moderately successful at improving habitat (Parklyn et al. 2003). By restoring other sites types, such as STB with LEV sites adjacent to one another, a restoration can be more successful than the individual scores of each site suggest (Teels et al. 2006). The creation of one long, continuous LEV site that spans a large portion of the river may also increase restoration success (Parklyn et al. 2003).

Model considerations

The effectiveness of the scoring system for restoration sites was influenced by key assumptions I made when creating the suitability analysis models. To make the model, I assumed that cost, political boundaries and distance from water features would be the major variables affecting restoration success. I placed a large emphasis on the elevation variable. However, I think that the other variables balanced out the elevation score. Other factors that I assumed were less important, such as the state the site was located in, could actually be more important. I did not know much about the differences between the two political boundaries, so I only kept the weighting at +/-1, with California receiving a better score and Arizona receiving a worse score. Due to funding, this difference may actually be much more important (Golet et al. 2009).

Factors I did not include in the model will be important as restoration planning moves forward. One ecological factor that that I did not consider is the need for Colorado River ecosystems to flood every 20-40 years to leech salts (Cohn 2001). Without floods occurring, salt builds up and the restoration will not be successful (Cohn 2001). Ecosystem processes will be important to consider as models become more refined (Beechie et al. 2010). Other variables that I did not consider were land ownership, soil type, plant species and endangered species. Land ownership can be very important in a restorations success, resulting from political power that a landowner may have (Golet et al. 2009). Soil type may be important, depending on the plant species used. Plant species, especially endangered species, present a special opportunity for restoration. Although protecting endangered species is aligned with the goals of this project (BLM 2012), endangered species can also migrate onto nearby land, impeding neighboring farms (Golet et al. 2009). In the future, the effects of a restoration on neighboring people or distances to private lands should be another factor in the suitability analysis model (Freemen et al. 2003).

Restoration in the Palo Verde Valley and beyond

Outlook for restoration

Future outlook for restoration in the Palo Verde Valley is mixed due government mandated restorations while ecosystem stress increases (BLM 2012). Stress will increase as a result of higher water demands from growing populations in California, Nevada, Arizona and Mexico, and from climate change (Cohn 2001). Climate change could change the hydrology of the region, resulting in a lower precipitation and higher evaporation (Cohn 2001, Vasey and Holl 2007). Less water would be available for restoration, so future projects will need to emphasize increasing ecosystem resilience to change (Cohn 2001). Although the political climate may improve for restoration, climate change and increasing water demand cast doubt onto the success of future restoration projects. Future projects will need to balance social issues with science (Sondergaard and Jeppesen 2007).

Applicability of conclusions to other river systems

The Colorado River is one of the most modified, channelized and controlled in the world, meaning that some conclusions may not be applicable to less modified river systems. First, due to the highly modified nature of the ecosystem, it is easy to use satellite imagery to distinguish land use and water features (Hu et al. 2013, Potere 2008). Land features in forested ecosystems are much harder to distinguish (Hu et al. 2013). In less modified river systems, a restoration may attempt to restore a river to a previous state (Vasey and Holl 2007). Channelizing a river damages it, making this restoration method unfeasible in the Colorado River (Sondergaard and Jeppesen 2007). Instead, restoration in modified rivers focusses on restoring an ecosystem to be resilient to future changes (Vasey and Holl 2007). Due to the pliability of suitability analysis, it may be possible to create models for these types of restorations as well.

The Colorado River also uniquely serves the needs of many different political parties. Multiple states and Mexico draw water from the river and the river serves as the border between several states (BLM 2012). Due to this complex political nature, politics are more important than in other river systems. However the politics and social aspects of a site may be incorporated into the suitability analysis model, increasing the likelihood of restoration success (Freeman et al. 2003, Golet et al 2009). Models can be modified to include the social needs of each region as well as the effects of restoration on neighboring landowners (Freeman et al. 2003, Golet et al 2009).

Limitations and future directions

The low number of field data sites limits the strength of the analysis between field data and remote sensing data. Taking cross sections is time intensive and I was only able to collect field data for about two sites per site type. As a result of the small number of comparisons, there is not enough data to make a statistically significant conclusion. The main goal of this study was to rapidly assess as many sites as possible in the Palo Verde Valley. Based on the trends we see in the data, it appears remote sensing data can be used to accurately predict if a site can be restored. A future study should gather more field data to draw statistically significant conclusions. A study could compare field and remote sensing data from 8-15 sites of each site type, using modified suitability analysis models. Statistical procedures should emphasize the difference between field and remote sensing data analysis.

Broader implications

Remote sensing is a promising new application to allow the rapid assessment of potential sites for restoration. Suitability analysis can be used as a preliminary assessment tool, allowing more effective and cheaper restoration planning. Time and money are saved from reducing field collection, as unsuitable sites are eliminated and data can be analyzed remotely. The flexibility of suitability analysis also allows for the model to be customized for the individual aspects of each project (Malczewski 2004). For example, in the Colorado River, my models were manipulated to incorporate politics and cost. In other sites, a model may incorporate the effects of restoration on the community (Golet 2009). In the future, new knowledge of larger scale ecosystem and physical processes can make the models even better. (Sondergaard and Jeppesen 2007, Beechie et al. 2010). Like most technology, remote sensing data will improve in quality over time, improving the output of the models (Zomer et al. 2007). This improvement will increase the effectiveness and reduce the cost of remote sensing, bringing restoration planning into the budget of more communities.

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APPENDIX A: Raw Data

Table A1. A table of raw data from suitability analysis.

Site ID	Area	Min	Max	Range	Mean	STD	Sum	Site Type	Mean Elevation (m)
1	5593275	-7	10	17	-1.00	2.14	-24849	IRR	-0.14
2	1275525	-2	0	2	-0.33	0.74	-1872	LEV	0.00
3	245475	-3	0	3	-1.27	0.74	-1391	LEV	-0.97
4	489600	-3	2	5	-0.30	0.92	-656	LEV	0.17
5	119250	-2	2	4	0.87	1.12	461	LEV	1.32
6	242325	-6	2	8	0.48	1.18	516	LEV	3.08
7	184950	-1	3	4	1.89	1.13	1556	LEV	2.35
8	4245525	-2	6	8	1.76	2.65	33163	IRR	1.40
9	2658150	-10	7	17	0.64	5.10	7609	IRR	2.78
10	5166000	-2	37	39	3.64	1.71	83564	STB	3.76
11	954000	-6	4	10	-1.87	1.97	-7915	IRR	1.39
12	6001200	-4	20	24	4.08	2.24	108931	IRR	4.40
13	51573600	-6	31	37	0.87	1.62	199661	IRR	0.96
14	935550	-5	0	5	-1.00	0.96	-4146	LEV	-0.56
15	355275	-2	3	5	1.10	1.60	1740	LEV	1.76
16	111825	-3	0	3	-0.86	0.87	-427	LEV	-0.26
17	106650	-2	0	2	-0.64	0.93	-304	LEV	0.00
18	139950	-1	2	3	1.18	1.07	735	LEV	1.94
19	225225	-3	0	3	-0.66	0.98	-658	LEV	1.97
20	471825	-3	1	4	-0.27	1.19	-568	LEV	0.44
21	334125	-3	0	3	-0.99	1.00	-1463	LEV	-0.42
22	120150	-6	1	7	-2.33	2.29	-1245	LEV	1.74
23	156375	-4	4	8	1.50	2.12	1040	LEV	2.69
24	227925	-2	3	5	2.20	1.26	2233	LEV	2.87
25	54225	-4	0	4	-1.32	1.19	-317	LEV	1.83
26	505800	-4	2	6	-0.15	1.32	-344	LEV	2.48
27	1062900	-2	1	3	-0.40	0.83	-1899	LEV	0.02
28	475200	-2	1	3	-0.40	0.85	-839	LEV	0.03
29	234225	-3	0	3	-0.72	0.94	-754	LEV	-0.09
30	251550	-2	8	10	-0.21	1.00	-235	STB	0.10
31	735975	-4	2	6	-0.29	1.14	-951	LEV	2.44
32	308925	-4	4	8	1.47	1.89	2016	LEV	2.18
33	342225	-2	4	6	2.26	1.76	3435	LEV	2.87
34	46800	-2	1	3	0.06	0.80	13	LEV	2.49
35	842400	-2	3	5	1.38	1.72	5151	LEV	2.04
36	506475	-2	5	7	-0.38	1.37	-848	LEV	0.28
37	673200	-6	17	23	-0.43	3.83	-1299	IRR	2.34

38	576900	-4	7	11	4.44	2.94	11381	STB	4.97
39	101925	-7	0	7	-4.78	2.06	-2164	STB	-3.51
40	2735550	-2	7	9	4.29	1.84	52198	IRR	4.52
41	938700	-4	3	7	-0.44	1.75	-1838	STB	1.89
42	530325	-4	0	4	-2.68	0.97	-6317	STB	0.06
43	406575	-6	0	6	-1.07	1.39	-1935	STB	-0.20
44	1465650	-5	6	11	1.21	3.26	7893	IRR	2.30
45	309600	-5	16	21	0.39	3.52	530	STB	3.33
46	6275925	-5	20	25	2.41	2.14	67273	STB	4.53
47	2413125	-5	1	6	-1.84	1.72	-19712	STB	0.72
48	1355175	-2	4	6	3.64	1.04	21944	LEV	3.88
49	943425	-2	4	6	3.68	0.89	15444	LEV	3.93
50	192600	-2	3	5	-0.13	1.45	-110	STB	0.62
51	121500	-4	1	5	-2.85	1.28	-1538	STB	0.29
52	281250	-4	2	6	-0.70	2.08	-872	STB	1.98
53	122625	-4	2	6	-2.51	1.59	-1369	STB	0.55
54	3908925	-6	7	13	2.44	3.10	42408	STB	3.13
55	2009925	-4	5	9	-0.48	1.71	-4269	IRR	0.94
56	5939775	-2	8	10	4.22	2.46	111340	STB	2.67
57	499725	1	4	3	3.75	0.67	8321	IRR	4.00
58	798300	-1	4	5	3.62	0.96	12855	LEV	3.91
59	168075	-8	-3	5	-6.80	1.24	-5081	STB	-3.81
60	140850	-2	3	5	-0.56	1.55	-352	STB	0.38
61	55575	-2	5	7	0.00	2.22	0	STB	1.01
62	88650	-2	5	7	0.65	1.90	255	STB	1.07
63	4576725	-4	8	12	2.52	2.93	51198	IRR	3.59
64	19029375	-6	13	19	4.22	1.93	356625	STB	6.27
65	2114550	-4	9	13	2.61	1.53	24533	STB	4.69
66	1516275	-2	8	10	5.47	2.07	36851	STB	5.78
67	970875	-2	9	11	6.07	2.75	26178	IRR	6.75
68	66600	-1	6	7	3.81	1.98	1129	STB	4.48
69	1257975	-4	19	23	5.18	3.02	28936	IRR	5.09
70	1931850	-4	7	11	1.94	3.02	16643	IRR	2.85
71	1677825	4	8	4	6.85	0.79	51061	IRR	6.98
72	2871450	0	6	6	4.62	0.74	58920	STB	4.63
73	1270800	-6	24	30	6.77	6.69	38235	STB	9.28
74	497700	-2	12	14	5.66	2.15	12510	STB	5.89
75	545175	-5	4	9	2.36	2.25	5727	LEV	4.97
76	215325	-4	7	11	-0.31	2.53	-301	STB	2.72
77	4856850	-3	6	9	2.59	1.32	55926	STB	2.76
78	12230550	-4	27	31	1.86	1.89	101366	STB	3.92
79	1044225	-5	6	11	0.58	2.02	2671	STB	2.88
80	873225	-3	6	9	3.29	1.59	12787	STB	3.47

81	4854150	-3	6	9	3.58	1.25	77315	IRR	3.76
82	9020250	-3	7	10	4.29	1.66	172034	IRR	4.56
83	3650625	-6	8	14	1.47	1.77	23821	IRR	3.45
84	8641575	-2	6	8	2.76	1.02	106122	IRR	2.99
85	3618225	-7	2	9	-0.72	1.29	-11540	IRR	-0.45
86	3323250	-4	3	7	-0.26	1.48	-3869	STB	1.88
87	708750	-7	4	11	2.26	2.72	7131	IRR	2.81
88	699300	-7	18	25	3.06	4.24	9516	STB	5.55
89	497475	-3	14	17	6.33	3.15	13985	STB	8.66
90	254250	-10	1	11	-1.52	1.89	-1716	IRR	-0.92
91	18244350	-2	7	9	3.73	1.19	302579	STB	3.77
92	115425	4	7	3	6.10	0.86	3131	STB	6.66
93	192150	4	8	4	6.56	0.94	5604	IRR	7.07
94	309375	4	7	3	5.96	0.98	8197	IRR	6.45
95	180000	-3	2	5	-0.13	1.50	-103	STB	2.43
96	294525	-6	3	9	-0.28	2.41	-364	STB	2.51
97	554850	-4	3	7	0.57	1.70	1400	IRR	3.17
98	2184300	-6	3	9	-1.72	2.36	-16696	IRR	0.72
99	1098450	-2	40	42	3.43	6.13	16759	STB	3.75
100	1983375	-5	8	13	4.28	2.25	37727	IRR	3.24
101	486900	0	7	7	5.13	1.72	11095	IRR	4.14
102	175500	-2	4	6	1.52	1.88	1185	LEV	2.36
103	360675	-4	3	7	-0.29	1.82	-469	LEV	2.60
104	760725	-2	1	3	0.61	0.80	2059	IRR	2.97
105	24379425	-2	14	16	1.95	2.03	211765	IRR	1.45
106	8797500	-4	6	10	2.07	1.18	80999	STB	2.14