ANALYSIS OF THE URBAN HEAT ISLAND EFFECT

Santa Clara County, California

Abstract

An analysis of land surface temperature by landcover class for Santa Clara County derived from Landsat 8 imagery and a supervised image classification. Presents results in maps, charts, and tables. Draws conclusions, identifies limitation of this study, and suggests areas for further study.

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Contents

1 Hypothesis

The hypothesis is that urban areas experience higher surface temperatures than non-urban areas. This is referred to as the urban heat island effect.

2 Analysis Method

The main steps in the analysis were to obtain the Landsat 8 imagery for the study area, process the imagery to generate a land surface temperature raster, perform a supervised land cover classification of the imagery, and generate zonal statistics and a histogram to show the land surface temperature distribution for each land cover class. The steps of the analysis are listed in more detail below.

2.1 Obtain Landsat Imagery for Study Area

Obtain Landsat 8 imagery covering the study area from the USGS EarthExplorer website. The study area includes Santa Clara County, California.

- Select the scene LC08_L2SP_044034_20210828_20 from August 28, 2021, for this study.
- Download all bands.
- Load all bands into a composite raster.

The model builder diagram below illustrates this process. The toolbox file ***uhi_tools_10_3.tbx*** contains this model, named ***load_landsat_data.***

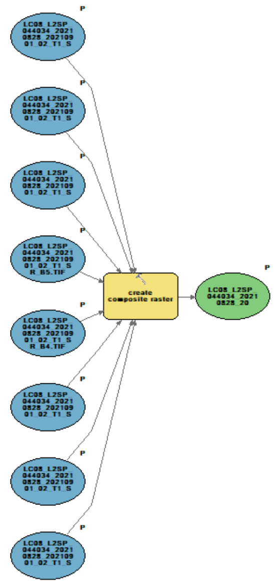


Figure 1 - Create a composite raster.

2.2 Create Land Surface Temperature Raster

Process bands 4, 5, and 10 of the composite raster created above to estimate the land surface temperature for each pixel in the study area. (For a fuller explanation of the algorithm see: https://www.gislounge.com/how-to-use-arcgis-pro-to-map-urban-heat-islands/). The model builder diagram below shows the process to calculate the land surface temperature. The toolbox file ***uhi_tools_10_3.tbx*** contains this model, named ***calculate_uhi.***

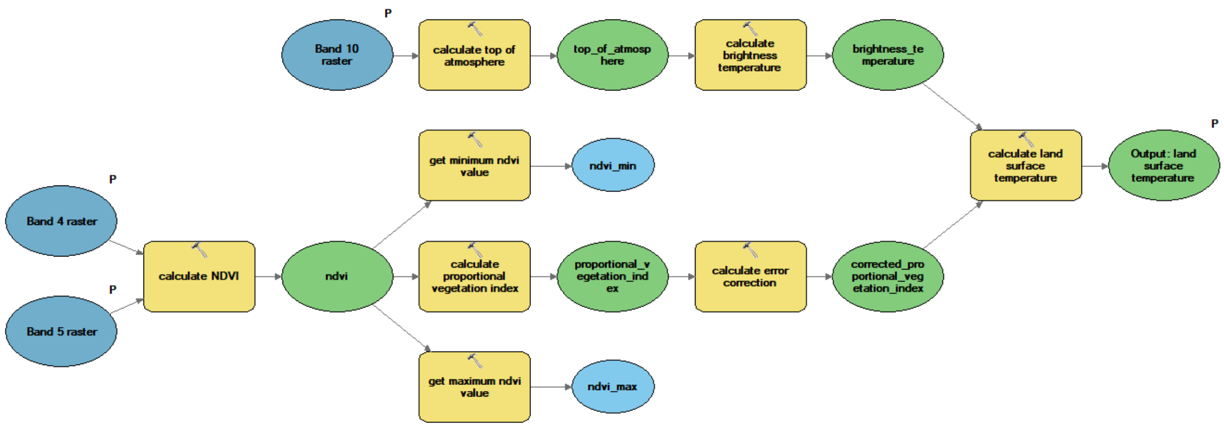


Figure 2 - Model to calculate land surface temperature.

The steps followed were as follows:

1) Generate an ***nvdi*** raster using the rater calculator expression:

```
Float( "%Band 5 raster%" - "%Band 4 raster%") / Float( "%Band 5 raster%" + "%Band 4 raster%")
```

2) Extract minimum and maximum pixel values from the ***ndvi*** raster.

3) Generate a ***proportional_vegetation_index*** raster from the ***nvdi*** raster using the raster calculator expression:

```
Square(Float("%ndvi%" - "%ndvi%".minimum) / Float("%ndvi%".maximum - "%ndvi%".minimum))
```

4) Generate a ***corrected_proportional_vegetation_index*** raster from the ***proportional_vegetation_index*** raster using the raster calculator expression:

```
(4E-3 * "%proportional_vegetation_index%") + 9.86E-1
```

5) Calculate a ***top_of_atmosphere*** raster from band 10 using the raster calculator expression:

```
(3.342E-4 * "%Band 10 raster%") + 1E-1
```

6) Generate a ***brightness_temperature*** raster from the ***top_of_atmosphere*** raster using the raster calculator expression:

```
(1.3210789E3 / Ln((7.748853E2 / "%top_of_atmosphere%") + 1.0)) - 273.15
```

7) Calculate the final *land_surface_temperature* raster from the ***brightness_temperature*** and ***corrected_proportional_vegetation_index*** rasters using the raster calculator expression:

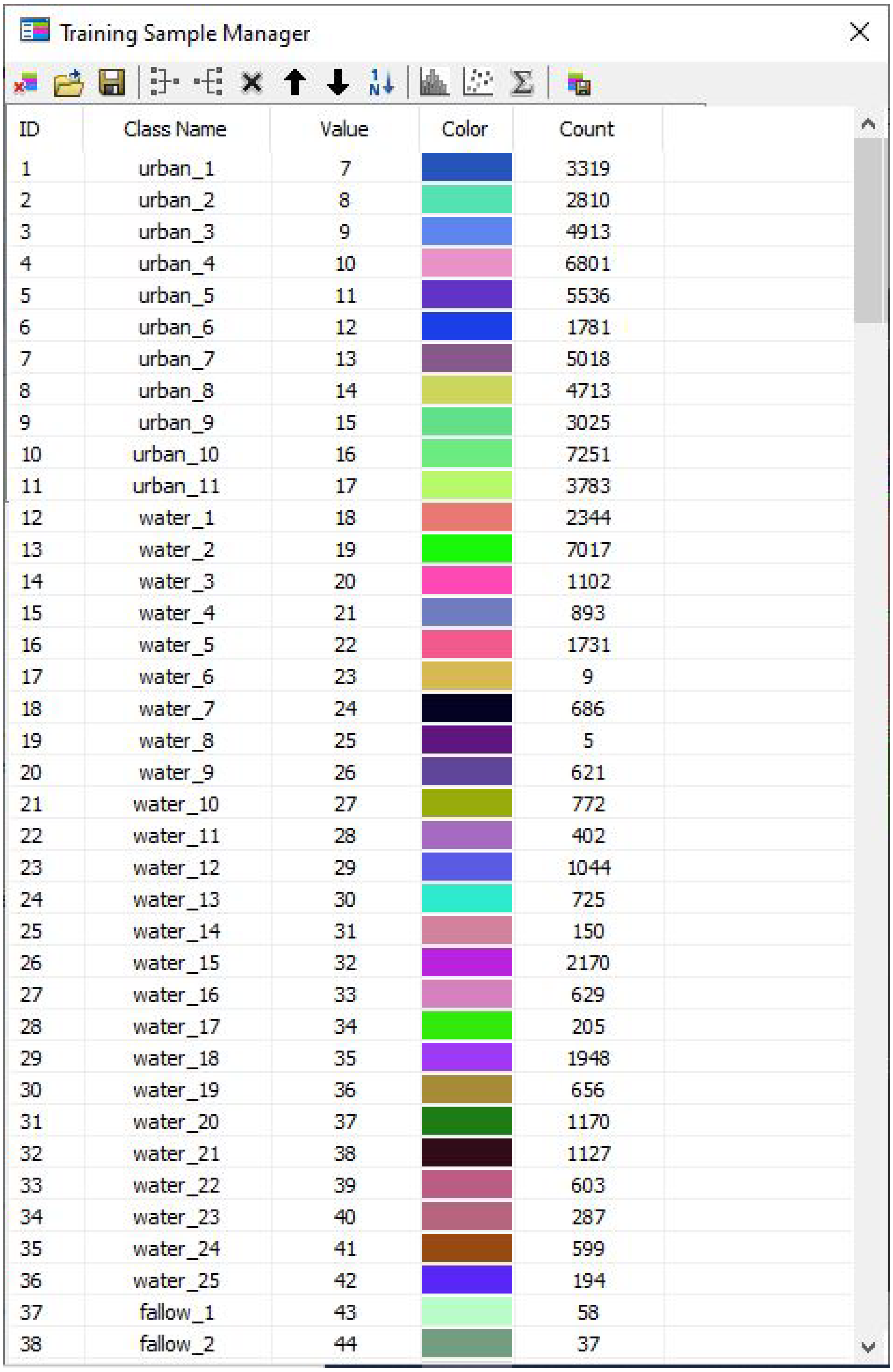
```
"%brightness_temperature%" / (1.0 + (1.15E-3 * "%brightness_temperature%" / 1.4388) *
Ln("%corrected_proportional_vegetation_index%"))
```

8) Save the ***land_surface_temperature*** raster in the project geodatabase.
9) Manually extract a raster for the study areas using the Santa Clara County border feature class as the mask.
10) Manually set the symbology to display layer including equal interval classification and color ramp.

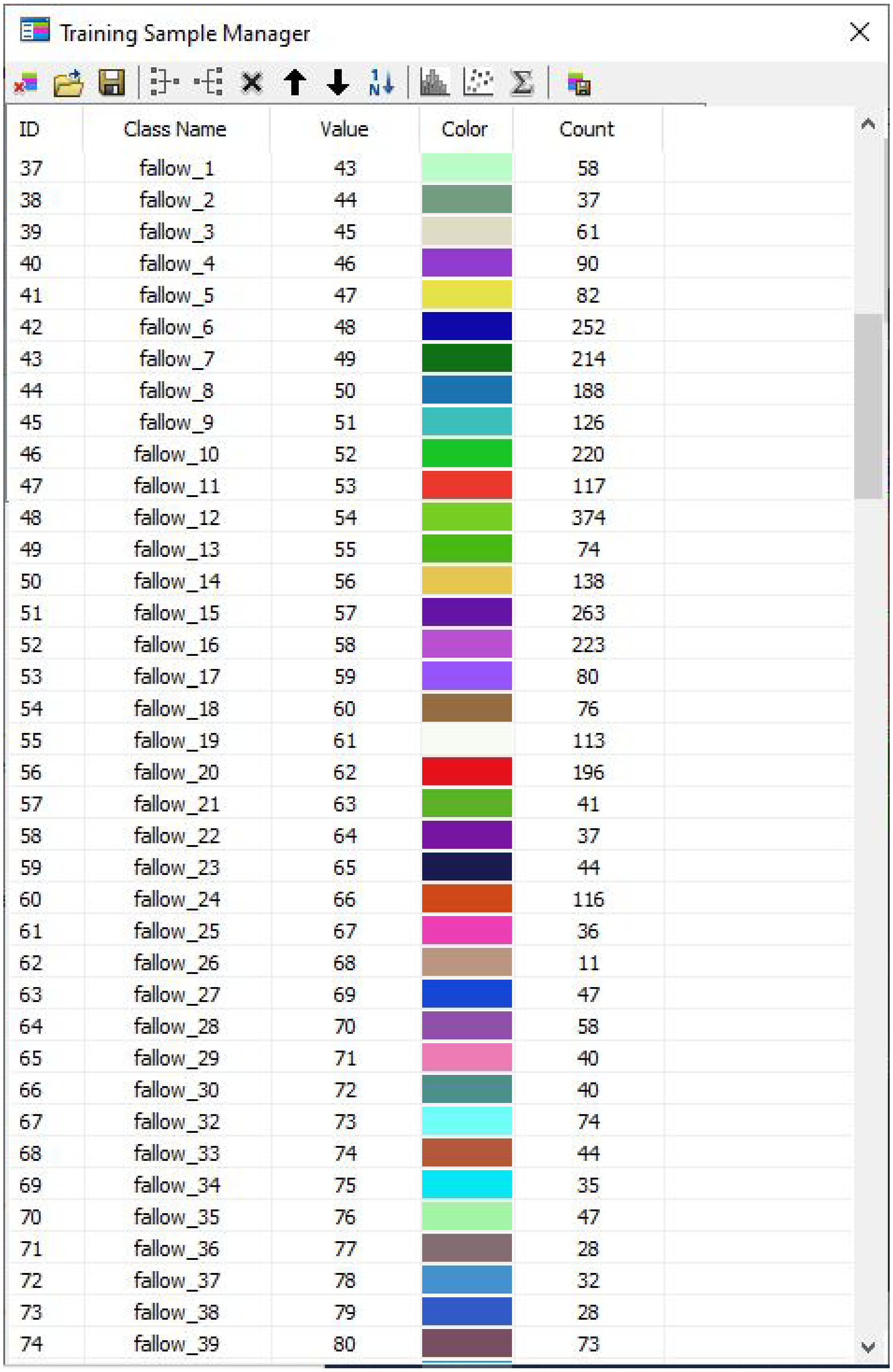
2.3 Perform Supervised Landcover Classification

The process assigns a landcover class to each pixel in the study area. The steps in the process were:

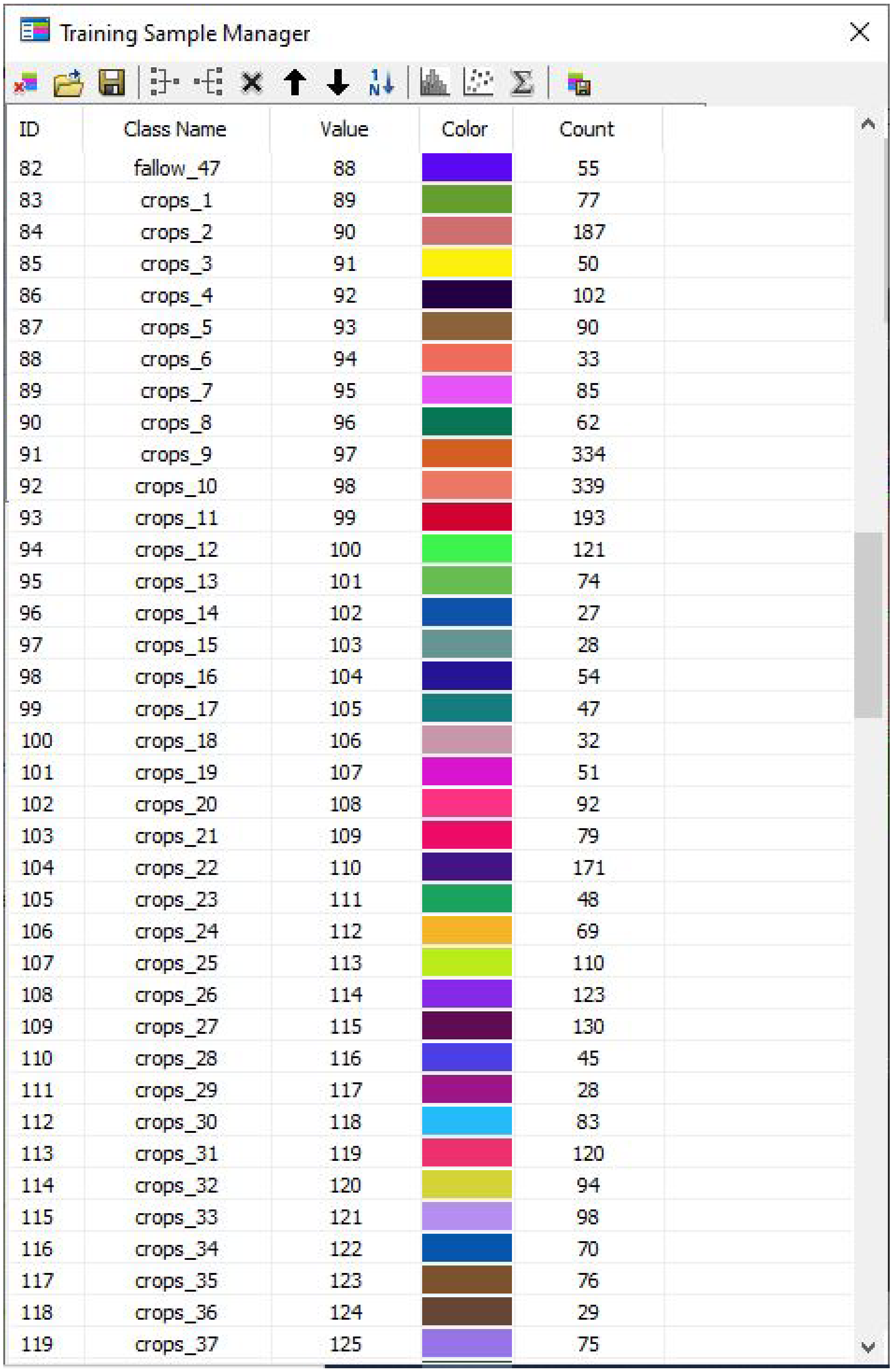
1) Manually create training samples using the training sample manager. Visually create samples for the following six landcover classes: water, forest, agriculture, urban, fallow land, and bare earth.
2) Merge individual training samples into six classes.
3) Save training samples as a feature class in the project geodatabase.
4) Unmerge the training samples and create the screenshot of the training sample manager. Capture screenshots and then merge the samples as before. The screenshots below show the unmerged training samples.



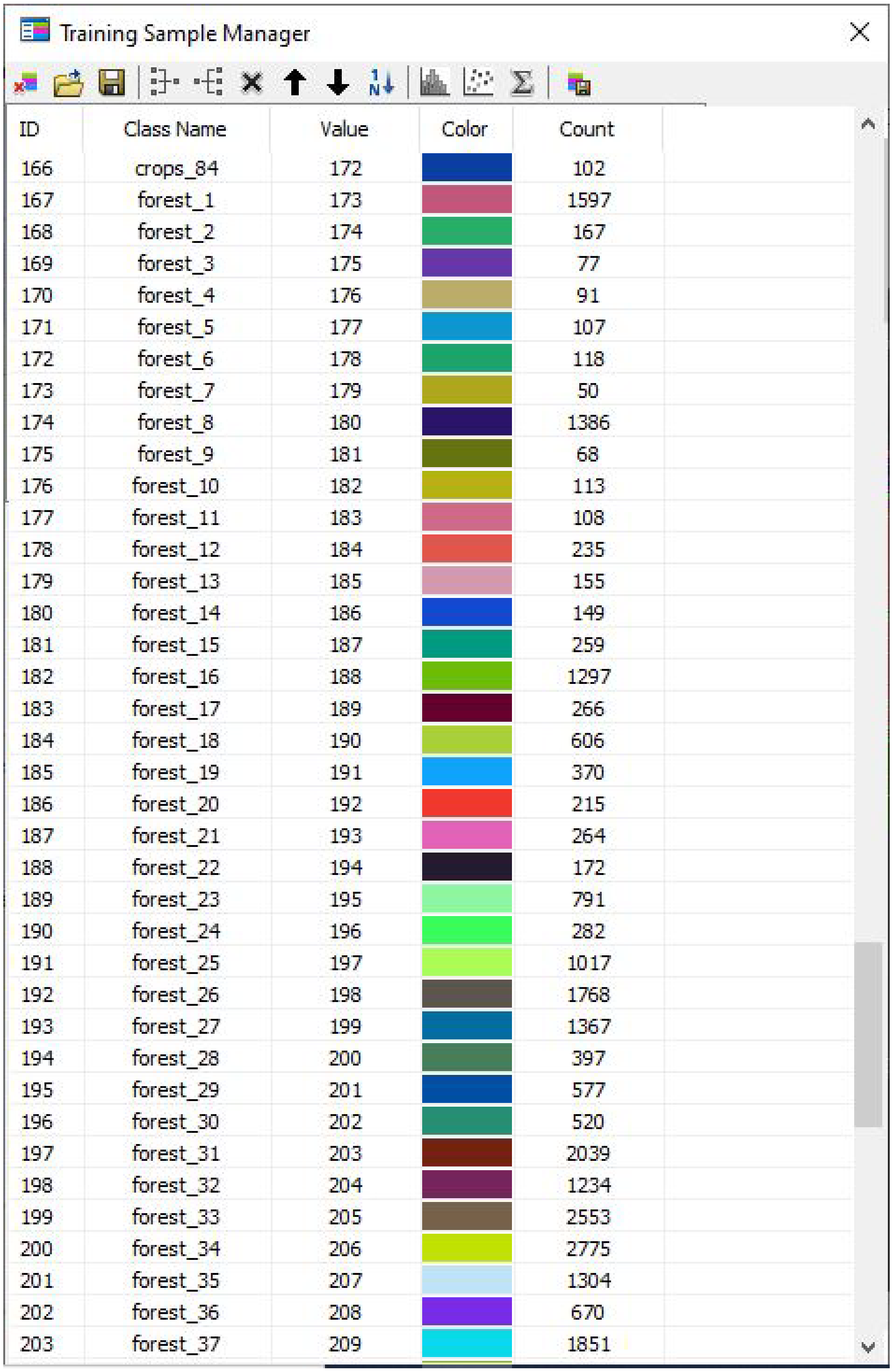
ID	Class Name	Value	Color	Count
1	urban_1	7		3319
2	urban_2	8		2810
3	urban_3	9		4913
4	urban_4	10		6801
5	urban_5	11		5536
6	urban_6	12		1781
7	urban_7	13		5018
8	urban_8	14		4713
9	urban_9	15		3025
10	urban_10	16		7251
11	urban_11	17		3783
12	water_1	18		2344
13	water_2	19		7017
14	water_3	20		1102
15	water_4	21		893
16	water_5	22		1731
17	water_6	23		9
18	water_7	24		686
19	water_8	25		5
20	water_9	26		621
21	water_10	27		772
22	water_11	28		402
23	water_12	29		1044
24	water_13	30		725
25	water_14	31		150
26	water_15	32		2170
27	water_16	33		629
28	water_17	34		205
29	water_18	35		1948
30	water_19	36		656
31	water_20	37		1170
32	water_21	38		1127
33	water_22	39		603
34	water_23	40		287
35	water_24	41		599
36	water_25	42		194
37	fallow_1	43		58
38	fallow_2	44		37



ID	Class Name	Value	Color	Count
37	fallow_1	43		58
38	fallow_2	44		37
39	fallow_3	45		61
40	fallow_4	46		90
41	fallow_5	47		82
42	fallow_6	48		252
43	fallow_7	49		214
44	fallow_8	50		188
45	fallow_9	51		126
46	fallow_10	52		220
47	fallow_11	53		117
48	fallow_12	54		374
49	fallow_13	55		74
50	fallow_14	56		138
51	fallow_15	57		263
52	fallow_16	58		223
53	fallow_17	59		80
54	fallow_18	60		76
55	fallow_19	61		113
56	fallow_20	62		196
57	fallow_21	63		41
58	fallow_22	64		37
59	fallow_23	65		44
60	fallow_24	66		116
61	fallow_25	67		36
62	fallow_26	68		11
63	fallow_27	69		47
64	fallow_28	70		58
65	fallow_29	71		40
66	fallow_30	72		40
67	fallow_32	73		74
68	fallow_33	74		44
69	fallow_34	75		35
70	fallow_35	76		47
71	fallow_36	77		28
72	fallow_37	78		32
73	fallow_38	79		28
74	fallow_39	80		73

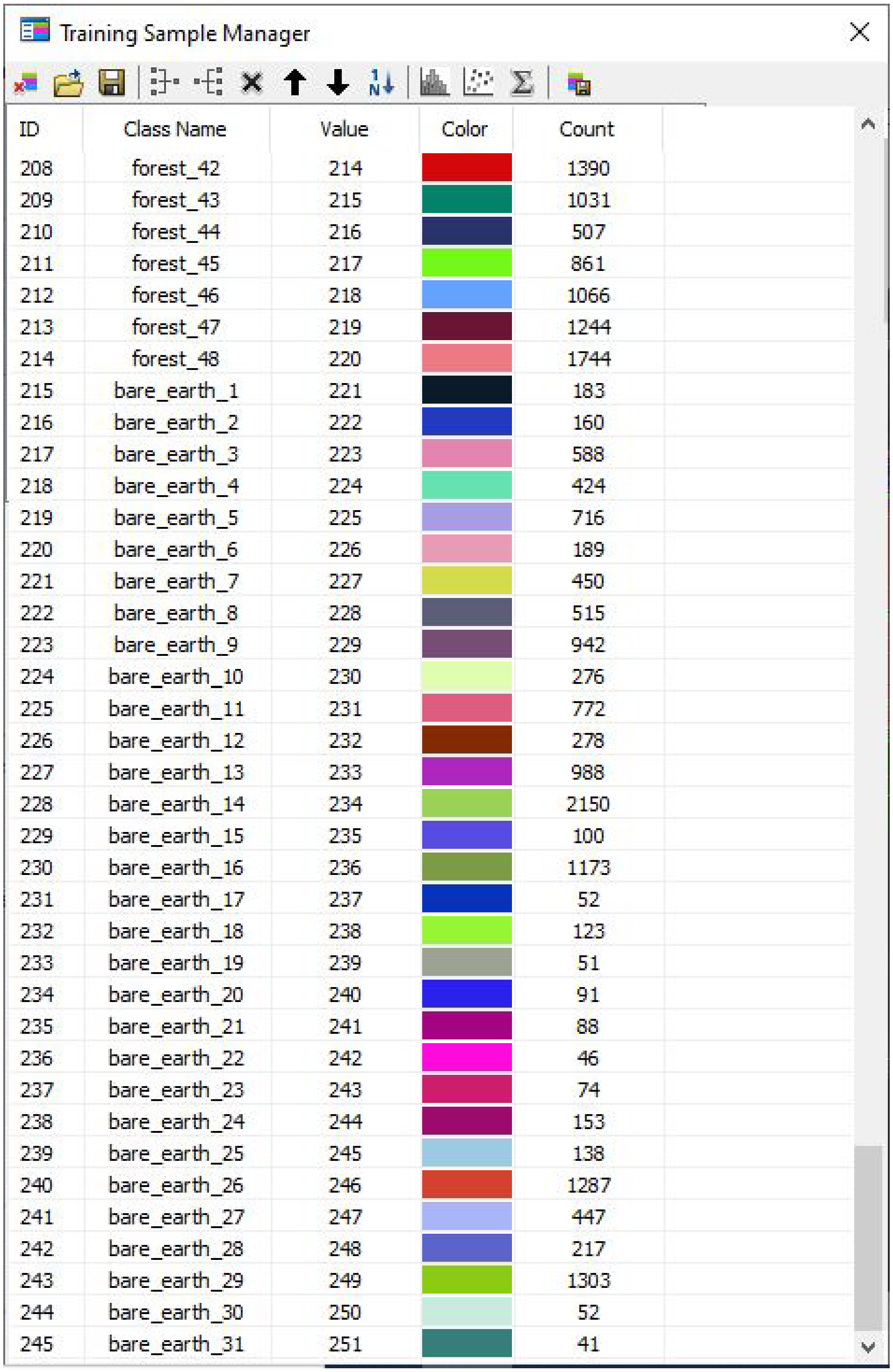


ID	Class Name	Value	Color	Count
82	fallow_47	88		55
83	crops_1	89		77
84	crops_2	90		187
85	crops_3	91		50
86	crops_4	92		102
87	crops_5	93		90
88	crops_6	94		33
89	crops_7	95		85
90	crops_8	96		62
91	crops_9	97		334
92	crops_10	98		339
93	crops_11	99		193
94	crops_12	100		121
95	crops_13	101		74
96	crops_14	102		27
97	crops_15	103		28
98	crops_16	104		54
99	crops_17	105		47
100	crops_18	106		32
101	crops_19	107		51
102	crops_20	108		92
103	crops_21	109		79
104	crops_22	110		171
105	crops_23	111		48
106	crops_24	112		69
107	crops_25	113		110
108	crops_26	114		123
109	crops_27	115		130
110	crops_28	116		45
111	crops_29	117		28
112	crops_30	118		83
113	crops_31	119		120
114	crops_32	120		94
115	crops_33	121		98
116	crops_34	122		70
117	crops_35	123		76
118	crops_36	124		29
119	crops_37	125		75



Training Sample Manager

ID	Class Name	Value	Color	Count
166	crops_84	172		102
167	forest_1	173		1597
168	forest_2	174		167
169	forest_3	175		77
170	forest_4	176		91
171	forest_5	177		107
172	forest_6	178		118
173	forest_7	179		50
174	forest_8	180		1386
175	forest_9	181		68
176	forest_10	182		113
177	forest_11	183		108
178	forest_12	184		235
179	forest_13	185		155
180	forest_14	186		149
181	forest_15	187		259
182	forest_16	188		1297
183	forest_17	189		266
184	forest_18	190		606
185	forest_19	191		370
186	forest_20	192		215
187	forest_21	193		264
188	forest_22	194		172
189	forest_23	195		791
190	forest_24	196		282
191	forest_25	197		1017
192	forest_26	198		1768
193	forest_27	199		1367
194	forest_28	200		397
195	forest_29	201		577
196	forest_30	202		520
197	forest_31	203		2039
198	forest_32	204		1234
199	forest_33	205		2553
200	forest_34	206		2775
201	forest_35	207		1304
202	forest_36	208		670
203	forest_37	209		1851



ID	Class Name	Value	Color	Count
208	forest_42	214		1390
209	forest_43	215		1031
210	forest_44	216		507
211	forest_45	217		861
212	forest_46	218		1066
213	forest_47	219		1244
214	forest_48	220		1744
215	bare_earth_1	221		183
216	bare_earth_2	222		160
217	bare_earth_3	223		588
218	bare_earth_4	224		424
219	bare_earth_5	225		716
220	bare_earth_6	226		189
221	bare_earth_7	227		450
222	bare_earth_8	228		515
223	bare_earth_9	229		942
224	bare_earth_10	230		276
225	bare_earth_11	231		772
226	bare_earth_12	232		278
227	bare_earth_13	233		988
228	bare_earth_14	234		2150
229	bare_earth_15	235		100
230	bare_earth_16	236		1173
231	bare_earth_17	237		52
232	bare_earth_18	238		123
233	bare_earth_19	239		51
234	bare_earth_20	240		91
235	bare_earth_21	241		88
236	bare_earth_22	242		46
237	bare_earth_23	243		74
238	bare_earth_24	244		153
239	bare_earth_25	245		138
240	bare_earth_26	246		1287
241	bare_earth_27	247		447
242	bare_earth_28	248		217
243	bare_earth_29	249		1303
244	bare_earth_30	250		52
245	bare_earth_31	251		41

Figure 3 - Unmerged training samples.

5) Compare the class histograms to ensure adequate separation between the classes

6) Run a supervised classification using the training samples defined above f using the "Maximum Likelihood Classification" option.
7) Manually adjust the training classes and repeat the classification until happy with results (very time consuming and frustrating!).
8) Save the classification results as a raster in the geodatabase.

2.4 Create Zonal Statistics

Run the Zonal Statistics as Table geoprocessing tool on the land surface temperature raster using the landcover classes from the supervised classification as the zones.

2.5 Create Zonal Histogram

Create a single chart to compare the distribution of land surface temperature across the six landcover classes identified above. (Note, I first attempted this step with the Zonal Histogram geoprocessing tool. However, the results were inflexible and poorly designed. My goal was to overlay the land surface temperature histograms for each landcover class in a single chart to enable easy comparison of the temperature distribution between landcover classes. However, the Zonal Histogram geoprocessing tool has some severe limitations. This main challenge is that this tool can only create charts with side-by-side bars for each class; this presentation is hard to interpret. This limitation impairs the ability to make the desired comparison of land surface temperature distribution between landcover classes.)

The process to create the desired chart is complex as illustrated by the model builder diagram below. The toolbox file ***uhi_tools_10_3.tbx*** contains this model, named ***landcover_analysis.***

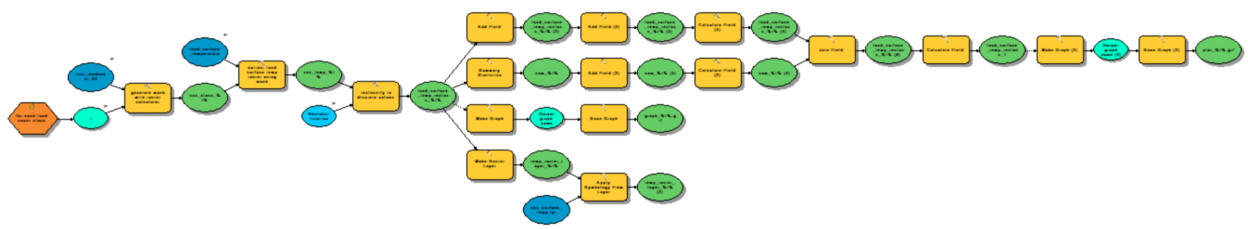


Figure 4 - Process to create zonal histogram.

The steps to create the zonal histogram are to iterate through the six landcover classes and do the following:

1) Crete a mask for the landcover class using the raster calculator expression:

```
SetNull(Con(Raster("%scc_landcover_03%") == float(%i%), 0, 1), 1)
```

2) Extract a land surface temperature raster for each landcover class using the Extract by Mask geoprocessing tool.
3) Reclassify the class specific surface temperature raster into discrete classes using the Reclassify geoprocessing tool. These discrete classes will become the bins in the final histogram.
4) Create a layer from each class specific temperature raster and apply standard symbology. The standard symbology uses an equal interval classification with 26 classes to create bin

that are separated by one degree Fahrenheit. Save the layer as a raster dataset in the project geodatabase.

5) Make and save a landcover class specific temperature histogram. (Note: the final presentation does not use these histograms because the temperature bins on the X-axis do not align due to the differing temperature ranges between the various landcover classes.)
6) Calculate the relative frequency for each temperature bin for each landcover class specific raster. This is necessary because the area covered by is class is different and we want to normalize all the histograms to a common scale so that they can be overlayed on a single chart. The attribute table for each class specific temperature raster provides a count field for each raster grouped by the raster value (temperature). Use the "Summary Statistics" geoprocessing tool to create a total of these individual count values. This tool returns results as a table. So, joint the summary results to the original attribute table to make the values available to the Calculate Field tool in the next step. (The details of this join require the addition of a new ***dummy_join*** field in both tables participating in the join. Populate this field with constant value 1. This is necessary because the Join geoprocessing tool does not permit a cartesian join). Add a new field, named ***rel_freq***, to the attribute table to hold the relative frequency. Fill values of ***rel_freq*** using the Calculate Field geoprocessing tool. Calculate the relative frequency by dividing the individual counts by the total.
7) Make and save the landcover class specific histogram.
8) Manually create a chart that overlays the temperature histograms for the six individual landcover classes. Present the results as a vertical line chart to enable easier visual comparison between the individual landcover classes. Set the colors of the lines for each

land cover class to match the colors for the corresponding classes shown on the landcover map.

3 Results

The maps and chart below illustrate the results of the analysis.

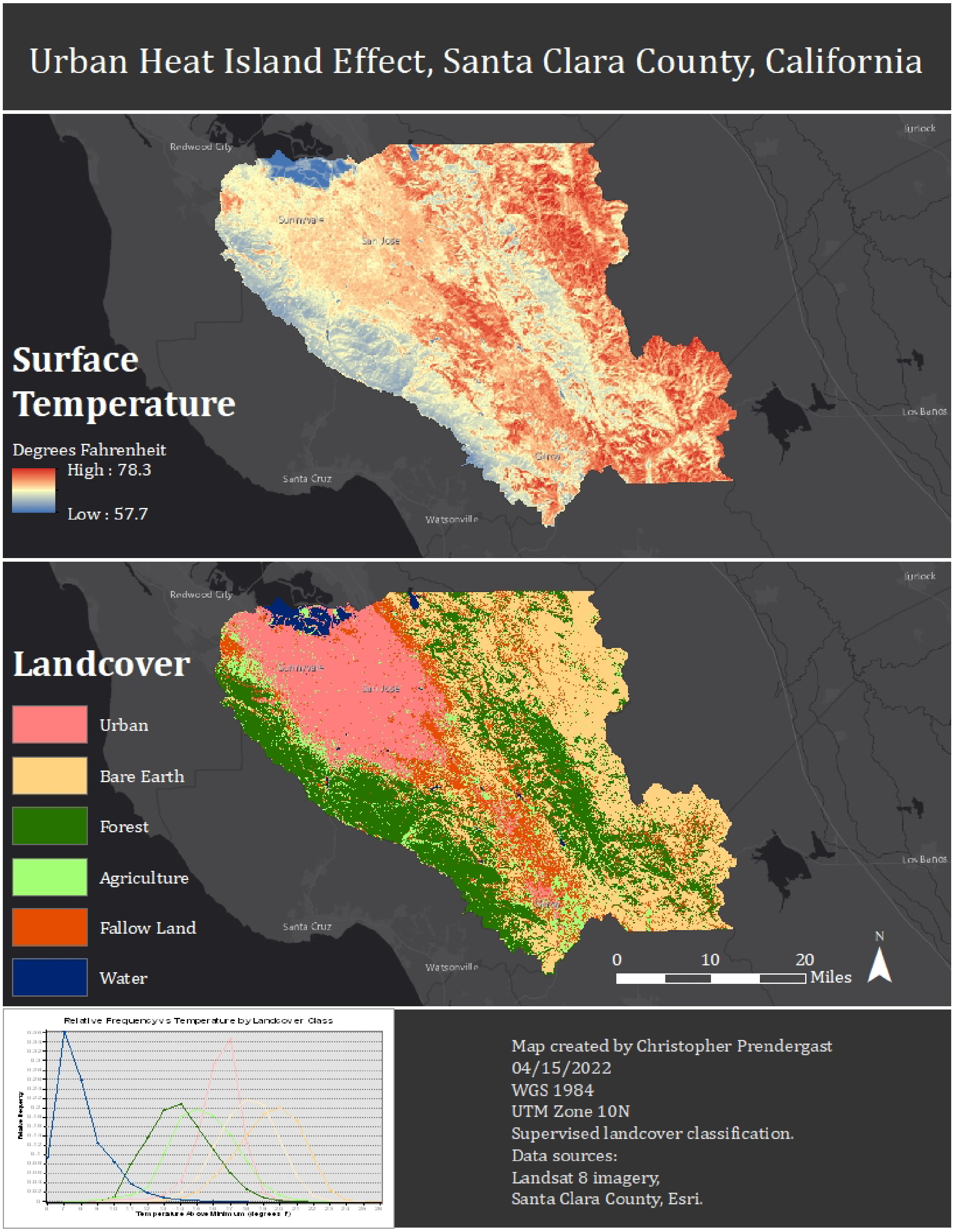


Figure 5 - Results of analysis.

3.1 Zonal Statistics

The table below shows the zonal statistics for land surface temperature broken out for individual landcover classes within Santa Clara County.

Landcover Class	Min Temp	Max Temp	Mean Temp	Temp Range	Std. Deviation
Urban	59.04	75.45	68.61	16.40	1.46
Bare Earth	60.73	78.33	71.80	17.60	2.00
Forest	60.43	74.62	66.16	14.19	1.95
Agriculture	59.03	75.80	67.64	16.77	2.05
Fallow Land	61.21	77.49	70.41	16.28	1.81
Water	57.74	70.13	59.97	12.39	1.55

Figure 6 - Zonal Statistics for Santa Clara County. Temperatures are in degrees Fahrenheit.

4 Conclusions

The results from the analysis supports the following conclusions:

- The mean temperature of water is lower than that of all other landcover classes. In addition, the breath of the range of temperature variation for water is significantly lower than for all other landcover classes.
- The breaths of the temperature ranges spanned by the agriculture, urban, and fallow land landcover classes are similar.
- The mean surface temperature in urban areas is higher than in areas covers by water, forest, or agriculture.
- The mean surface temperature for areas covered by fallow land and bare earth is higher than urban areas. The mean temperature of bare earth was higher than all other landcover

classes. The breath of the temperature range spanned by the bare earth landcover class is greater than that of all other classes.

In summary,

- Areas covered by water, forest and agriculture stay cooler than urban areas. Water has the smallest range of variation in temperature.
- Areas covered by fallow land and bare earth get hotter than urban areas. Bare earth has the highest range of variation in temperature.

These conclusions support the hypothesis that urban areas experience higher surface temperatures than non-urban areas except for areas covered by fallow land and bare earth.

5 Limitations

This study and analysis have the following limitations:

- This analysis covers a single day in August 2021 which may not be representative.
- The study uses only six landcover classes.
- Confusion exists between the landcover classes generated by the supervised classification.

6 Further Study

Future projects could expand and improve the accuracy and predictive capability of the results by:

- Refining the training samples to reduce confusion between landcover classes and improve the results of the supervised classification process.
- Expanding the number of landcover classes.

- Evaluating other classification methods including unsupervised classification.
- Using the landcover classes provided by the USGS National Landcover Database (NLCD).
- Conducting this analysis for a larger sample of days which span different seasons and different years to aggregating the results and assess their variation.
- Studying the impact of aspect and elevation on land surface temperatures.
- Expanding the study area to cover a larger area.