

# **Dark Sky Impact Analysis**

## *of the IDA/IES Model Lighting Ordinance (MLO)*

### *second public review draft, June 2010*

Christian B. Luginbuhl  
U.S. Naval Observatory Flagstaff Station  
cbl@nofs.navy.mil  
8 January 2011

## **Summary**

*The June 2010 draft of the IDA/IES Model Lighting Ordinance (MLO) is examined to gauge its impact on dark skies. Total lighting amounts permitted by both the prescriptive and performance methods for all Lighting Zones are calculated for 15 actual commercial site plans. Off-site impacts, as prescribed under Option B of the MLO performance method, as well as uplight amounts, are also evaluated.*

*Total lighting amounts allowed by the MLO in Lighting Zone 2 (generally described as the minimum Lighting Zone for commercial/business districts) range from an average of about 120 kilolumens per acre (klm/ac) using the hardscape area method to 400 klm/ac using the performance method. In LZ3 these values increase to 250 klm/ac and 780 klm/ac, and in LZ4 to 400 and 1100 klm/ac, respectively. Though for some land uses the MLO allowances in LZ2 are less than unregulated lighting practice, for most land uses in LZ2 and for all land uses in higher lighting zones they exceed unregulated practice. Compared to effective and long-standing 100 klm/ac lighting codes, MLO allowances are much larger: 2x – 9x in LZ2; 2x – 15x in LZ3; 4x – 26x in LZ4.*

*These full lumen allowances can be used without reduction, even those derived using the performance method, provided only that BUG luminaire standards are followed. The “off-site” impact limits under option B of the performance method are not found to reduce these total lumen amounts, or produce lighting design restrictions or pressures with unexpected and potentially undesirable effects.*

*With such large light outputs, even aggressive shielding standards do not effectively control sky glow since both direct and reflected uplight are proportional to total light output. The apparently tight fractional uplight restrictions provided by the BUG standards, when combined with the possibility of large numbers of fixtures and with the large lumen allowances of MLO, lead to potentially dramatic increases in the amount of uplight when compared both to unregulated practice and to lighting under effective codes already in existence.*

## 1. Introduction

The Joint IDA/IES Model Lighting Ordinance, Second Public Review Draft, is a lighting ordinance under development since 2002. As of this writing, it is undergoing final revision following public comment. It is described as a practical lighting code for adoption throughout the U.S., and has (presuming votes of support by the respective Boards of Directors) the support of both IDA and the lighting industry represented by IESNA.

The Task Force responsible for recent drafts of this MLO followed some of the general lighting standards and legal approaches contained within numerous lighting codes developed in the previous 40 years. Yet when determining total lighting amounts, the Task Force rejected the general (i.e. not use-specific) lumen cap approach presented by codes such as those adopted in 1989 in Flagstaff and Coconino County, as well as the USA Pattern Code contained in the IDA Outdoor Lighting Code Handbook (IDA, 2000).

Recognizing that limiting lighting amounts was nonetheless vital, the Task Force instead sought to define lighting limits that were responsive to specific lighting uses recognized by the lighting professional community. They drew guidance from the energy densities allowed by California Title 24 (and from ANSI/ASHRAE/IESNA Standard 90.1), which in turn were based upon the Recommended Practices of the IESNA. This is an entirely new approach to limiting light pollution: instead of setting the amount of light to be allowed based first on the amount of light pollution or sky degradation expected, the amounts were to be defined by the illumination recommendations of the lighting industry. The Task Force has evidently made the judgment that light pollution will be adequately controlled if outdoor lighting conforms to the recommendations of this industry. It is however not clear whether lighting standards developed in this manner will actually curtail light pollution, either when compared to unregulated outdoor lighting or to lighting developed under current lighting codes with general lumen caps. Analysis to evaluate the dark sky impacts was never undertaken during the development process of the MLO.

In recent months some attempts have been made at such “dark-sky benchmarking,” initiated by IDA staff with assistance of Monrad Engineering. These analyses include total lumen allowances allowed following just the MLO “prescriptive hardscape area method,” and assume a lighting zone or zones associated with each project, with the implication that projects are associated with a particular lighting zone. Yet beyond general descriptions of ambient lighting or typical lighting levels in the different lighting zones, MLO has no specific guidance of what kinds of development (e.g. shopping centers, banks, convenience stores, etc.) are or are not allowed in any lighting zone. Therefore it is more informative to consider that projects might be allowed in any lighting zone, and set about determining how much light MLO will allow based on the lighting zone and the details of the project (hardscape area, building façade area, etc.).

This report describes a thorough analysis of the lighting amounts allowed by the MLO. The MLO includes a variety of allowed approaches to determine lighting amounts (prescriptive hardscape area method; performance method combined with luminaire photometric (BUG) standards (IESNA, 2007); performance method combined with limits to

two measures of “off-site impacts”). First, total lumen allowances permitted by MLO were determined for a selection of development projects. These MLO allowances were then compared to the average amount found on unregulated sites in the Flagstaff Lighting and Land Use Project (Luginbuhl, 2009) and to 100,000 lm/ac codes already in place in many communities across the U.S. Finally, the effects of off site impact limits described in the MLO are investigated.

## 2. Lighting Amounts and Off-Site Impacts under the IDA/IES MLO

### 2.1 Total Light Allowance

The uplight and sky glow caused by lighting on a development site, other aspects (such as shielding) being similar, will be directly proportional to the total amount of light used on the site. Therefore the first analysis of the dark sky impacts of the MLO is to determine the total amount of light allowed.

Total lumen allowances permitted by the IDA/IES MLO were determined following the *prescriptive hardscape area* and the *performance method* for the 15 commercial development projects listed in Table 1 (the prescriptive parking space method is not applicable to the sites evaluated). The necessary information for these projects was obtained from Monrad Engineering, the author's records, and from several other sources, including IDA. The projects include seven shopping centers, three convenience-store/service stations, a car dealer, motel, restaurant, office building, and a bank. Site plans for each of the projects analyzed are shown in Appendix A; detailed total light allowance calculations for each site are available from the author.

As the MLO does not identify permitted or prohibited land uses, the allowances by both the prescriptive and performance methods for all five lighting zones were evaluated, as described in greater detail below, producing a total of 10 allowances for each site.

Table 1: Projects Analyzed

#	Project Name	Type
1	Fry's/CM 9914	Shopping center
2	Safeway/CM 0151	Shopping center
3	Safeway/CM 0151	C-store/fuel station
4	Thornycroft Crossing	Shopping center
5	Fry's	Shopping center
6	Sellers Toyota	Car dealer
7	Motel 6	Motel
8	Red Lobster/Olive Garden	Restaurant
9	Love's Truckstop	C-store/fuel station
10	Conoco	C-store/fuel station
11	Homer Glen Center	Shopping center
12	Capital One Bank	Bank
13	Physicians and Surgeons Building	Office/hospital
14	Safeway 1983	Shopping center
15	IDA Site 9	Shopping center

### 2.1.1 Prescriptive hardscape area method

The total lumen allowance following the prescriptive hardscape area method is set by determining the total square footage of hardscape on the site, with an addition (beyond the measured hardscape area) of 600 ft.<sup>2</sup> for each intersection of a site drive with a public road. The lumen allowances, per acre, are shown in Table 2.

Table 2. MLO total lumen allowances (in kilo-lumens per acre, klm/ac) for the projects in Table 1, following the prescriptive hardscape area method.

Project #	MLO Lumen Allowance (klm/ac)				
	LZ0	LZ1	LZ2	LZ3	LZ4
1	49	82	133	270	411
2	49	82	133	274	423
3	41	69	110	220	330
4	45	75	121	247	379
5	47	79	129	272	429
6	52	88	144	302	473
7	45	76	124	263	417
8	48	81	131	268	412
9	51	86	138	280	424
10	50	85	140	304	493
11	27	46	76	160	251
12	36	62	104	234	387
13	40	67	109	227	353
14	39	65	106	220	342
15	39	66	111	246	404
<b>ave</b>	<b>44</b>	<b>74</b>	<b>121</b>	<b>252</b>	<b>395</b>

### 2.1.2 Performance method

Determining the total lumen allowance following the performance method is much more complex. Besides an allowance based on the area of the hardscape, as in the prescriptive hardscape area method, there is an additional allowance based on the length of the hardscape perimeter. Further, 15 other use-specific allowances are provided in addition to the hardscape area/perimeter allowance.

The most allowances critical for this analysis, i.e. those leading to the largest increments in the total lumen allowance, include:

- façade lighting (with allowance based on the square footage of building façade)
- ornamental lighting (with allowance based on the hardscape area)
- “special security lighting for retail parking and pedestrian hardscape” (with allowance determined by “the total area of illuminated retail parking and pedestrian landscape identified as having special security needs”).

As there are no explicit definitions within the IDA/IES MLO for building façade area nor for what constitutes a legitimate “special security need,” allowances were determined here assuming all building faces could be illuminated and all hardscape would claim “special security needs.” The façade allowance uses the total area of building faces (con-

servatively assuming 12 foot single-story walls); the “special security” allowance used the total hardscape area, as defined in the definition section of the MLO. The total lumen allowances for all projects are shown in Table 3.

Responsible lighting designers may challenge these presumptions, so the point bears emphasis. As the purpose of this analysis is to determine how much lighting the *MLO allows*, ALL allowances in the MLO performance method were included. As all the MLO allowances are described as upper limits, using less is possible but not the purview of the MLO. Should a developer use less than the maximum permitted by MLO, the designer or property owner may deserve some credit, but such a condition cannot be ascribed to the standards contained within the MLO. What the MLO allows is what the MLO allows: this analysis is about the MLO.

The MLO performance method includes, as an option, two additional constraints. The impact of these will be discussed below. These limits can be avoided (and the full allowances listed in Table 3 used without reduction) if all luminaires adhere to the BUG standards.

Table 3. MLO total lumen allowances for the projects in Table 1, following the performance method.

Project #	MLO Lumen Allowance (klm/ac)				
	LZ0	LZ1	LZ2	LZ3	LZ4
1	37	86	268	531	732
2	35	82	243	481	664
3	36	328	713	1,360	1,860
4	28	67	200	389	552
5	36	84	247	492	679
6	42	234	920	1,550	2,570
7	82	209	565	1,010	1,450
8	40	97	280	553	766
9	38	273	612	1,360	2,030
10	39	319	698	1,450	2,110
11	37	85	255	508	700
12	31	85	227	445	618
13	33	78	248	498	702
14	32	73	227	451	633
15	40	115	328	645	932
<b>ave</b>	<b>39</b>	<b>148</b>	<b>402</b>	<b>782</b>	<b>1,130</b>

## 2.2 Off-Site Impacts

The Performance method includes two alternative approaches (options) that are intended to limit “off site impacts.” The first alternative (Option A) requires only that the luminaires follow the BUG restrictions in MLO Table C, exactly as required using the prescriptive hardscape area method. The second alternative (Option B) has no luminaire shielding restrictions, instead limiting the ratio (lumens leaving the site)/(total installed lumens) and limiting the maximum illuminance at any point located on the vertical planes of the site boundary (called “TV illuminance” in MLO).

For the projects analyzed in this study that had specific lighting plans (five projects), the off-site impacts described under Option B of the MLO were calculated, and are listed in Table 4. These calculations are performed assuming that asphalt surfaces reflect 6% of the incident light, other ground surfaces reflect 15%, and building surfaces reflect 40%.

Table 4. Off site impacts. Projects labeled “A” are modified from the nominal lighting designs to explore the influence of various aspects of lighting design on the off site impacts, and are discussed in Section 3.2.

<b>Project #</b>	<b>Design klm/ac</b>	<b>Off-site lm /total lm</b>	<b>Max “TV” Illuminance (lux)</b>	<b>Direct Uplight (klm/ac)</b>
5	47	0.11	47	0
5A <sup>1</sup>	47	0.07	4	0
9	66	0.04	18	0
9A <sup>2</sup>	79	0.04	18	11
10	137	0.05	11	0
10A <sup>3</sup>	158	0.08	12	7
11	79	0.10	150	0
13	44	0.09	21	0
13A <sup>4</sup>	440	0.09	21	0

<sup>1</sup> same luminaires as 5 but with all moved minimum two mounting heights from parcel boundary

<sup>2</sup> same design as 9 with the addition of 16 B5-U5-G5 luminaires

<sup>3</sup> same design as 10 but with 10 fully shielded luminaires replaced with B5-U5-G5 luminaires

<sup>4</sup> same design as 13 but with all luminaire outputs increased 10x

### 2.3 Uplight

No accurate determination of the amount of uplight permitted under MLO standards is possible for several reasons, discussed under section 3.2 and 3.3 below.

## **3. Discussion**

### 3.1 MLO Total Lumen Allowances

The amount of light allowed under MLO standards varies widely, affected by both lighting zone as well as which method is used to calculate the allowance (prescriptive hardscape area or performance). Figure 1 shows the maximum, minimum and average allowances from Tables 2 and 3. Beginning with Lighting Zone 2, (described in the MLO user's guide as the appropriate or “default” zone for light commercial business districts and high density or mixed use residential districts), allowances average 121 kilolumens per acre (klm/ac) (range 76 to 144) using the hardscape area method (Table 2) and 402 klm/ac (range 200 to 920) using the performance method (Table 3).

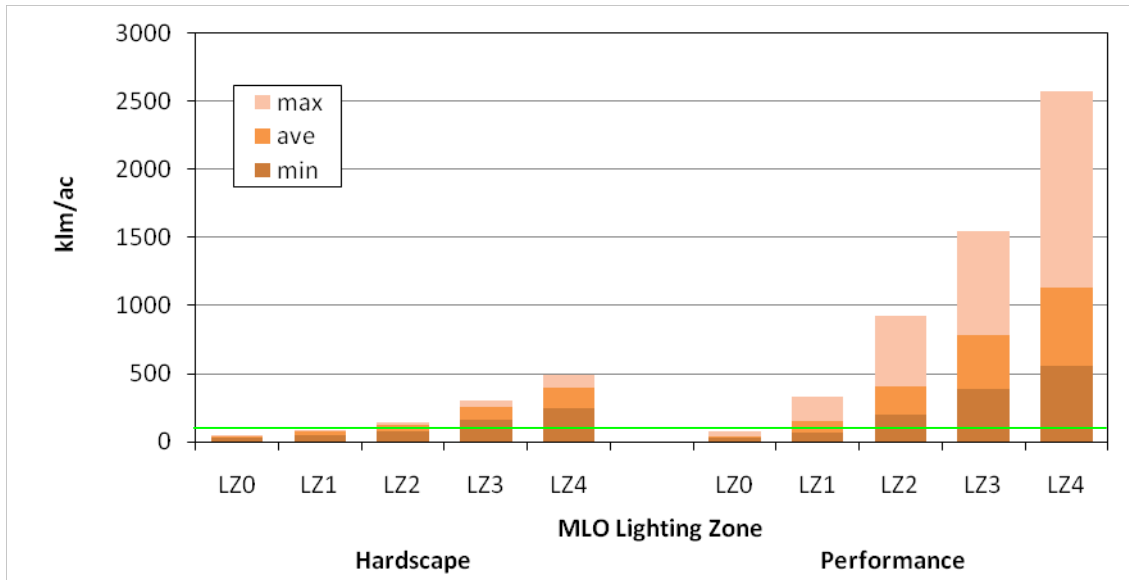


Figure 1. MLO Maximum, minimum and average lumen allowances for the projects in Table 1, by Lighting Zone. The green line is at 100 klm/ac (see Section 3.1.1).

In Lighting Zone 3 (described in the MLO user's guide as the recommended zone for the business district of a large city), these allowances rise to an average of 252 klm/ac (range 160 to 304) using the hardscape area method and 782 klm/ac (range 389 to 1550) using the performance method.

Finally, in Lighting Zone 4 (described in the MLO user's guide as appropriate for high intensity business or industrial districts), the allowances rise to an average of 395 klm/ac (range 251 to 493) and 1130 klm/ac (range 552 to 2570) using the hardscape area and performance methods respectively.

While the total lighting allowance determined following the hardscape area method does not vary significantly for reasons attributable to land use (indicating that the fraction of a parcel developed as hardscape falls within a relatively narrow range for the variety of land use types analyzed), some land uses strongly influence the allowance under the performance method. Table 5 summarizes the lumen allowances by type of land use.

The shopping centers, bank, office and restaurant projects analyzed all show similar allowances using the performance method (from 227 to 280 klm/ac in LZ2), while the fuel stations/convenience-store, auto dealer and motel projects show significantly greater allowances (from 565 to 920 klm/ac in LZ2). For the fuel station/c-stores and auto dealer, this increment is driven by the service station canopy and display lot lighting, respectively. For the motel this increase is due to the large number of exterior entrances and associated entry lighting at this motel (this site plan is for a particular chain of motels that utilizes individual exterior entrances for all of the rooms).

Table 5. Average MLO total lumen allowances by land use. N indicates the number of projects in the average from Table 1; light outputs include the prescriptive hardscape area method (upper) and the performance method (lower); Values exceeding unregulated practice (column 8) are indicated by **bold**. The unregulated values are adjusted from the mean effective lumen outputs presented in Luginbuhl *et al.* (1999) and assume fixture CU=0.65, LLD=0.90, LDD=0.85. The Lighting Fraction in the last column is the fractional contribution of the land-use category to the total uplight in the Luginbuhl *et al.* (2009) study.

Land Use	N	MLO Lumen Allowance (klm/ac)					Unregulated (klm/ac)	Lighting Fraction
		LZ0	LZ1	LZ2	LZ3	LZ4		
Shopping Center	7	42	71	115	<b>241</b>	<b>377</b>	173	0.095
		35	85	<b>251</b>	<b>500</b>	<b>699</b>		
Fuel Station / C-Store	3	47	80	129	268	416	450	0.048
		38	306	<b>674</b>	<b>1390</b>	<b>2000</b>		
Auto Dealer	1	52	88	144	302	473	37	0.007
		42	234	<b>920</b>	<b>1550</b>	<b>2570</b>		
Motel	1	45	76	124	<b>263</b>	<b>417</b>	161	0.050
		82	209	<b>565</b>	<b>1010</b>	<b>1450</b>		
Bank	1	36	62	104	234	<b>387</b>	257	--
		31	85	227	<b>445</b>	<b>618</b>		
Office	1	40	67	109	227	353	--	--
		33	78	248	498	702		
Restaurant	1	48	81	131	268	412	487	0.054
		40	97	280	<b>553</b>	<b>766</b>		

<sup>1</sup> includes two measures from Tucson reported in Luginbuhl *et al.* (2009)

### 3.1.1 Comparison of MLO Total Lumen Allowances to Unregulated Lighting Practice

To understand whether the MLO will lead to reduced amounts of lighting used outdoors, and thus expected decreases in sky glow (independent of possible shielding effects, discussed below), the amount of light allowed by MLO must be compared to unregulated lighting practice. Unfortunately, little is known about the amount of light used where no lumen limits are in place. Luginbuhl *et al.* (2009) published the only known study where the amount of light used for different land-use types before adoption of a lumen limiting code (i.e. on grandfathered sites), was measured. Whether or not the measures of uncapped lighting amounts in Flagstaff are typical for all cities is hard to ascertain given the limited data. Nonetheless, if there were a significant difference in the way outdoor lighting was done in different communities, particularly in the sense (as often claimed) that larger cities use more light per acre, per project, or per person, then the observed constancy or near-constancy of the relation between city brightness measured from satellite data or sky brightness measured from the ground versus population would not hold (Garstang, 1986; 1989; Falchi & Cinzano, 2000; Luginbuhl *et al.*, 2009). These studies indicate that a city of 400,000 inhabitants is twice as bright as a city of 200,000 inhabitants, and eight times as bright as a city of 50,000 inhabitants, and therefore that in general lighting practices do not appear to be strongly influenced by the size of the community.

Therefore comparison of MLO total lumen allowances to the amount of light used in Flagstaff, AZ before adoption of its current lumen limiting code should provide a reasonable estimate of whether application of the MLO standards would be likely to produce a decrease in the overall amount of light used and thus sky glow. The amount of light used on unregulated sites in the Flagstaff area (population 55,000) as determined by Luginbuhl *et al.* (2009) is listed in Table 5, and displayed along with the MLO allowances in Figures 2 through 7.

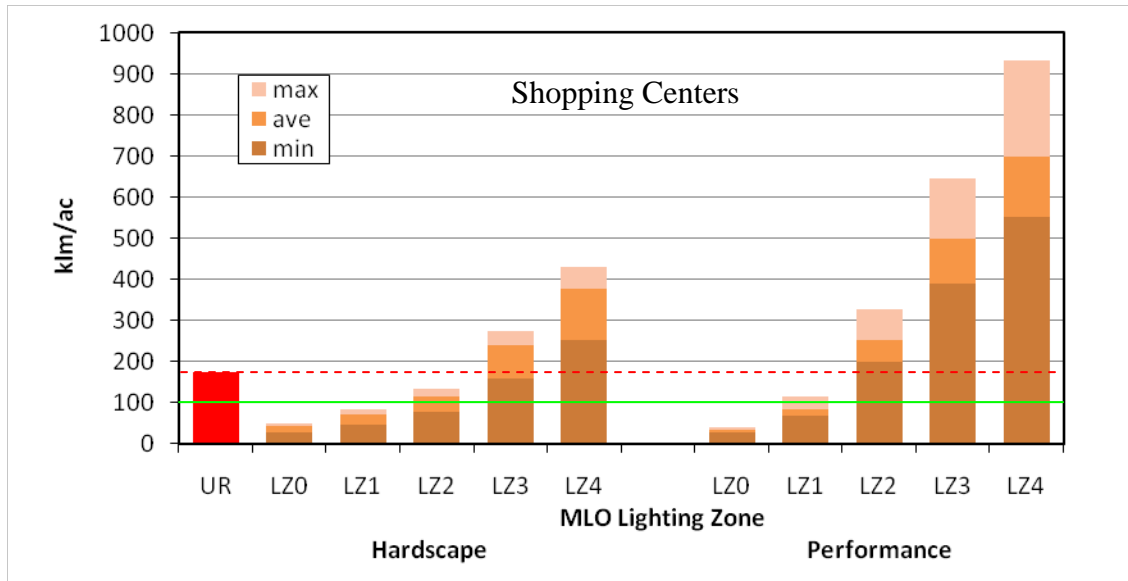


Figure 2. MLO lumen allowances for the 7 shopping centers compared to unregulated practice (UR). The green line is at 100 klm/ac (see Section 3.1.1).

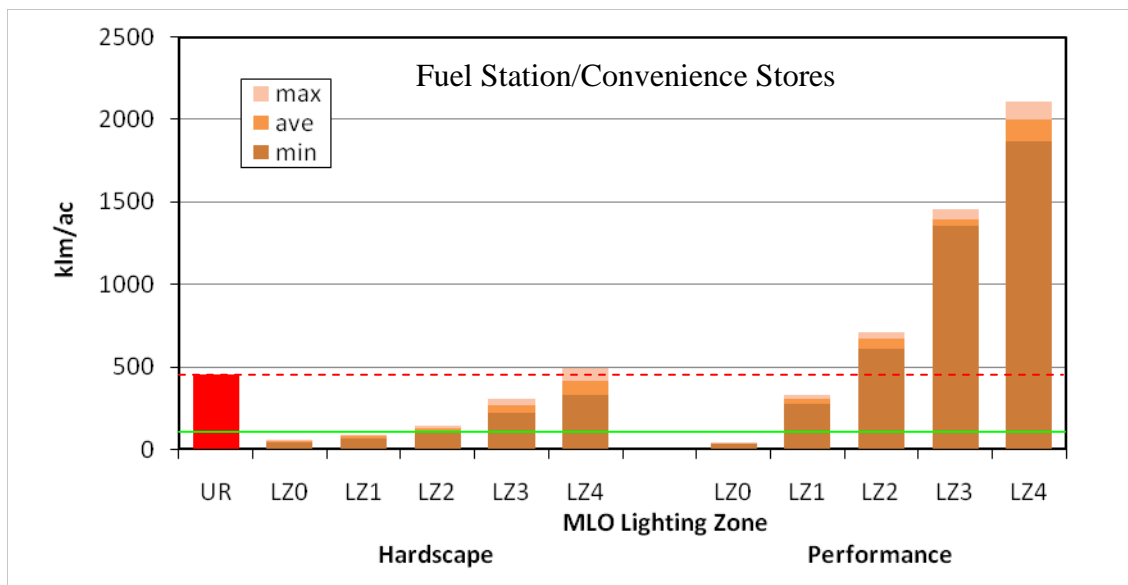


Figure 3. MLO lumen allowances for the 3 fuel station/convenience stores compared to unregulated practice (UR). The green line is at 100 klm/ac (see Section 3.1.1).

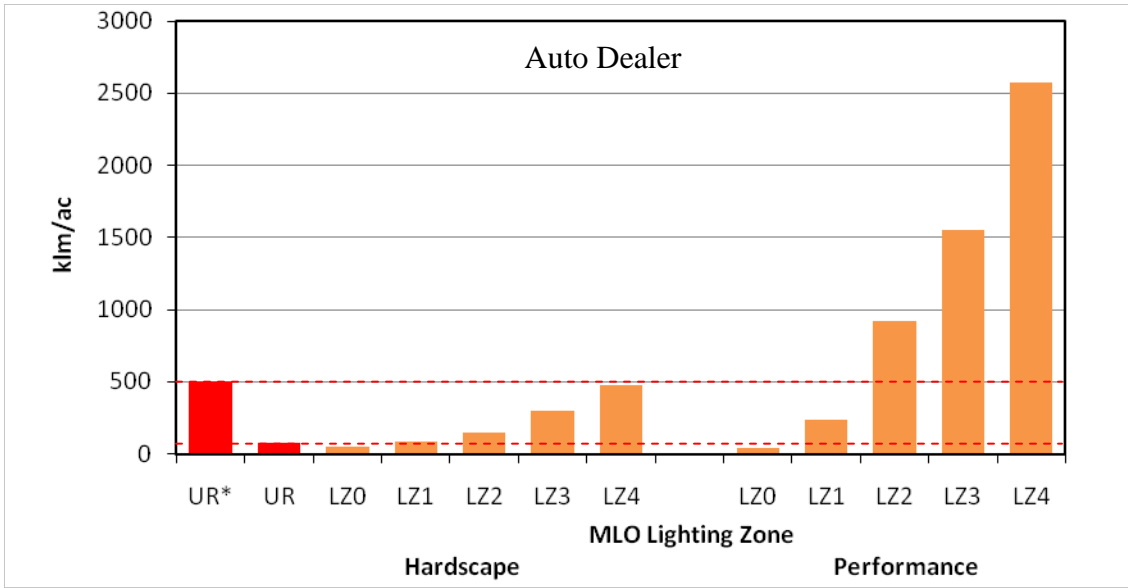


Figure 4. MLO lumen allowances for the single auto dealer compared to estimates of unregulated practice from Luginbuhl *et al.* (2009) (UR) and the Luginbuhl *et al.* value supplemented with two sites measured in Tucson, AZ (UR\*).

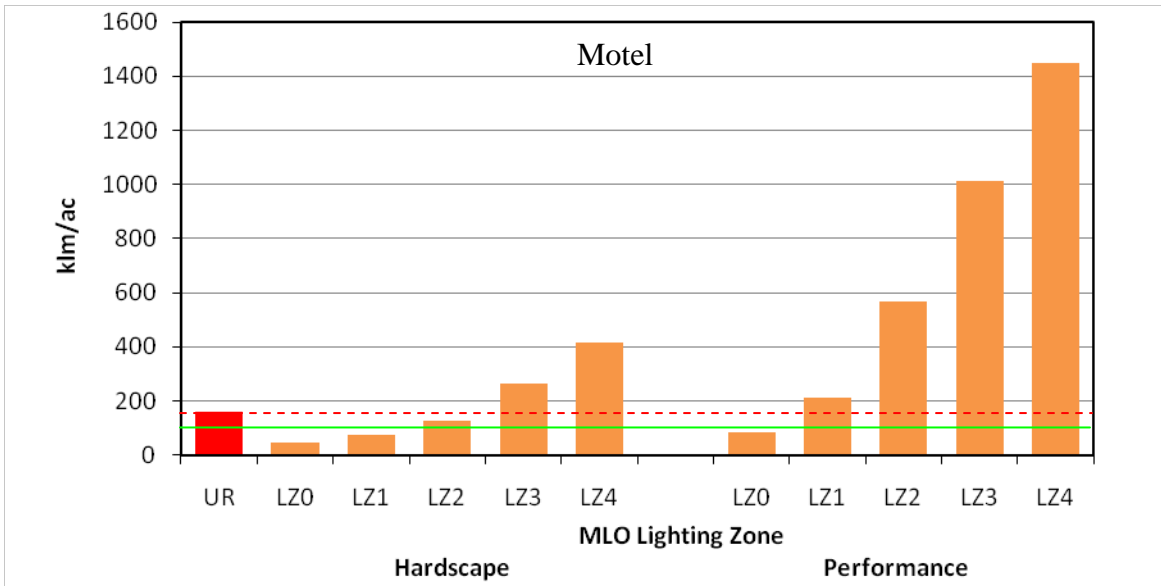


Figure 5. MLO lumen allowances for the single motel compared to unregulated practice (UR). The green line is at 100 klm/ac (see Section 3.1.1).

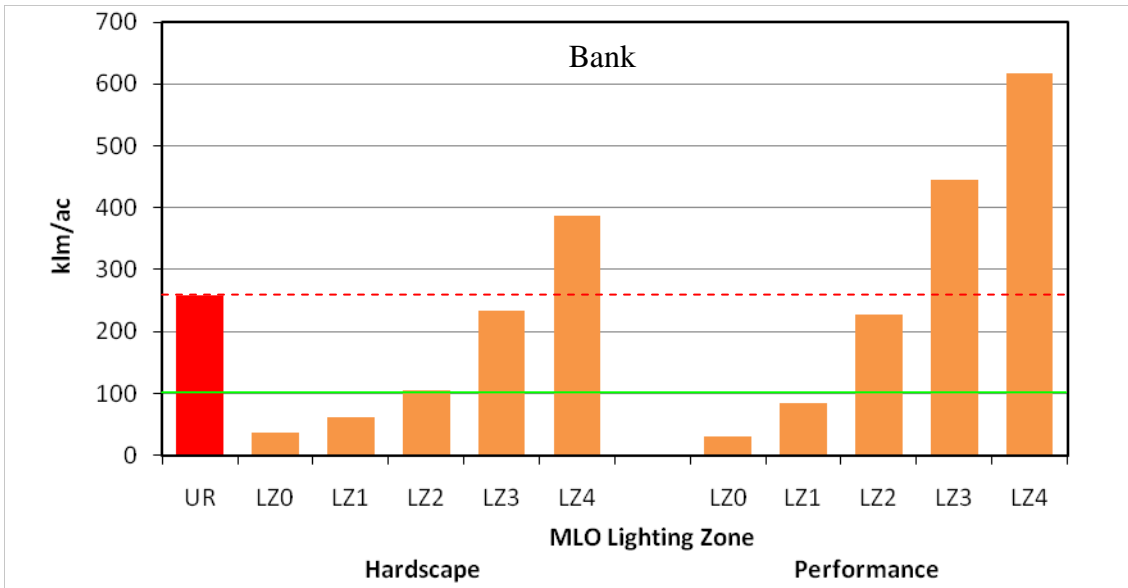


Figure 6. MLO lumen allowances for the single bank compared to unregulated practice (UR). The green line is at 100 klm/ac (see Section 3.1.1).

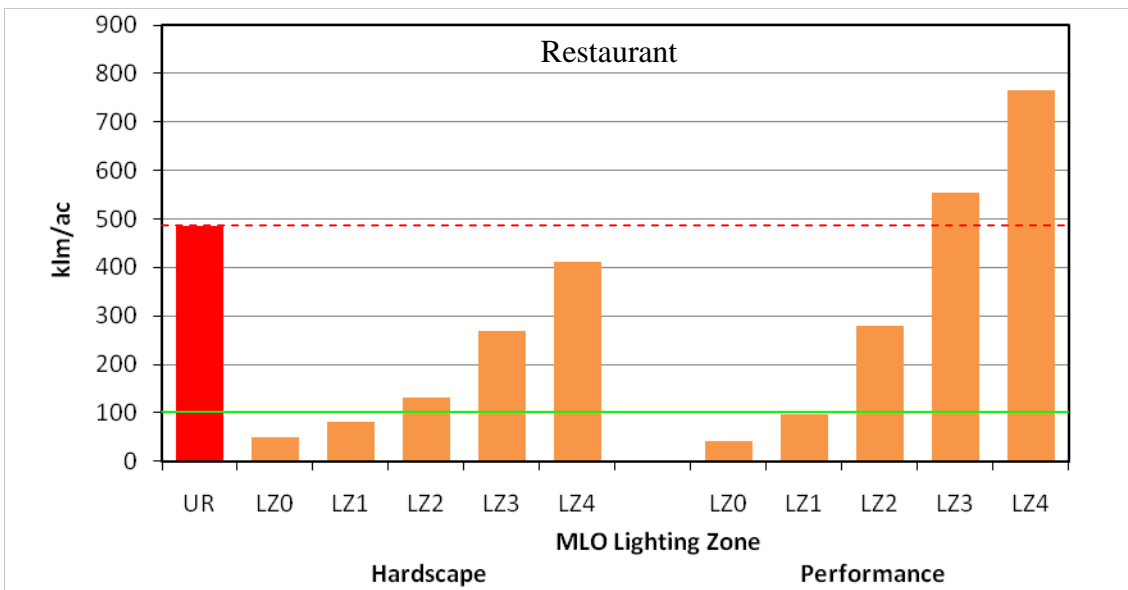


Figure 7. MLO lumen allowances for the single restaurant compared to unregulated practice (UR). The green line is at 100 klm/ac (see Section 3.1.1).

These results show that both the hardscape area and performance method MLO allowances are less than the average amount of light used in unregulated practice for all land-use types (for which comparisons are possible in this study) in LZ0 and LZ1.

In LZ2 the hardscape area method yields lower amounts than the average unregulated practice in all five of the land-use categories for which sufficient data are available. Unfortunately, the performance method – available as an option to any lighting user – shows reductions for only the banks and restaurants (allowing approximately 88 percent and

57% of unregulated practice, respectively). In the other three land-use categories the performance method allows substantially more light (ranging from a 45% increase at shopping centers to 250% at the motel, and an 82%-2500% increase at auto dealers). Further, the last column of Table 5 shows that the shopping centers produce a disproportionate amount (9.5%) of the uplift in Flagstaff. And though in Flagstaff auto dealers are a very small fraction (0.7%), it appears likely that in larger communities this land-use will contribute a much higher fraction. Thus it is of considerable concern that in LZ2 MLO does not appear to represent a reduction from unregulated practice for these two important land-use categories.

In LZ3 and LZ4 most MLO allowances (17 of 24), and all 12 from the performance method, exceed the average unregulated practice for all land-uses for which data are available. For the three high-intensity uses (fuel station/c-store, auto dealer, and motel) the performance method allows in excess of 1 million lm/ac in LZ3, and from 1.5 to 2.5 million lm/ac in LZ4. These values are far in excess of unregulated practice. Fuel stations and motels are likely to be significant contributors to sky glow in all communities (both at about 5% in Flagstaff); in many larger communities auto dealers are likely to be a large contributor as well.

In summary, the MLO total lumen allowances appear to represent a step forward compared to unregulated lighting practice in only LZ0 in LZ1; in LZ2 through LZ4 most land uses would be permitted to use more light than used in the average unregulated practice, in some cases substantially more.

### *3.1.1 Comparison of MLO Total Lumen Allowances to 100 klm/ac Lighting Codes*

Many lighting codes have established general caps of 100,000 lm/ac and less. With up to 20+ years experience, these codes and this limit have been shown to be effective. The actual lighting installed on the site and/or analyzed in Section 2.2 conforms to this limit or lower for the majority of the projects analyzed in this study (projects 5, 6, 8, 9, 10, 11, 13; in Table 5 project 10 nominally exceeds 100 klm/ac, but due to the special treatment of canopy lighting – due to the reduced uplift impacts of canopy lighting – this design conforms to a 100 klm/ac limit). Essential lighting needs on all the sites are met; most have nonessential lighting such as façade lighting as well. Thus, when assessing whether MLO lumen allowances represent a step forward compared to currently effective lighting codes, a relevant comparison is to a 100 klm/ac limit. The 100 klm/ac value is shown for reference in Figures 1 through 7 (except 4).

The average lumen allowances for all project types in LZ2 and above, following both the hardscape area and performance methods, exceed 100 klm/ac (see Table 5). While the hardscape area allowances are for some uses quite close to 100 klm/ac in LZ2, in LZ3 they are about two times greater, and in LZ4 3½ to 4½ times greater. Allowances are much larger following the performance method, exceeding 100 klm/ac by factors of 2½ to 26, depending on lighting zone and project type. As demonstrated in Section 3.2, there are no effective standards within MLO to limit the full utilization of these performance method allowances. Whatever the feasibility or practicality of 100 klm/ac codes (and it

has not been demonstrated that they are impractical for any community), certainly for the medium-sized and small communities and rural areas in which these codes are in place, the standards of the MLO appear to represent a significant step backward in light pollution limitation and control.

### 3.2 Off-Site Impacts

The performance method includes, as an alternative option to following the BUG standards, no explicit luminaire shielding standards but instead demonstrating that two measurements of off-site impacts are below certain limits. The stated goal is to limit dark sky impacts (such as glare, sky glow and trespass) of the very large lumen allowances and in the absence of shielding requirements under option B. The two criteria are a maximum ratio of lumens leaving the site (evaluated as the average illuminance on a virtual “box” with vertical sides at the property boundary and top at least 10 feet above the tallest luminaire, times the surface area of the “box”) of 0.10 in all lighting zones (hereafter referred to as “box/total lumen ratio”), and a maximum illuminance on the interior sides of this same “box,” dependent upon lighting zone.

#### *3.2.1 Maximum Off-Site / Total Lumen Ratio*

Table 4 shows that for sites without fueling canopies (projects 5, 11 and 13), the box/total lumen ratio is about 10% (11%, 10% and 9%). For the two fuel station/c-stores analyzed (projects 9 and 10) the box/total lumen ratio is between 4% and 5%. It is important to note here that all of these nominal lighting plans – except as noted below – include only fully shielded fixtures.

To explore the impact of total lighting amount on this ratio, project 13 was altered by increasing the output of all luminaires by a factor of 10 (see Table 4 project 13A). Though of course this is an artificial change (i.e. a given luminaire cannot accommodate a lamp with 10 times the output usually specified, even if such a lamp were available), this analysis gives a sense for the effect of changing lumen amounts on this ratio. As expected, both the box lumens and the site lumens increase in the same proportion, so the ratio is not changed (9%). Thus, the box/total maximum does not reduce the total lumen allowance permitted under the performance method.

For sites such as fuel stations with large amounts of light located under canopies, and thus a lower box/total lumen ratio, the ratio not only does not limit the total amount of light used on the site (as above), but leaves room for substantial amounts of unshielded light. To explore this possibility, sixteen B5-U5-G5 luminaires of 9500 lm each (these are classic “barnyard” fixtures) were added to the parking area of project 9. The results (see Table 4 project 9A) show that the box/total ratio was only slightly increased (from 3.9% to 4.4%), whereas direct uplight was increased from zero to 11,000 lm. Further, since the unshielded luminaires were not located close to any site boundaries, the maximum “TV” illuminance was not changed. Since the box/total lumen ratio remained substantially below the 10% limit, there is still room to add more unshielded fixtures without exceeding this criterion.

In summary, the limit on the ratio of total lumens leaving a site to total lumens produced on the site does not limit the total amount of light allowed on the site following the performance method, as this ratio is not sensitive to the amount of light used on the site, being instead sensitive to shielding and reflectivity of surfaces. For ordinary sites (i.e. without canopies) this ratio is about 10% – the MLO limit – when exclusively fully shielded fixtures are used. Thus, for such sites the current MLO limit for this ratio essentially requires that all lighting utilize fully shielded fixtures. On the other hand, for some of the brightest sites (i.e. those using the greatest amount of lumens), unusual shielding characteristics such as canopies can bring this ratio considerably below 10%, allowing substantial amounts of lighting using very poorly shielded fixtures with the resultant direct uplight, glare and trespass associated with such fixtures.

Finally, it should be noted that this ratio is not useful for estimating the sky glow impacts of an outdoor lighting installation, as it contains no information on the direction the light striking the insides of the box is headed, critical to sky glow impacts (Luginbuhl, Walker & Wainscoat, 2009). It does not even distinguish light headed toward the ground from light headed for the sky (Rae *et al.*, 2010).

### 3.2.2 Maximum “TV” Illuminance

The limits to maximum “TV” illuminance (hereafter referred to simply as the TV limit or TV maximum) in the MLO are 0.5, 1, 3, 8 and 15 lux in LZ0 through LZ4, respectively. The results for the five projects analyzed in Table 4 show that all of the nominal designs would exceed this criterion in LZ0 and LZ1, and one of the projects (11) exceeds the criterion in all zones. As none of these projects were designed with this criterion in mind, it is instructive to examine the factors that lead to this criterion being exceeded, and the criterion's likely effects on lighting designs.

In every case, the TV maximum occurs (naturally) at a site boundary near a light fixture or fixtures. To highlight this sensitivity, project 5 was artificially rearranged to move all luminaires a minimum of two mounting heights from property boundaries (this is not a practical lighting solution for this site, of course). Yet we see the dramatic effect on the TV maximum (see Table 4 project 5A), which decreases from 47 to 4 lux. Thus the site, with the same amount of light, would now meet the TV limit for all lighting zones. Therefore, a tight TV limit will cause lighting designers to seek wherever possible to locate light fixtures away from property boundaries.

In project 10 the TV maximum (11 lux) occurs at the site boundary nearest to an auto fueling canopy. This canopy is located approximately 25 feet from the adjacent highway frontage. The design illuminates the ground under the canopy to 150 lux initial, utilizing 40 initial lumens per square foot of canopy. The TV maximum indicates that this design is appropriate for LZ4 only. To further demonstrate the insensitivity of the TV maximum to unshielded lighting on the site, the site was redesigned replacing most of the interior site lighting (10 fixtures) with unshielded 9500 lm B5-U5-G5 fixtures (see Table 4 project 10A). Total direct uplight was thus increased from 0 lm to 7,000 lm. It would be

hard to describe this as other than a poor, glaring and trespassing lighting design. Yet the TV maximum is barely affected, increasing from 11 to 12 lux. It would still be permitted in LZ4, with room for many more B5-U5-G5 fixtures.

In some cases locating light fixtures far from property boundaries might be possible while still meeting lighting needs. In others it is impractical, inadvisable or impossible. In the actual case of project 5, the principal offending fixtures are three fully shielded 3500 lm fixtures illuminating pedestrian crossings of the site entrance drives, entering the site from the adjacent arterial and collector roadways (the high TV maximum on project 11 arises from a similar situation). It is hard to imagine how to illuminate these critical areas, inescapably located very close to property boundaries, without running into trouble with the TV limit. Another high TV value, of second severity on the project 5 site, arises at two emergency egress lights located on a non-frontage face of the building and approximately 10 feet from the adjacent collector roadway. Without dramatically changing the location of the building, the TV limit would be very difficult to meet due to these lights as well. This design is not a high-intensity lighting use – it is a supermarket using 50 klm/ac; by any objective measure a low impact lighting use. In fact, due to the efficiencies necessitated by the tight lumen budget, small critical areas needing higher illumination, such as these pedestrian crossways, are illuminated with nearby low-output fixtures (in this case close to the property boundary). The more common approach when lumen budgets are high or unlimited is to raise the illumination of the entire site to assure that critical areas are illuminated but with a smaller number of fixtures that can be located farther from the critical areas. It appears in this case that the MLO approach using the TV limit works at odds to maximum efficiency and lowest lumen outputs.

On the other hand, as shown above in section 3.2.1, the TV limit is insensitive to poorly shielded fixtures if they are located at some distance from the property boundary.

This analysis shows that the TV limit criterion is very sensitive to some kinds of “classically” measured light trespass – i.e. trespass that is measured as illuminance at a property boundary. Perhaps too sensitive, and perhaps too broadly. For example, the consequences of, or appropriate limits for, light trespass at all property boundaries cannot be considered equal, not even approximately so; a commercial-commercial, or commercial-roadway boundary has considerably different sensitivity to trespass than a commercial-residential boundary. Variation in sensitivity to other types of adjacency impacts is commonly recognized in land-use zoning, and addressed for example through variation in setback distances and/or landscaping buffer requirements. Yet the MLO sets the TV maximum based on the single criterion of the subject parcel's lighting zone: the limit is not sensitive to an adjacent parcel's lighting zone nor its land-use. In fact, the way this limit is implemented leads to a nonsensical situation at the boundary between two adjacent parcels with different lighting zones: the parcel allowed more light is allowed to trespass onto the fainter parcel more than the faint parcel is allowed to trespass onto the brighter parcel. Finally, as different communities have different setback requirements and many different rules regarding what are and are not suitable adjacent land uses, it does not seem realistic to develop light trespass standards in this way.

In summary, the maximum “TV” illuminance is very sensitive to the location of luminaires relative to property boundaries: it appears to be inordinately and inappropriately sensitive. Luminaires located near property boundaries, such as on building faces when building setbacks from property boundaries are small, or for illuminating critical areas such as pedestrian walkways at site driveway entrances, will exceed the maximum TV illuminance values in nearly every circumstance, even with fully shielded luminaires. This criterion is on the other hand insensitive to shielding (or lack of shielding) of luminaires located at some distance from property boundaries. On sites with large lumen allowances but unusual structural shielding (such as fuel stations), large amounts of unshielded lighting may be installed without exceeding the TV limits. Finally, the linking of this criterion to a site's lighting zone only (with no cognizance of the lighting zone or land-use on the other side of the boundary) leads to nonsensical trespass results.

### 3.3 Uplight

Determining total uplight allowed under the MLO is highly uncertain, due to the way the standards are written. Nonetheless, a rough idea can be gained by making a number of assumptions, as described in the following discussion.

As shown in Section 3.2, the MLO box/total ratio and TV limits do not effectively limit unshielded lighting (i.e. direct uplight) in many common circumstances. To characterize potential uplight amounts under the MLO standards, we will conservatively assume 400 klm/ac, the average of all LZ2-LZ4 allowances (including both hardscape area and performance methods) shown in Table 5. Using the average performance method value (850 klm/ac) could be justified.

The BUG limitations, required under the hardscape area method and one of the two options available under the performance method, establish absolute per fixture limits in the “U” zone (unfortunately at present still including down-directed light in the “FVH” and “BVH” zones). At first appearance it might seem that an upper limit on the amount of uplight could be determined. But that is not possible: as the BUG system limit in a particular “U” classification is based on an absolute lumen amount *per fixture*, the total amount of “U” light will depend on the “U” rating *and* the number of luminaires used. As an example, a lighting designer using 500,000 lm with a “U2” standard (max 200 lm/fixture direct uplight) could use ten 50,000 lm luminaires, producing a maximum amount of direct uplight of 2,000 lm (or 0.6% of fixture lumens, assuming 65% fixture efficiency), fifty 10,000 lm luminaires, producing a maximum amount of 10,000 lm (or 3%), or 100 5,000 lm luminaires for a maximum direct uplight amount of 20,000 lm (or 6%).

#### *3.3.1 Comparison of MLO Uplight Amounts to Unregulated Lighting Practice*

While 6% as a direct uplight *fraction* is an improvement over unregulated outdoor lighting practice (with direct uplight fractions estimated between 8% (Luginbuhl *et al.*, 2009) and 15% (e.g. Garstang, 1986)), the total uplight *amount* (direct + reflected) is the critical measure for dark sky impacts. Reflected uplight will in general be proportional to the

amount of light allowed on the site: 400 klm/ac will have four times the reflected uplight of 100 klm/ac. With 6% direct uplight and assuming an average ground reflectivity of 15% (Garstang, 1986) and average fixture efficiency of 65%, 400 klm/ac gives about 37 klm/ac reflected uplight, while 100 klm/ac gives 9 klm/ac. Further, a particular direct uplight *fraction* also produces a proportionately larger direct uplight *amount* when the lumen budget is large: 6% with 400 klm/ac translates to 16 klm/ac direct uplight, while 6% with 100 klm/ac translates to 4 klm/ac. Thus total uplight, direct + reflected, with 6% direct uplight, is about 53 klm/ac using 400 klm/ac and 13 klm/ac using 100 klm/ac.

This MLO total uplight amount appears to be significantly more than with unregulated practice. The commonly cited 10% direct uplight fraction (Garstang, 1986; 1989) combined with 260 klm/ac (the average of the six unregulated lighting amounts shown in Table 5) gives 40 klm/ac total (direct + reflected) uplight. The MLO amount is then a 30% increase, despite the better shielding. The specific figures, for both MLO and unregulated lighting, will vary significantly depending on the specific land-use and (for MLO) on Lighting Zone. The figures compared here are particular examples that are illustrative of the broad picture.

### 3.3.2 Comparison of MLO Uplight Amounts to a 100 klm/ac Lighting Code

The Coconino County (AZ) outdoor lighting code ([http://www.coconino.az.gov/uploadedFiles/Community\\_Development/Section17.pdf](http://www.coconino.az.gov/uploadedFiles/Community_Development/Section17.pdf)) allows, in its Lighting Zone 3, 100 klm/ac and a maximum of 3 klm/ac not-fully-shielded. Assuming a worst-case 50% uplight fraction for the unshielded lighting, this code allows up to 1.5 klm/ac (or effectively  $1.5/(0.65 \times 100) = 2.3\%$ ) direct uplight and 11 klm/ac total uplight. Thus the 400 klm/ac + 6% direct uplight fraction MLO example allows almost five times (53/11) as much total uplight and almost 11 times (16/1.5) as much direct uplight as the Coconino County code.

Finally, even the 400 klm/ac + 6% uplight MLO analysis provided here is not representative of the maximum direct uplight possible with the MLO, as lighting designers are free to choose the performance method Option B, which does not require adherence to BUG luminaire standards. As shown above in Section 3.2, considerably larger amounts of direct uplight are possible. While it would not be reasonable to evaluate the overall uplight permitted with MLO based on the *worst* case values (which 6% and 400 klm/ac are not, in any case), what the *average* will be is not possible to determine. On the other hand, the Coconino County comparison is a plausible worst case.

In summary, though it is possible to make only an approximate estimate of the amount of uplight permitted by the MLO, under reasonable assumptions it appears that the MLO allows about 30% more total uplight than measured in unregulated lighting practice. This is due to the large lumen allowances, and despite the better average shielding. Compared to the 100 klm/ac cap and shielding standards of the Coconino County (AZ) lighting code, the MLO allows 5x more total uplight and more than 10x more direct uplight.

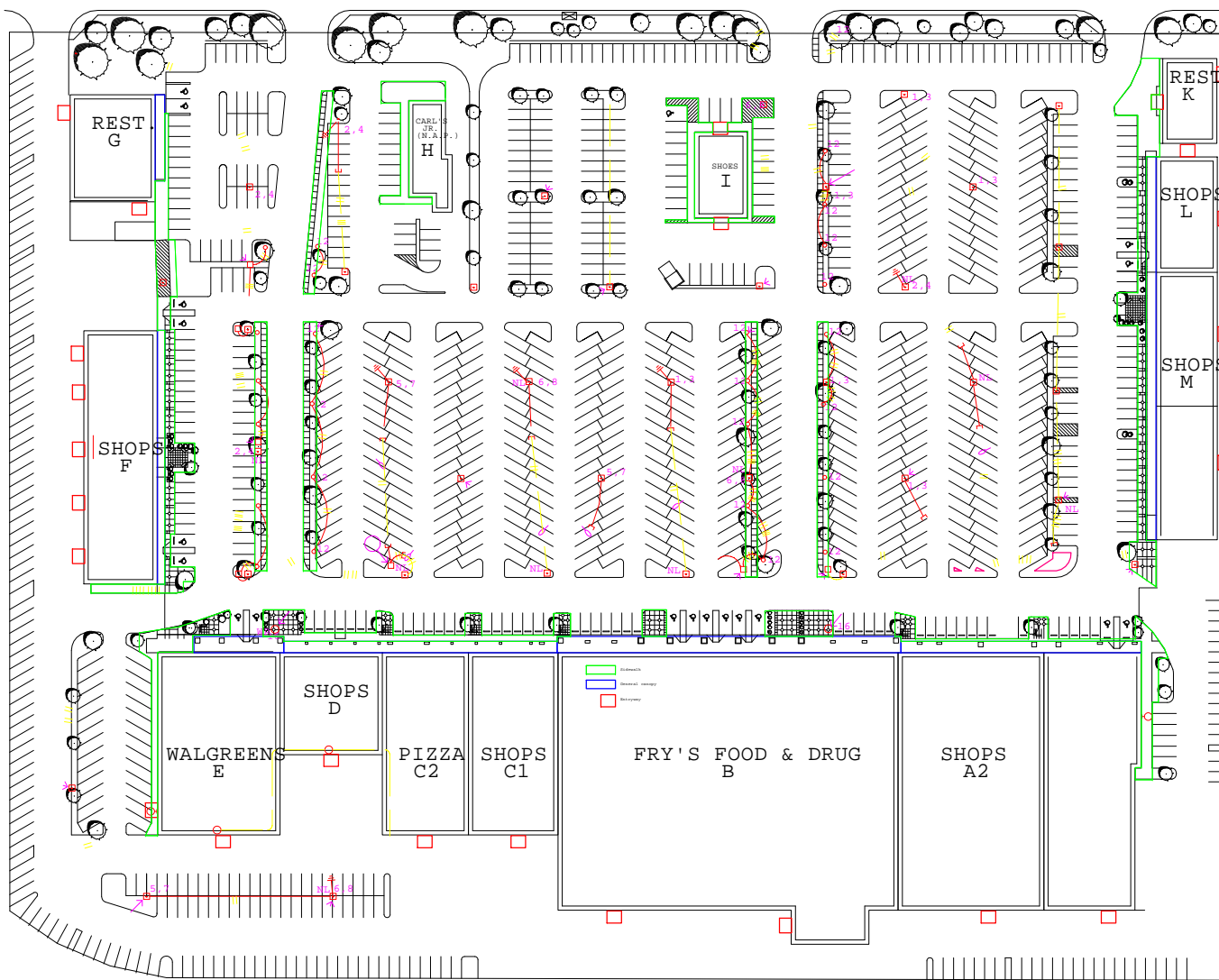
## References

- Falchi, F. and P. Cinzano, 2000, "Maps of Artificial Sky Brightness and Upward Emission in Italy from DMSP Satellite Measurements," *Memoirs of the Italian Astronomical Society*, 71: 139
- Garstang, R.H., 1986, "Model for Artificial Night-Sky Illumination," *Publications of the Astronomical Society of the Pacific*, 98: 364
- Garstang, R.H., 1989, "Night-Sky Brightness at Observatories and Sites," *Publications of the Astronomical Society of the Pacific*, 101: 306
- Illuminating Engineering Society of North America, 2007, "TM-15-07: Luminaire Classification System for Outdoor Luminaires"
- International Dark-Sky Association, 2000, *The IDA Outdoor Lighting Code Handbook and USA Pattern Lighting Code*.
- International Dark-Sky Association/Illuminating Engineering Society of North America, 2010, *Joint IDA-IES Model Lighting Ordinance (MLO) with User's Guide (Second Public Review)*, June 22, 2010
- Luginbuhl, C.B., 1999, "Using DMSP Imagery to Evaluate Lighting Practice in the American Southwest," in *Preserving the Astronomical Sky*, IAU Symposium 196: 103
- Luginbuhl, C.B., *et al.*, 2009, "From the Ground Up I: Light Pollution Sources in Flagstaff, Arizona," *Publications of the Astronomical Society of the Pacific* 121:185
- Luginbuhl, C.B., Walker, C.E., and Wainscoat, R.J., 2009, "Lighting and Astronomy," *Physics Today*, 62: 32
- Rea, M.S. *et al.*, 2010, "Many Facets of Light Pollution," *Physics Today*, 63: 8

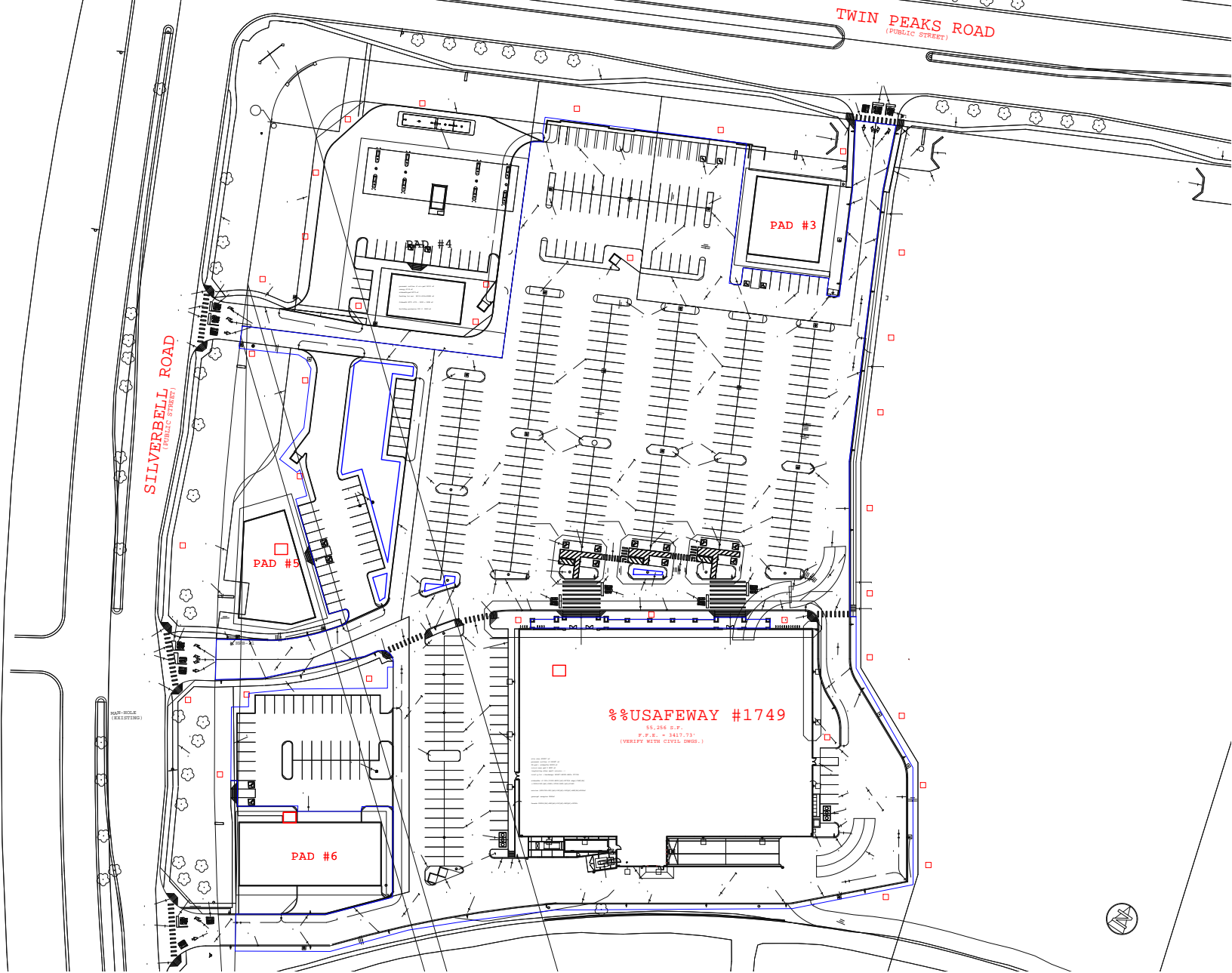
## **Appendix A**

Site plans showing the projects analyzed in this study are shown below. Several of the sites also have detailed lighting designs, allowing the analysis of off-site impacts that are an optional consideration under the MLO performance method.

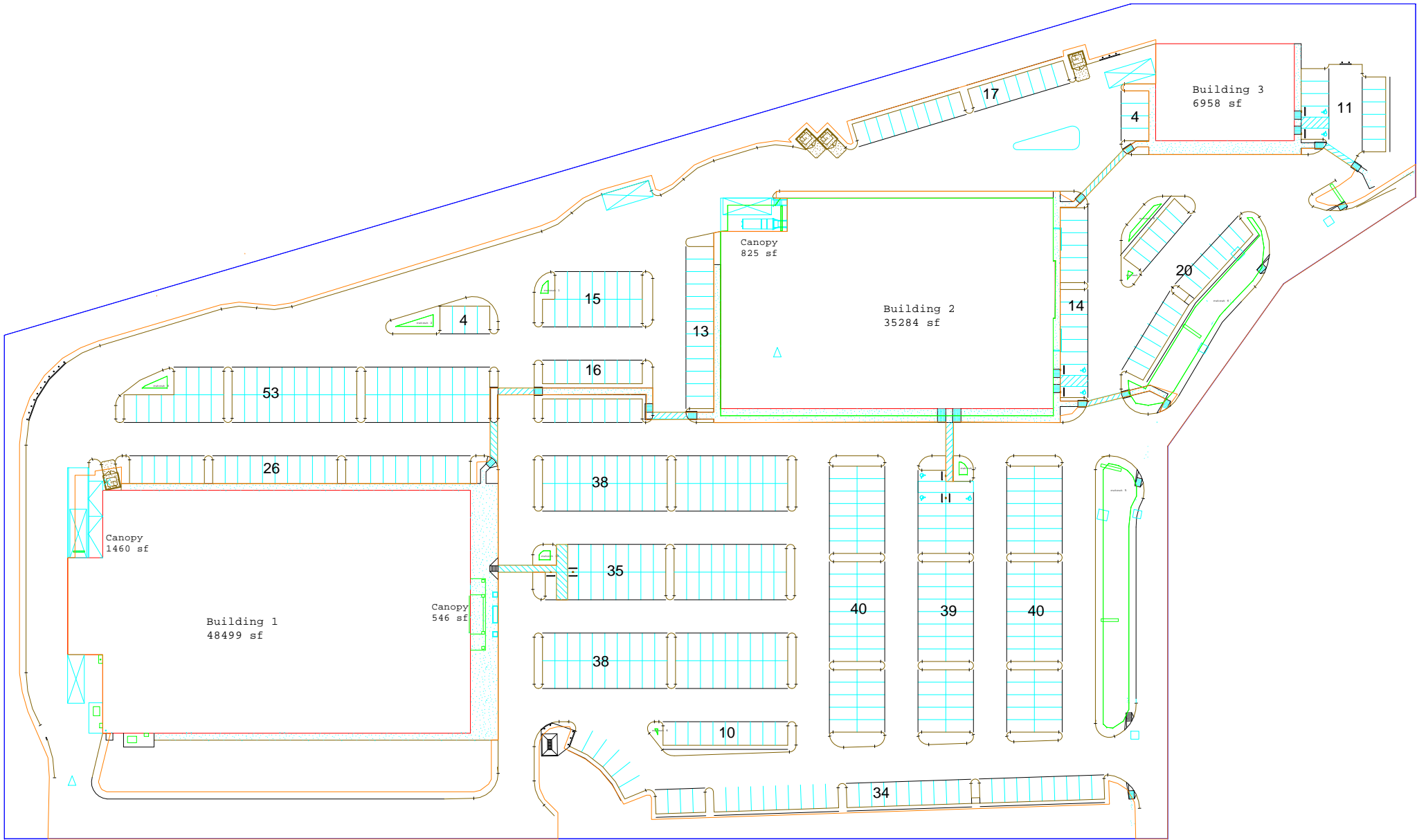
22ND STREET



Project 1

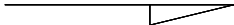


Projects 2, 3



Project 4

North



Total Rental

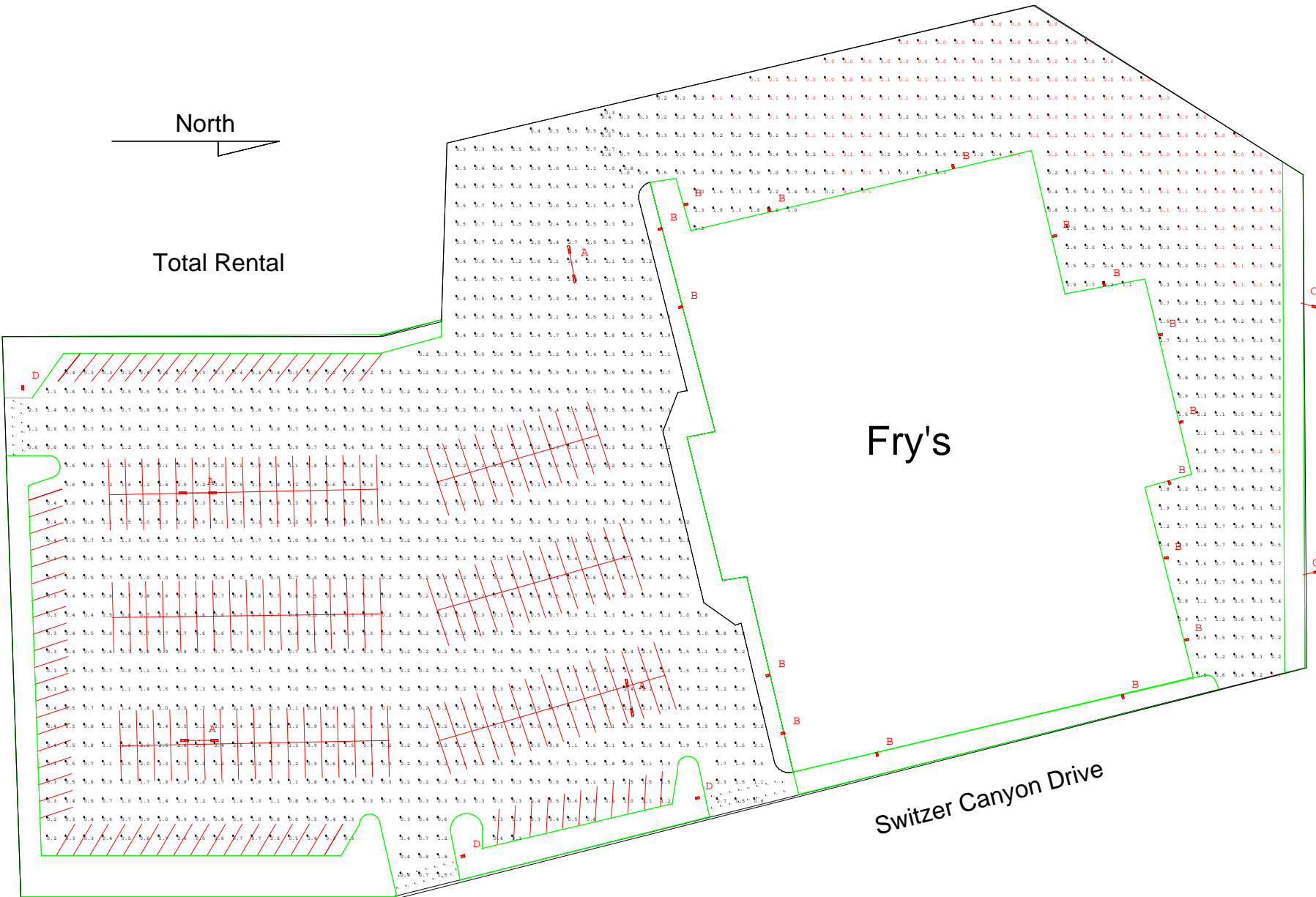
Old Route 66

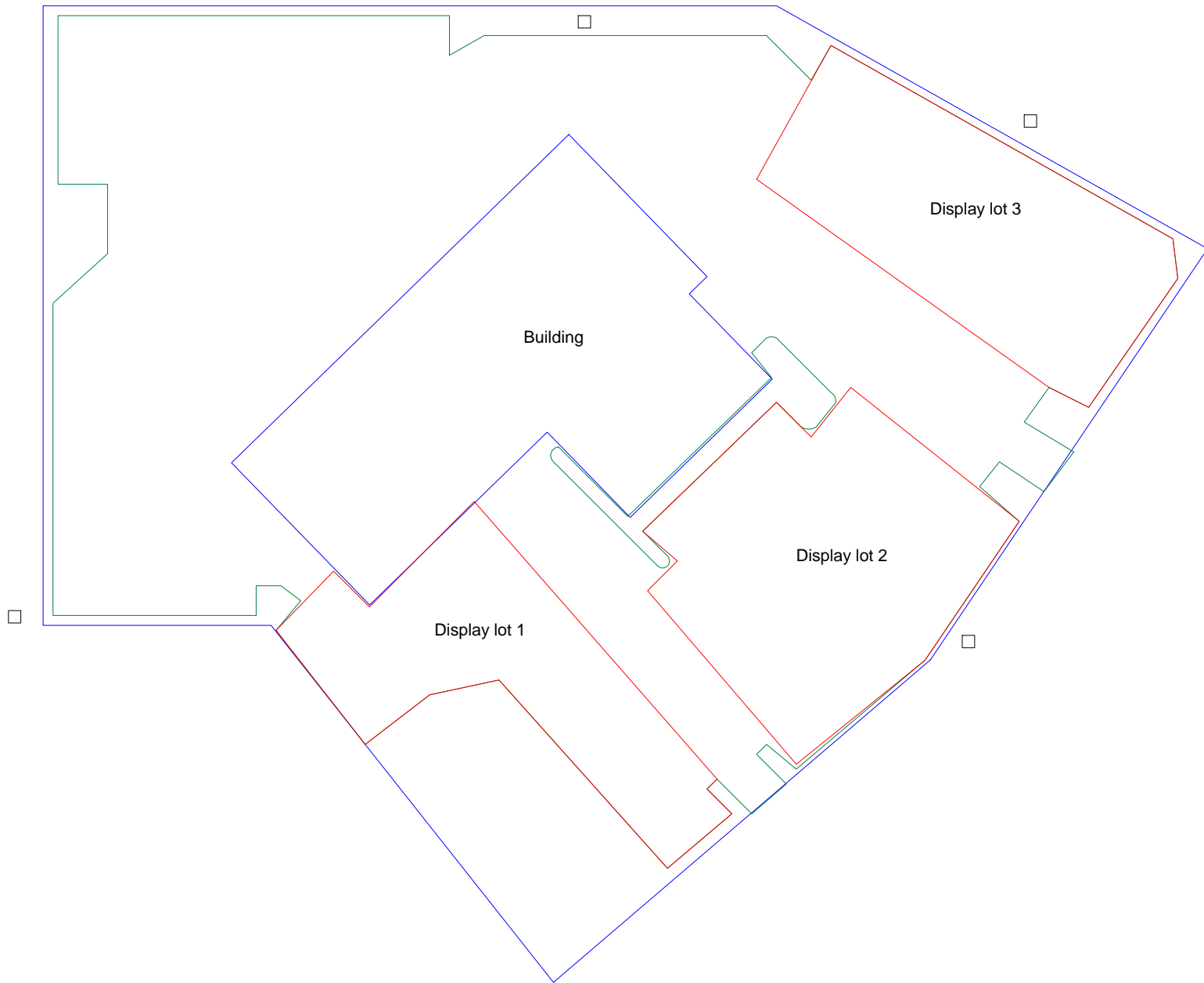
Fry's

McCoy Motors

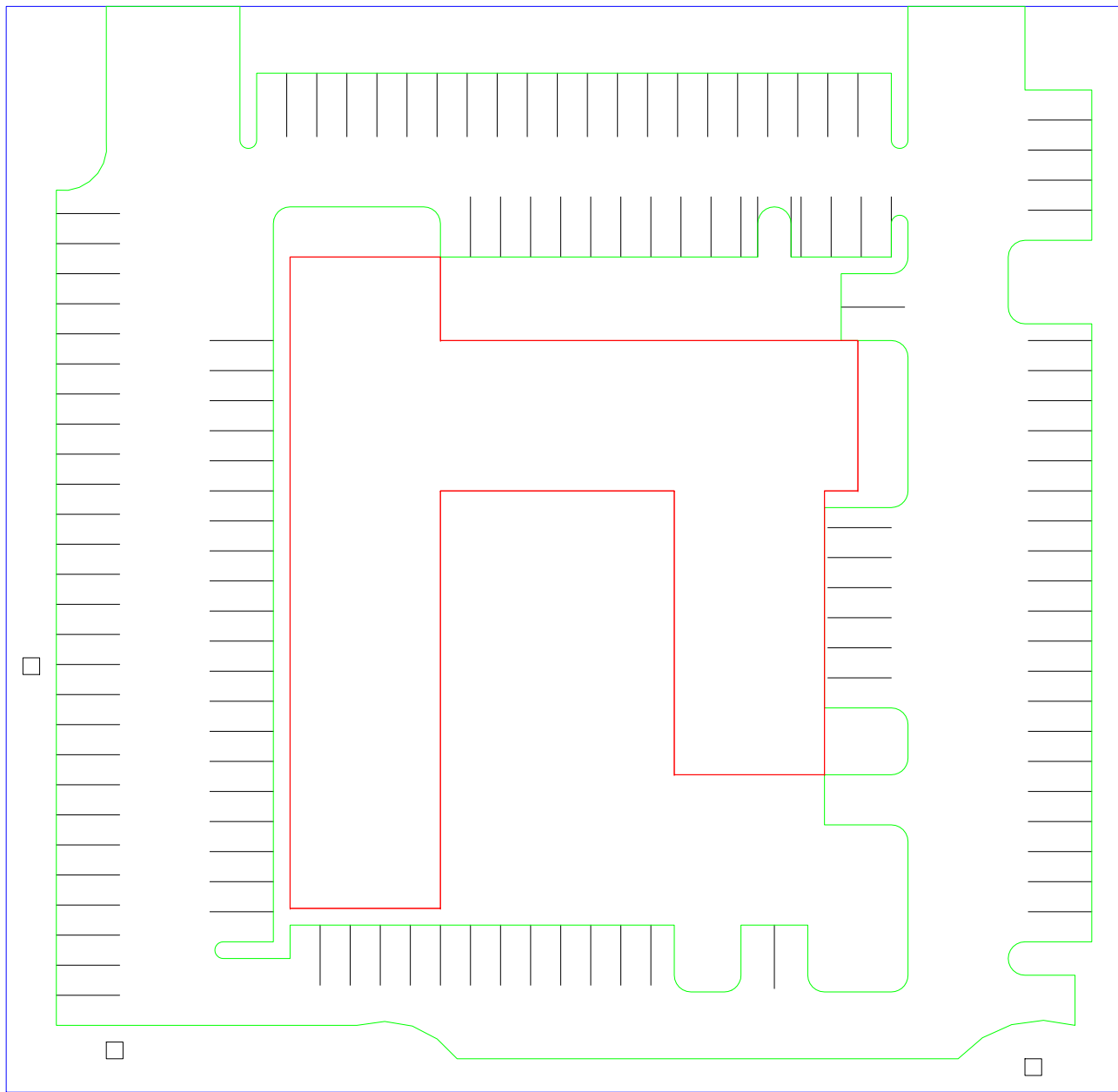
Switzer Canyon Drive

Project 5

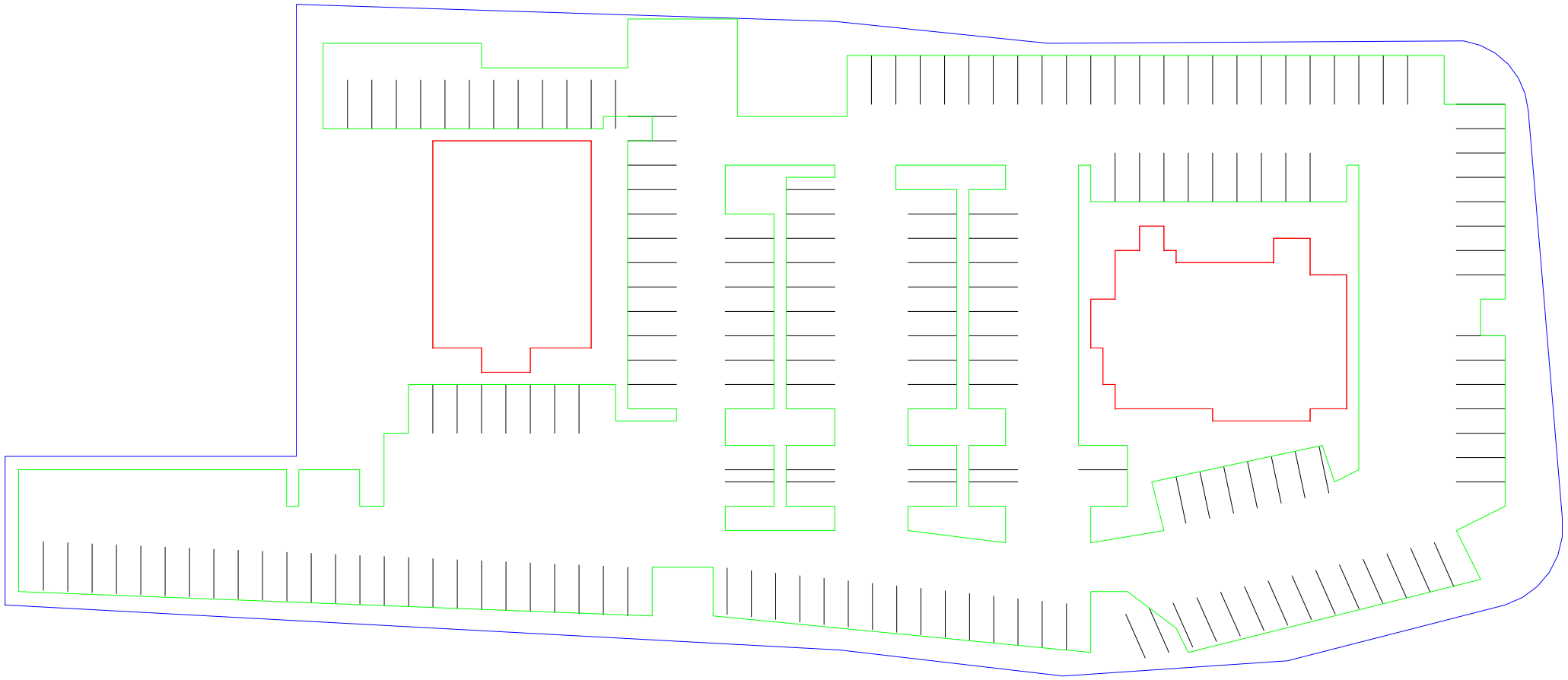




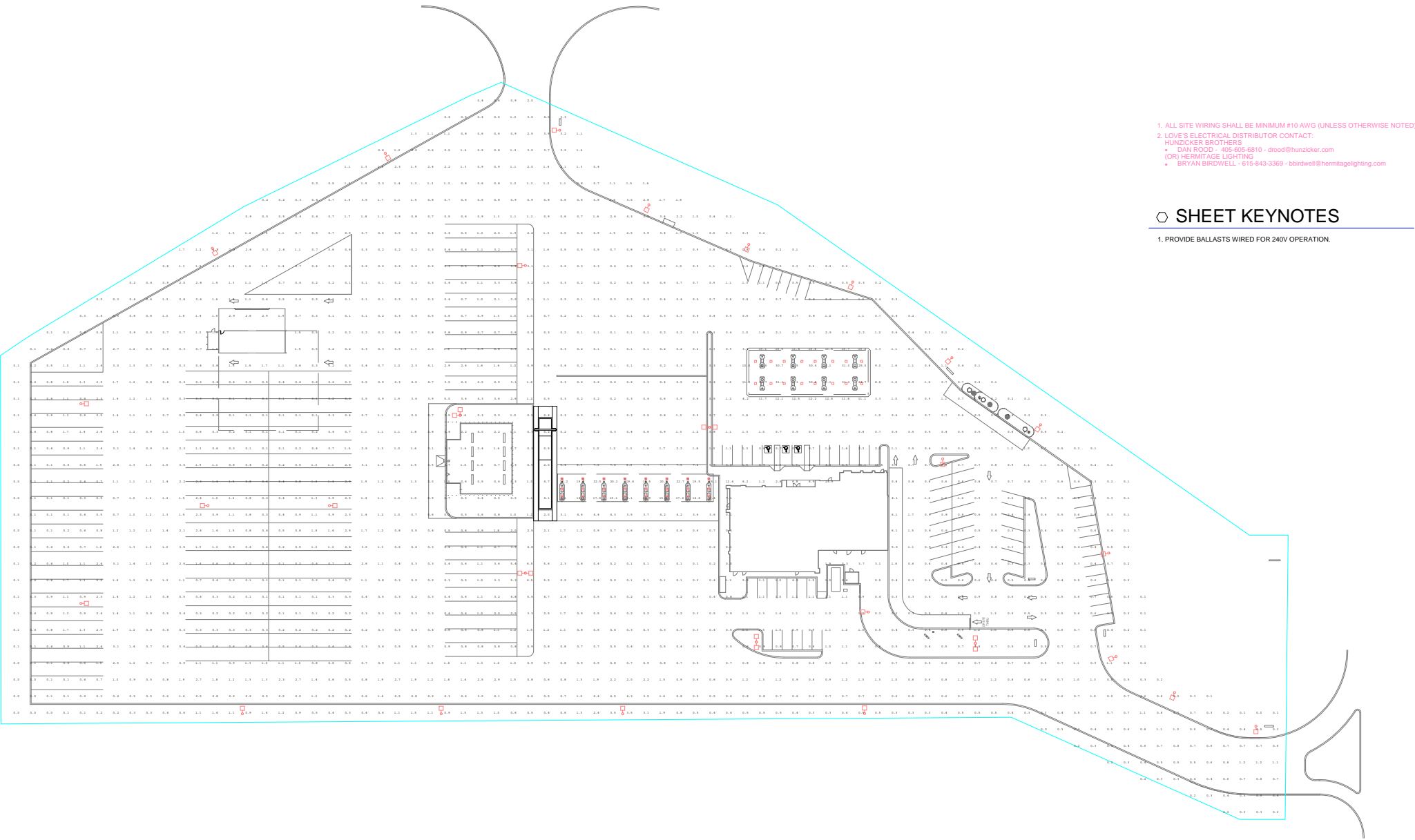
Project 6



Project 7



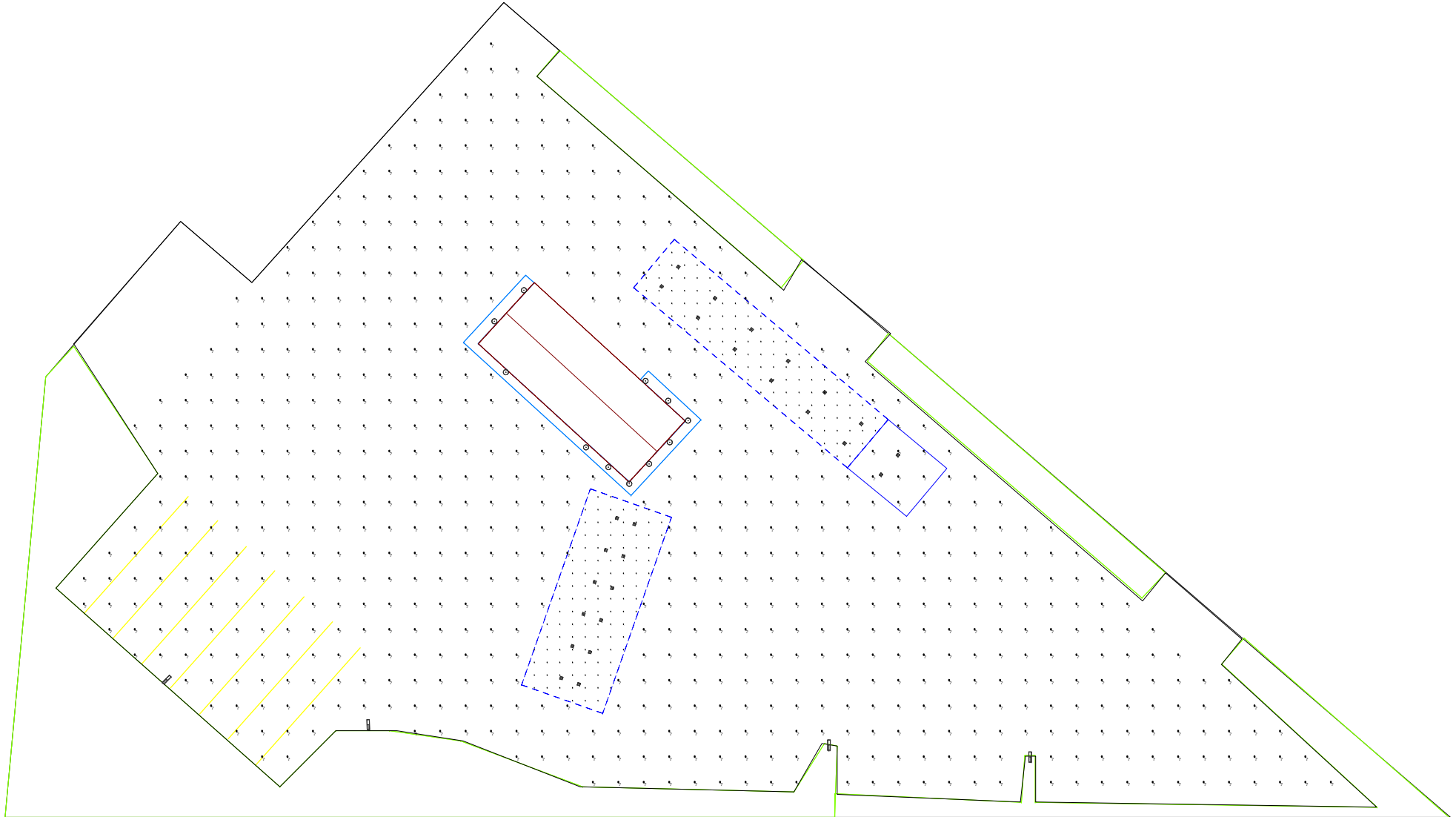
Project 8



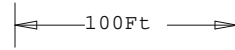
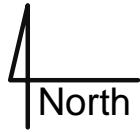
1. ALL SITE WIRING SHALL BE MINIMUM #10 AWG (UNLESS OTHERWISE NOTED).  
2. LOVE'S ELECTRICAL DISTRIBUTOR CONTACT:  
HUNZICKER BROTHERS  
• DAN ROOD - 405-605-8810 - drood@hunzicker.com  
(OR) HERMITAGE LIGHTING  
• BRYAN BIRDWELL - 615-843-3369 - bbirdwell@hermitagelighting.com

## ○ SHEET KEYNOTES

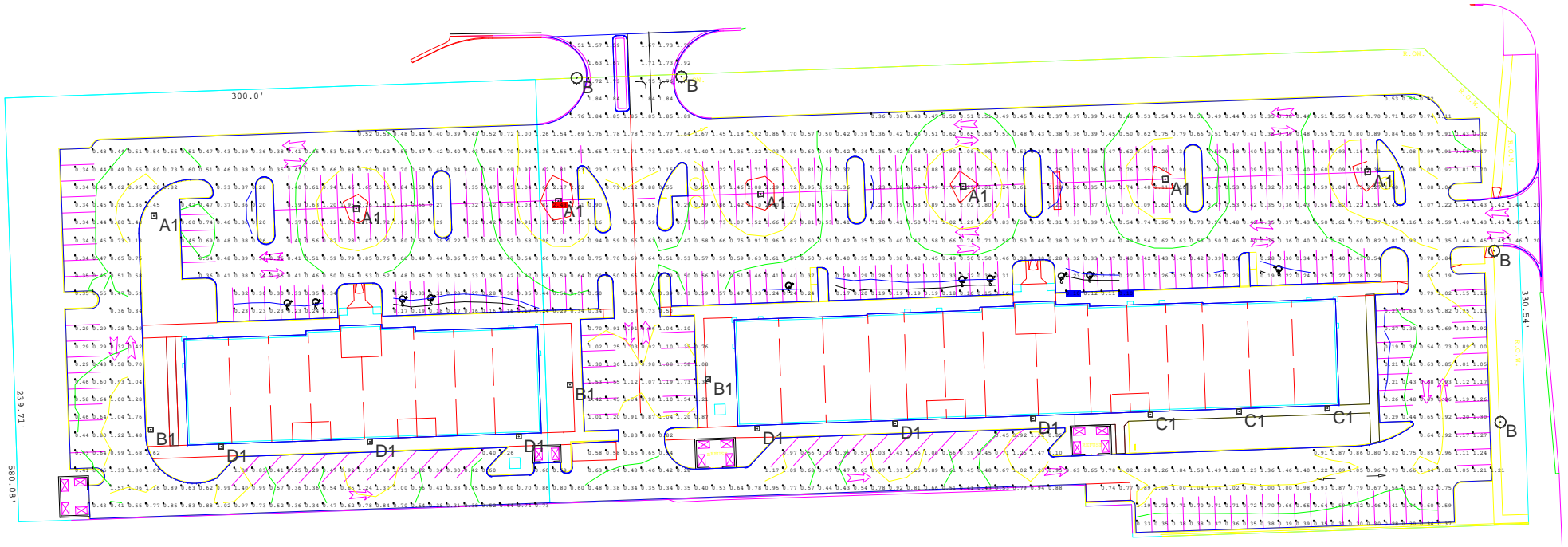
- 1. PROVIDE BALLASTS WIRED FOR 240V OPERATION.



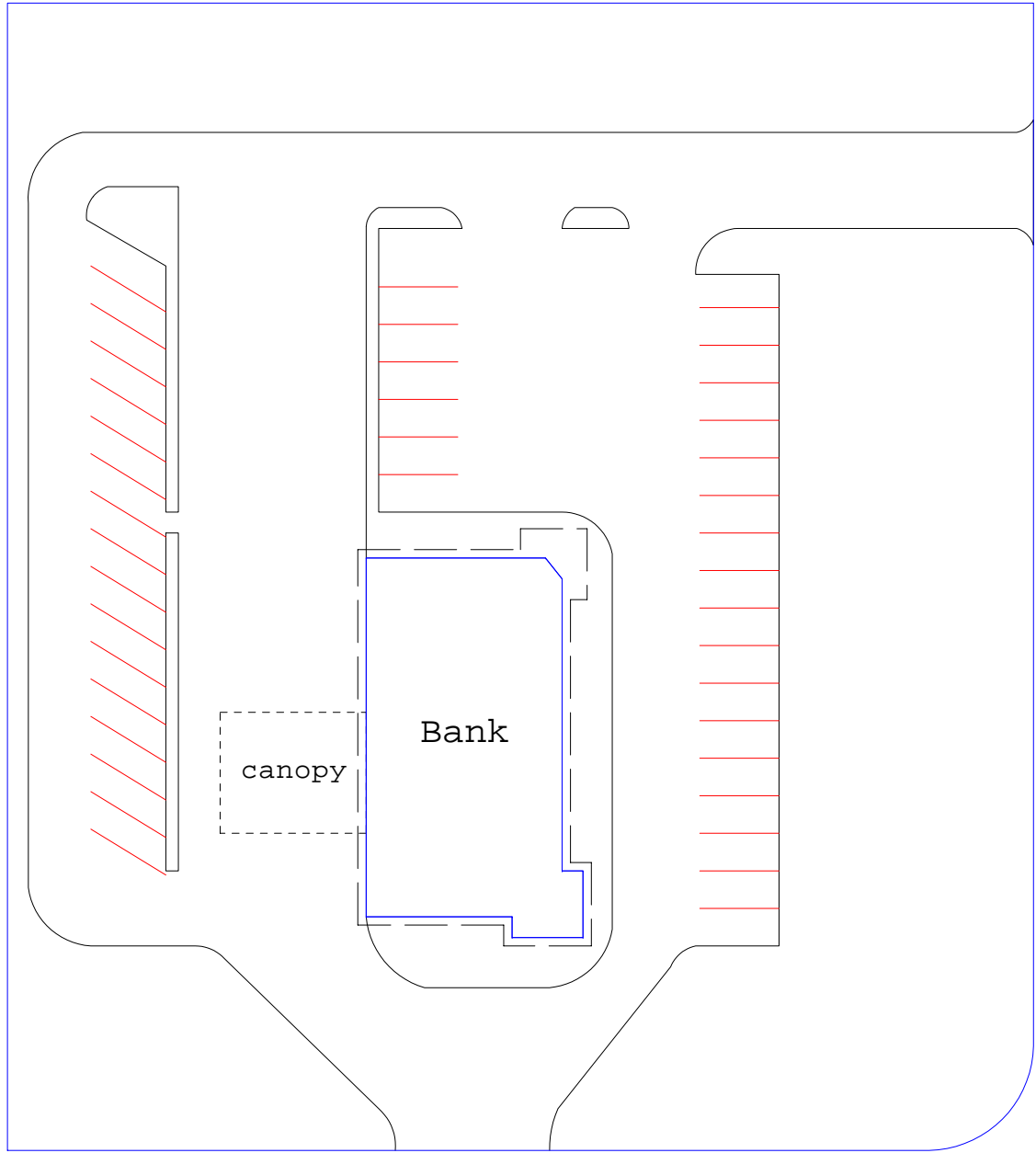
Project 10



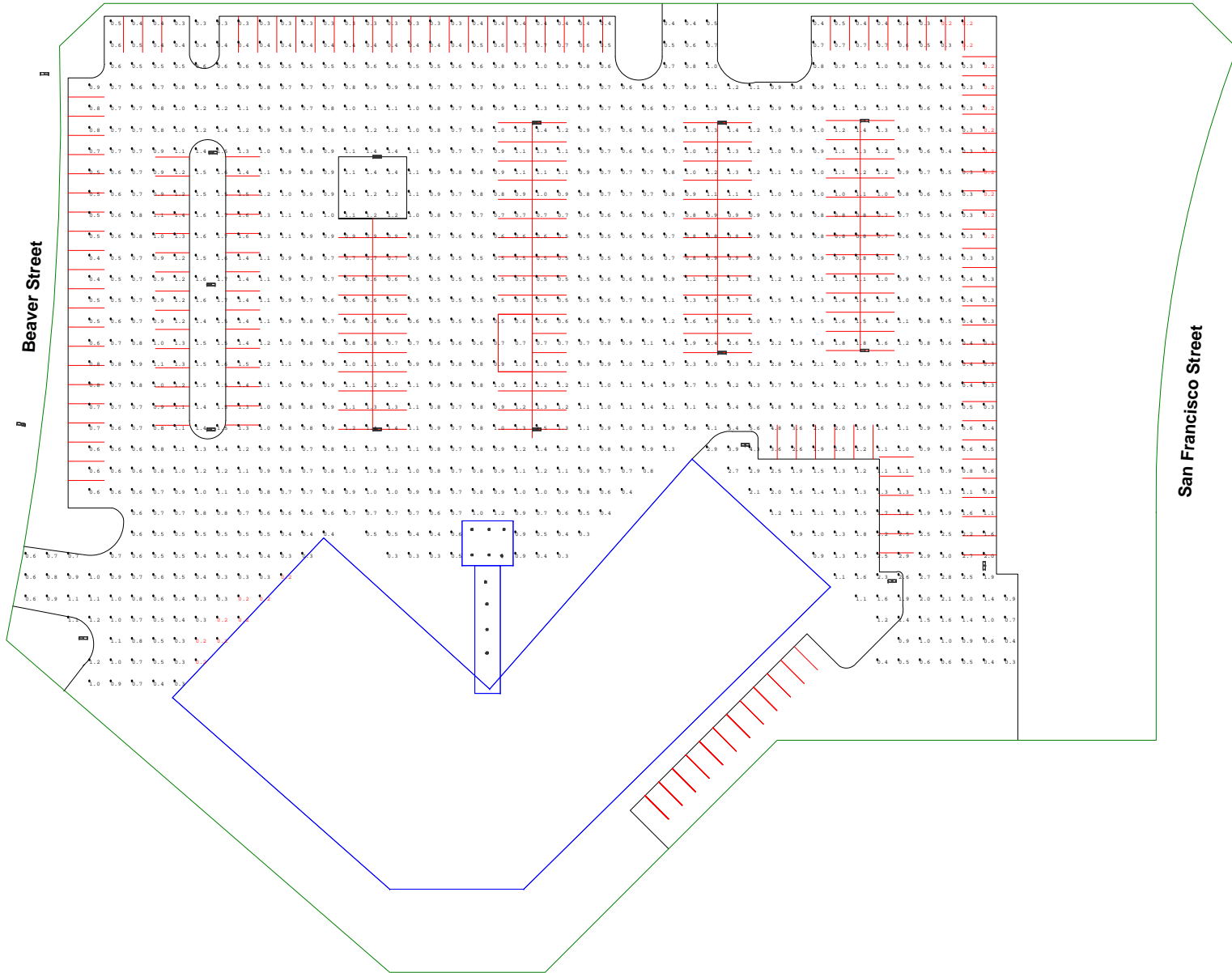
Calculation Summary						
Label	Units	Avg	Max	Min	Avg/Min	Max/Min
Parking lot_Planar	Fc	0.75	2.43	0.10	7.50	24.30



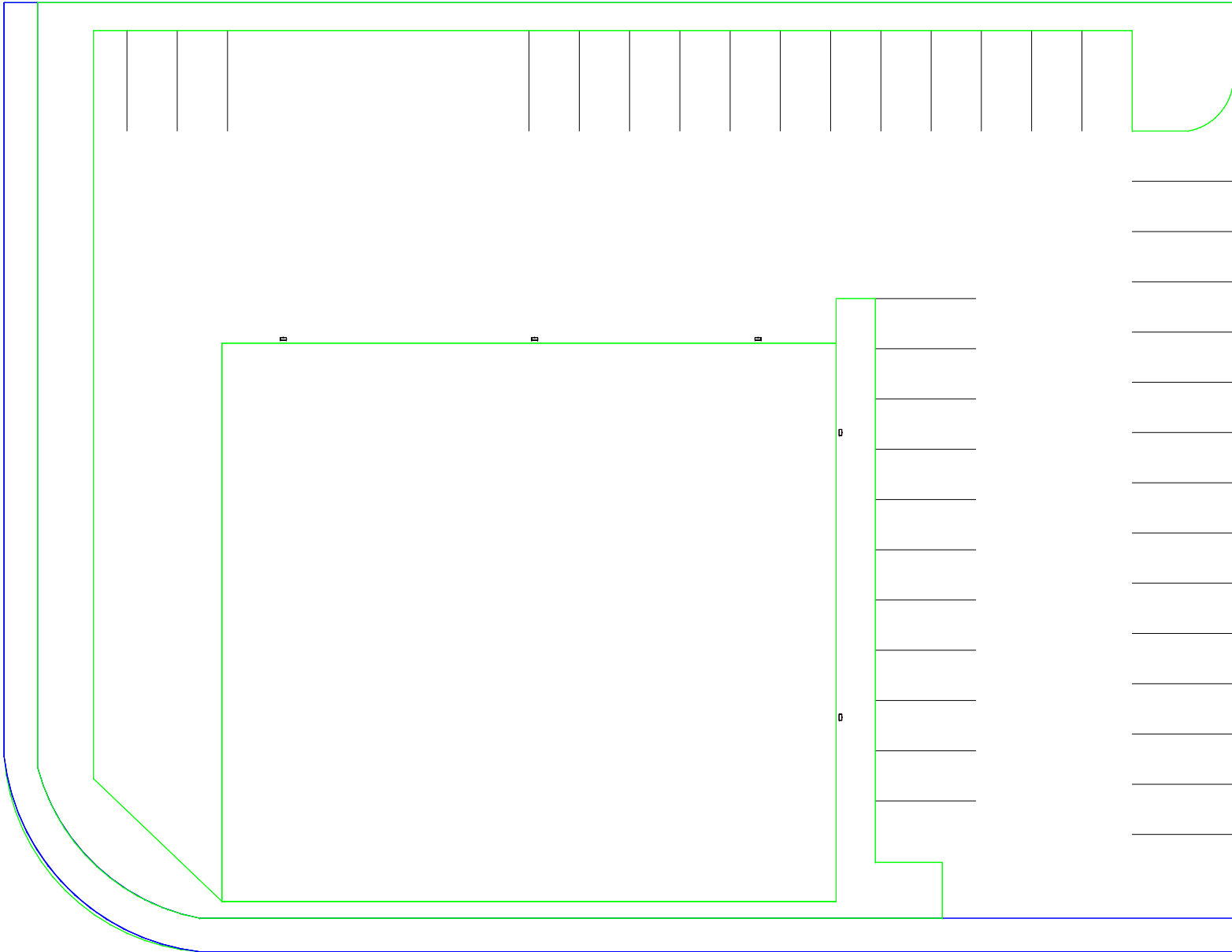
Luminaire Schedule				
Label	Description	Qty	Lumens	LLF
A1	Cooper AES-150-HPS-XX-5S	7	16000	0.750
B	American Elec. AVL 40S XX AM FG4	3	29000	0.750
B1	Cooper AES-150-HPS-XX-4S	3	16000	0.750
C1	Cooper AES-150-HPS-XX-SL	3	16000	0.750
D1	Cooper AES-100-HPS-XX-SL	6	9500	0.750



Project 12







Project 15