M E M O R A N D U M

To: Paul Griffin (BLM)
CC: Mary D'Aversa, Jay D'Ewart; Kimberlee Foster; Bryan Fuell; Gavin Lovell; Robert Price; June Wendlandt, Bea Wade (BLM)
From: Bruce Lubow, IIF Data Solutions
Date: 6/24/2015
RE: Statistical analysis for 2015 horse survey of Rock Springs area horse populations

I. Summary Table

Survey areas and Dates:	February 18, 2015 Little Colorado HMA February 19, 2015 Little Colorado HMA, White Mountain HMA April 13, 2015 Salt Wells Creek HMA & Adobe Town HMA April 14, 2015 Salt Wells Creek HMA April 18, 2015 Salt Wells Creek HMA & Adobe Town HMA April 19, 2015 Adobe Town HMA April 27, 2015 Divide Basin HMA April 28, 2015 Divide Basin HMA* April 29, 2015 Divide Basin HMA
Type of Survey	Simultaneous Double-observer
Aviation Company	Shane Gonzalez and Gene Boyle, pilots, Arrow West Aviation (Price, UT)
Agency Personnel	Jay D'Ewart, Lacey Anderson, Kent Benson, Shawn James, Caleb Hiner, Ben Smith (BLM), Paul Griffin (USGS), Eddie Lopez, Lou Arambel (in cooperation with the Rock Springs Grazing Association).

* Observations of four groups of Lost Creek HMA horses were incidental.

Table 1. Estimated population sizes (Estimate) are for the numbers of horses in the surveyed areas at the time of survey. 90% confidence intervals are shown in terms of the lower limit (LCL) and upper limit (UCL). The coefficient of variation (CV) is a measure of precision; it is the standard error as a percentage of the estimated population. Number of horses seen (No. Seen) leads to the estimated percentage of horses that were present in the surveyed area, but that were not recorded by any observer (% Missed, stated both as a percentage of the estimated horses and as a percentage of the horses seen). The estimated number of horses associated with each HMA but located outside the HMA's boundaries is already included in the total estimate for that HMA, as is the estimated number of adult horses on checkerboard lands.

Area	Age Class	Estimate (No. Horses)	% Missed (as percent of estimate)	LCL[a]	UCL	Std Err	CV	No. Horses Seen	% Missed (as percent of No. seen)	Estimated # of Groups	Estimated Group Size	Foals per 100 Adults	Est. No. Horses Outside HMA	Est. No. Adult Horses On Checker-board
Little Colorado HMA	Total	356	21.6%	264 [a]	460	58.3	16.4%	279	27.5%	47	7.5	7.8	0	0
	Foals	26		17	33	5.0	19.4%							
	Adults	330		246	428	53.9	16.3%							
White Mountain HMA	Total	270	10.1%	195 [a]	359	52.8	19.5%	243	11.2%	21	12.6	0.8	0	150
	Foals	2		1	5	0.8	37.6%							
	Adults	268		192	356	52.6	19.6%							
Complex Total (White Mtn. / Little Colorado)	Total	626	16.6%	515 [a]	816	83.6	13.4%	522	19.9%	69	9.1	4.7	0	150
	Foals	28		20	36	5.1	18.3%							
	Adults	598		494	779	79.9	13.4%							
Salt Wells Creek HMA	Total	616	25.1%	462	796	101.7	16.5%	461	33.5%	97	6.4	1.5	14	216
	Foals	9		4	14	2.7	29.6%							
	Adults	607		455	783	101.0	16.6%							
Adobe Town HMA	Total	858	13.9%	753	974	65.4	7.6%	739	16.1%	138	6.2	0.8	38	26
	Foals	7		4	10	1.7	24.9%							
	Adults	851		748	966	65.1	7.7%							
Complex Total (Adobe Town / Salt Wells)	Total	1473	18.6%	1287	1669	124.9	8.5%	1200	22.8%	235	6.3	1.1	51	242
	Foals	16		11	21	3.0	18.7%							
	Adults	1457		1272	1652	124.2	8.5%							
Divide Basin HMA	Total	579	17.3%	506	710	61.9	10.7%	479	20.9%	110	5.3	3.7	97	232
	Foals	20		15	27	3.3	15.9%							
	Adults	559		487	690	60.1	10.8%							

[a] 90% confidence interval based on percentiles of bootstrap simulation results. The lower 90% confidence interval limit (LCL) is actually less than the number of horses sighted during the survey for these estimates. This is a normal statistical result and reflects the fact that a confidence interval expresses what would likely happen if the survey were repeated. If repeated many times, some surveys would miss more horses and produce lower estimates, even after corrections, than were actually observed during this survey. Clearly, I conclude that there are at least as many horses as were observed during this survey, rather than using the lower confidence limit as a minimum number.

II. Narrative

In February and April of 2015, Bureau of Land Management (BLM) personnel conducted simultaneous double-count aerial surveys of the wild horse populations in: White Mountain HMA, Little Colorado HMA, Adobe Town HMA, Salt Wells Creek HMA, and Divide Basin HMA (Figure 1). White Mountain HMA and Little Colorado HMA are considered to be a complex, for management purposes. Similarly, Adobe Town HMA and Salt Wells Creek HMA are considered to be a complex, for management purposes.

I analyzed these data to estimate sighting probabilities, which I then used to correct the raw counts for systematic biases (undercounts) that are known to occur in aerial wildlife surveys, and to provide confidence intervals (which are measures of uncertainty) associated with the estimated population sizes for the HMAs and surrounding areas that were surveyed.

Population Results

The estimated total horse populations (Table 1) within these areas provided a relatively large sample size of observations (343 horse groups, Table 2, Figure 1), on which to base statistical estimates of sighting probability. In addition to the horses reported in Table 1, 22 horses were seen within the Lost Creek HMA, which was not fully surveyed; those horses contributed to my analysis but I am not presenting any conclusions about Lost Creek HMA populations.

Estimated sighting probabilities were somewhat lower than for similar surveys and lower than the 2014 survey of these areas (see Sighting Probability Results section). Relatively low sighting probabilities resulted in relatively large confidence intervals and coefficients of variation that may be adequate for some management purposes, but are not as good as might be desired. In addition to the estimated errors, biases in the estimates could still exist due to heterogeneity of sighting probabilities that were not fully accounted for in this dataset, particularly due to the excessively large number of observers used in this survey, which required pooling some observers with insufficient data, thereby precluding estimation individual acuity for those observers. The large number of observers also reduces precision by requiring many more parameters to be estimated than would otherwise be necessary. Suggestions for improving future surveys are offered in the Recommendations section.

Sighting Probability Results

The front observers saw 50.4% of the groups (53.3% of the horses) seen by any observer, whereas the back seat observers saw 83.4% of all groups (88.0% of horses) seen (Table 2). There were undoubtedly additional groups not seen by any observer; I address this issue in the analysis that follows. These results demonstrate that simple raw counts do not fully reflect the true population without statistical corrections for missed groups, made possible by the double observer method and reported here.

Correction for sighting probability resulted in a statistically estimated 17.9% of horses present in the surveyed areas not being observed, on average, although the percentage missed was as high as 25.1% at Salt Wells Creek HMA.

The analysis method used for the surveyed areas were based on simultaneous double-observer data collected during these surveys. Informed by preliminary analyses and *a priori* reasoning, all models used in the double-observer analysis contained an estimated parameter for an intercept common to all observers. I also included a parameter in all models to account for the lower sighting probability for the front-seat observers when a group was on the pilot’s side of the flight path due to the pilot’s focus on flying and the obstructed view from the opposite side. This is a well established effect. I also included individual parameters for each unique back-seat observer based on a preliminary analysis that indicated virtually no support for models with only a common effect of back seat location relative to the individual effect by observer (i.e., there was very strong evidence for differences in sighting acuity among the back-seat observers).

No groups were recorded on the centerline, so I did not include a parameter to account for the inability of back-seat observers to see this type of group. Only 1 group was recorded as seen spread across both sides of the flight path and visible from both sides of the airplane so I pooled this observation with those seen on only 1 side. I did not consider parameters for effects of vegetation, snow, topography, or lighting because conditions were too uniform to obtain meaningful estimates of these effects.

I tested all combinations of 6 possible effects on sighting probability by fitting models for all possible combinations of these effects, resulting in $2^6 = 64$ alternative models. The 6 effects were: (1) horse movement, (2) horse group size, (3) distance from observer to horse group, (4) unique effects for each front seat observer, (5) a unique effect for pilot SG (2 pilots were used for different portion of these surveys, pilot GB was considered the default), and (6) survey area (HMA), but with observations for Lost Creek pooled with Divide Basin due to the small sample size for Lost Creek and the apparent similarity of these adjacent areas.

Differences in sighting acuities of front-seat observers were strongly supported (90.6% of model weight). The effect of horse activity had minimal effect (27.1%). The remaining effects received moderate support: survey area 68.6%, pilot SG 63.8%, group size 60.1%, and distance 53.0%.

Visibility in the front for groups on the pilot's side was markedly lower, as expected (Table 3). Visibility was greater for active groups, larger groups, and groups closer to the flight path, also as expected. Sighting probability was higher for the average back seat observer than for front-seat observers. Average sighting probability (under baseline conditions, see Table 3) ranged widely across individual observers from 78.4% to 94.7% for front seat observers and between 81.4 – 96.8% for back-seat observers. Average sighting probabilities also varied widely among survey areas, from 74.0% in Little Colorado to 92.2% in White Mountain

The estimated sighting probabilities for the combined observers and the covariates recorded for all observed horse groups ranged across from 56.7-82.7%. For front-seat observers, independent sighting probability ranged from 9.5-89.2% and for back-seat observers it was from 33.6-93.2%. Comparing actual horses seen (No. Horses Seen, i.e., the 'direct count') to the estimated population size computed from the estimated sighting probabilities (Estimate, No. Horses), I estimate that 17.9% of the horses in these combined surveys were never seen by any of the observers, with as much as 25.1% missed in Salt Wells Creek HMA (Table 1). The low sighting probabilities resulted in wide confidence intervals and coefficients of variation ranging from 7.6% to 19.5% across survey areas (excluding Lost Creek). Even in these survey areas with excellent sighting conditions characterized by very open and relatively smooth terrain, significant adjustment to raw counts for those groups not seen by any observer are needed. This underscores the importance of using a statistical method for correcting raw counts.

Assumptions and Caveats

The results obtained from these surveys are estimates of the horses present in the areas surveyed at the time of the survey and should not be used to make inferences beyond this context.

The reliability of results from any population survey that is based on the simultaneous double-observer method rests on several important assumptions. Given several potential sources of bias, listed below, it is more likely that the estimates are somewhat lower, rather than higher, than the true population.

First, the simultaneous the double-observer method assumes that all groups of animals are flown over once during a survey period, and thus have exactly one chance to be counted by the front and back seat observers, or that groups flown over more than once are identified and considered only once in the analysis. Groups counted more than once would constitute ‘double counting,’ which would lead to estimates that are biased higher than the true number of groups present. Additionally, groups that were never available to be seen (for example, due to temporary emigration from the study area or due to moving, undetected, from an unsurveyed area to one already surveyed) can lead to estimates that are negatively biased compared to the true population size. Although attempts were made to minimize the potential for horse movement among survey days by making use of fences, rivers, and topographic barriers, inter-day horse movements during a multi-day survey could potentially bias results if those movements result in unintentional double counting or unavailability of groups. The identification of ‘marker’ horses (horses with unusual coloration) in each group, and variation in group sizes, helped to reduce the risk of double counting during aerial surveys, and the results presented here are based on a survey design and methods that assume that any unobserved movements were random, so the effects would cancel each other out. Unfortunately, the assumption of no movement within the survey area during the survey (potentially leading to double counting or unavailable animals) may have been violated in the complex made up of the Adobe Town HMA and Salt Wells Creek HMA; there, the survey had to be suspended for 3 days because an unexpected storm interrupted the survey. Before the storm, the survey crew did manage to survey most of the complex west and north of Kinney Rim, which is a substantial topographic barrier that the survey lead assumes would have limited any movement (J. D’Ewart, pers. comm.).

Second, this method assumes that all horse groups with identical sighting covariate values have equal sighting probability. If there is additional variability in sighting probability not accounted for in the sighting models, such heterogeneity could lead to a negative bias (underestimate) of the population. This is of greater concern when sighting probabilities are lower, as was the case in this survey and is another reason why modifying future surveys to improve sighting probability would be desirable.

A third assumption is that the number of horses in each group is counted accurately. In very large groups it may be common to miss a few horses unless photographs are taken and scrutinized after the flight. Relying on raw counts made from the airplane could lead to biased low estimates of population size.

Recommendations for Future Surveys

Several observations about the data may offer opportunities to improve future surveys.

1. There is a substantial benefit to maximizing the sighting probabilities and minimizing the number of different factors that cause variation in sighting probability. By far the most potent means to accomplish both objectives is to drastically limit the number of observers used in future surveys. In this survey 6 individuals observed from the front seat and 8 from the back. Two of these observed only 6 groups each–a completely inadequate sample size for estimating their individual acuity. First of all, there is no need to rotate observers in the front seat–a single observer should be used for the entire set of surveys, if possible, and no more than 2. Using a single pilot is also preferred (2 were used in these surveys), but it is understandable that, sometimes, pilot availability in long sets of surveys can be out of agency control. Back seat observers must be rotated, as they were, but they should be limited to as few as possible–ideally only 2 but no more than 3 or 4 unique individuals. All observers should be present long enough to accumulate >30 observations. Most important, observers should be carefully selected based on their past performance and ability to spot horses. The

wide variation in acuity of the observers used in this survey suggests a great opportunity to both reduce the total number of observers and retain only those with high sighting probabilities. It is especially important to use the best possible observer in the front seat. These changes could dramatically improve the precision and reduce the risk of undetected biases in future results.

2. Group sizes range from 1 to 80 horses in this survey with 53 groups (15.5%) containing >10 horses (14 groups of those groups had >20 horses), so inaccurate counting was a substantial risk for some groups. Observers circled over large groups to get as accurate a count as possible but did not use photography to record group size of large groups. Using photography is in the drafted standard operating procedures for double-observer aerial surveys for horses, when group size is 20 or more. The survey lead indicated his reluctance to use photography, as it requires additional circling around groups that could cause air sickness. If photos are only taken of groups with 20 or more horses, though, that would have required photography in less than 1 in 20 observations. I emphasize the importance of using photography for large horse groups (>10 preferable, >20 is extremely important) to ensure that such groups are counted accurately. Given the tendency for horses in this area to form large groups, all future surveys should use photography so that group sizes recorded in flight can be validated with reference to photographs after the flight. Surveys should use a reliable, high-resolution camera with an adequate telephoto or zoom lens for the distance between observer and horses for this purpose.

3. The pilot followed predetermined transect lines that were loaded into the pilot's GPS unit during most of the fight. The flight lines were spaced at regular distances approximately 1.5 miles apart, reflecting the fact that there was little variation in topography or vegetation and sighting conditions were favorable. The pilot followed the same pattern of planned flight lines (Figure 1) as was used for these surveys in 2014. However, there were significant deviations from the planned flight path that left a gap of 3 miles in the area of Pine Butte in the Salt Wells Creek HMA and another of about 4.5 miles in Adobe Town. The spacing of actual flight lines flown in White Mountain was also somewhat inconsistent. Pilots should be instructed to avoid these variations and gaps by closely tracking the preplanned path on the GPS. As an alternative to improving the number and ability of observers, closer transect spacing could be another way to improve sighting probabilities, however, this alternative would increase flight time and costs, whereas limiting the observers may only incur relatively minimal travel costs.

4. Temporary emigration into or out of the surveyed areas was unlikely to have been a significant problem, because the survey lines extended well beyond the HMA boundaries, especially where fencing, highways, and other barriers were not present, such as west of the Divide basin HMA. There were some horse group observations at the northern extent of the survey lines for Little Colorado HMA and Divide Basin HMA, though; future surveys may need to have survey lines that extend slightly further north there, to fully encompass the horse populations using those areas.

5. To the extent possible, future inventories should continue to include all the HMAs in any complex together on consecutive days, in a consistent season, and using as many of the same observers across all HMAs as possible. Whenever a storm that could disrupt a survey is forecast and the aircraft can be rescheduled, it would be best to wait to begin the survey of a given HMA or complex until the storm has passed.

Table 2. Tally of raw counts of horses and horse groups by observer (front and back) and survey year for combined HMAs. This table is based on raw counts (not statistical estimates) and, therefore does not address groups not seen by any observer.

Observer	Groups Seen (Raw Count)	Horses Seen (Raw Count)	Actual Sighting Rate[a] (groups)	Actual Sighting Rate[a] (Horses)
Front	173	1,185	50.4%	53.3%
Back	286	1,956	83.4%	88.0%
Both	116	918	33.8%	41.3%
Combined	343	2,223		

[a] Percentage of all groups seen that were seen by each observer.

Table 3. Effect of observers and sighting condition covariates on estimated sighting probability of horse groups for both front and rear observers. The Baseline detection probability for the front observer and the baseline detection probability for the back seat observer are both shown in bold in the far right columns. These baseline values reflect the mean effect of all front observers or all back observers, respectively, for the baseline covariates (BC), defined here as a group of 5 horses (the median value of group size), that was standing still, visible on the right side of the flight line (e.g., not the pilot's side), at a distance of ½-1 mile from the transect (the most common value), with pilot GB, using the mean value across all HMA survey areas. The effects of variation from the baseline covariates are shown in this table, one effect at a time, as indicated in the "BC or Other Effect" column. Sighting probabilities for each row should be compared to the baseline (first row) to see the effect of the change in observer or condition. Baseline values are shown in bold wherever they occur. Sighting probabilities are calculated from weighted averaged model parameters across all 64 models.

	Area	Front Seat Observer ID	Back Seat Observer ID	BC or Other Effect	Sighting Probability, Front Observer	Sighting Probability, Back Observer
Baseline	Mean	Mean	Mean	BC	**88.4%**	**92.4%**
Effect of Pilot's Side [a]	Mean	Mean	Mean	BC	49.3%	**92.4%**
Effect of Pilot = SG	Mean	Mean	Mean	Pilot = SG	93.9%	**92.4%**
Effect of activity	Mean	Mean	Mean	Horses moving	88.8%	92.7%
Effect of group size	Mean	Mean	Mean	N = 1	65.5%	75.2%
				N = 10	97.8%	98.6%
Effect of distance	Mean	Mean	Mean	1/4-1/2 mile	89.9%	93.4%
Effect of area						
	Little Colorado	Mean	Mean	BC	74.0%	82.0%
	White Mountain	Mean	Mean	BC	92.2%	95.0%
	Salt Wells Creek	Mean	Mean	BC	87.0%	91.5%
	Adobe Town	Mean	Mean	BC	89.1%	92.9%
	Divide Basin = Lost Creek			BC	91.1%	94.3%
Effect of front observer						
	Mean	CH	Mean	BC	94.7%	**92.4%**
	Mean	LS	Mean	BC	87.1%	**92.4%**
	Mean	EL	Mean	BC	85.4%	**92.4%**
	Mean	LA	Mean	BC	81.8%	**92.4%**
	Mean	SJ	Mean	BC	78.4%	**92.4%**
	Mean	KB	Mean	BC	94.5%	**92.4%**
Effect of back observer						
	Mean	Mean	LA	BC	**88.4%**	96.8%
	Mean	Mean	PG = SJ = JD = BS	BC	**88.4%**	94.5%
	Mean	Mean	CH	BC	**88.4%**	91.9%
	Mean	Mean	LS	BC	**88.4%**	78.9%
	Mean	Mean	EL	BC	**88.4%**	81.4%

[a] Sighting probability for the front observers acting as a team when the horses were on the pilot's side of the flight path, regardless of which of the front observers saw the horses first.

Figure 1A. Map of February 18-19, 2015 survey of White Mountain HMA (blue outline) and Little Colorado HMA (red outline), and April 27-29, 2015 survey of Divide Basin (green outline) with GPS recordings of actual flight paths (white lines) flown. Circles are GPS waypoints at the locations where observers saw groups of animals. Black lines are fences. Adjacent management areas not included in this survey are shown for reference: Salt Wells Creek (yellow), Antelope Hills (pink), and Lost Creek (purple).

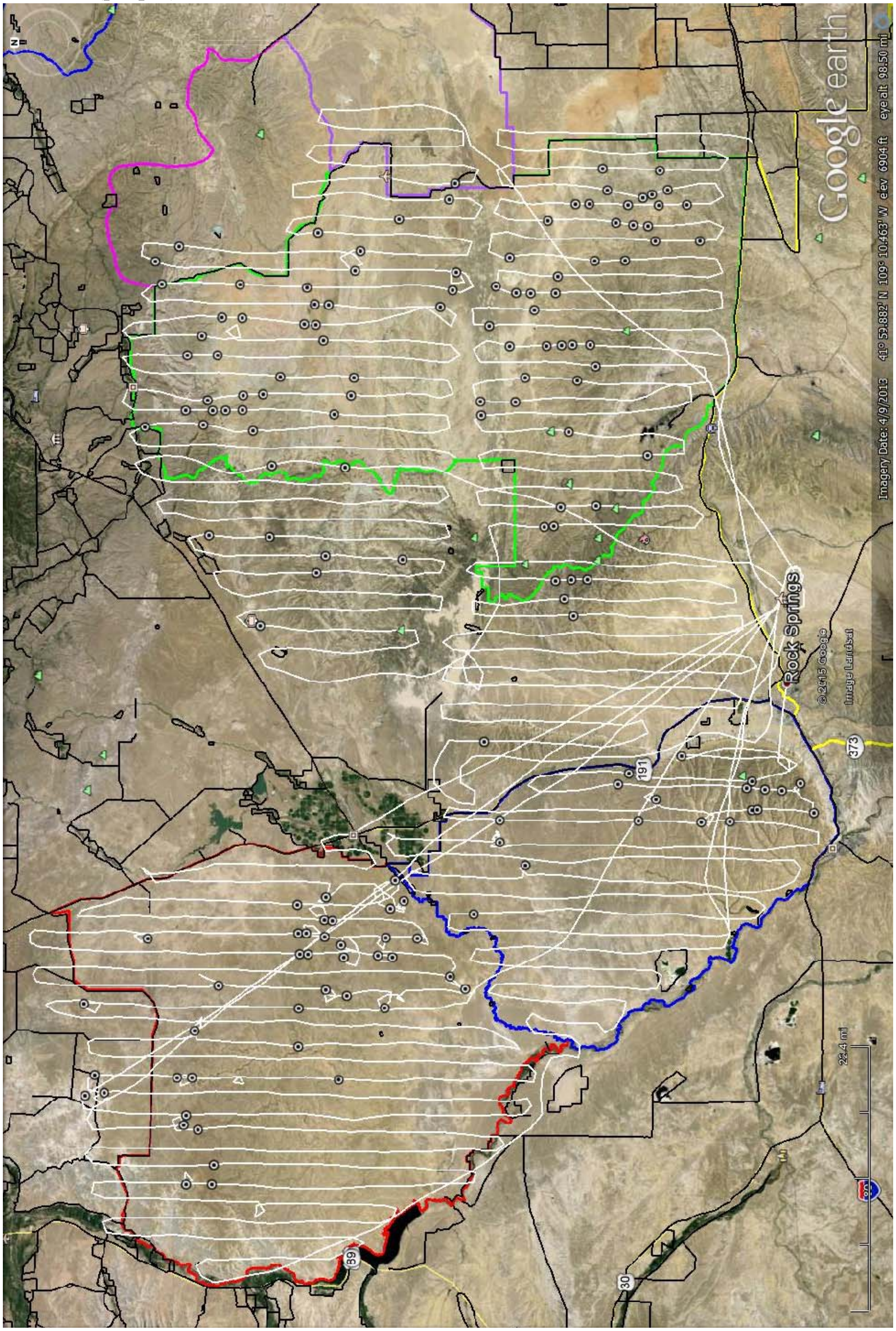

Figure 1B. Map of Adobe Town (orange outline) and Salt Wells Creek (yellow outline) and GPS recordings of actual flight paths (white lines) flown for April 13-19, 2015 survey. Circles are GPS waypoints at the locations where observers saw groups of animals. Black lines are fences. Adjacent management areas not included in this survey are shown for reference: White Mountain HMA (blue outline) and Divide Basin (green outline).