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SEEDING INCREASE ESTIMATES FOR THE LOPEZ LAKE WATERSHED CLOUD SEEDING PROGRAM OPERATED DURING THE 2020 WATER YEAR

SUMMARY OF RESULTS

Table 1.

Summary of Results

Measure	Total for Seedable Period (AF)	Increase Attributed to Seeding (AF)	Cost per AF ($)
Runoff	3,098	468	353
Precipitation	30,000	3,200	52

The 2020 Water Year was characterized by long dry spells resulting from persistent high-pressure systems above the central coast. With contracts formalized near the end of December the commencement of operations was delayed until the first part of January. The first seeding opportunity came in March of 2020. Though still below average, the earlier start in operations during the current season has yielded far more seeding opportunities. NAWC has already performed more seeding for the 2021 Water Year than was performed during the entirety of the 2020 Water Year.

The Cloud Seeding program performed by NAWC for the 2020 Water Year cost a total of $165,525 and resulted in a calculated inflow (runoff captured by Lake Lopez) increase of an estimated 468 acre-feet (AF) of water. This equates to a cost per acre-foot of $353, which is substantially less than other sources of water in the region. For the 2021 Water Year, NAWC recommended the transition to a “ground-only” seeding program to increase the overall program efficiency. Ground based programs in California’s Central Coast have been the topic of numerous studies over the course of the last 50 years, and have been found to yield similar results to aircraft programs when seeding “convective” storms, particularly “convective bands.”

LOPEZ LAKE WATERSHED

Updating the Target Area and Watershed Maps

In order to provide an accurate estimate of the total rainfall and runoff that benefitted Lopez Lake, NAWC undertook a topographical review of the Lopez Lake Watershed. NAWC reviewed the KMZ files of the watershed internally, then compared our findings to the Basin maps provided by the California Nevada River Forecast Center (CNRFC). Updating the boundary map of the watershed was critical to ensuring an accurate estimate of the 2019-2020 program benefits.

The current map was defined in the original Feasibility and Design Study (Figure 1.) and represents a land area of roughly 61,285 acres. After thorough topographical review, NAWC determined that roughly 19,000 acres of the defined area drained into Huasna Creek, not into Lopez Lake. Comparison with CNRFC basin boundaries confirmed NAWC's findings.

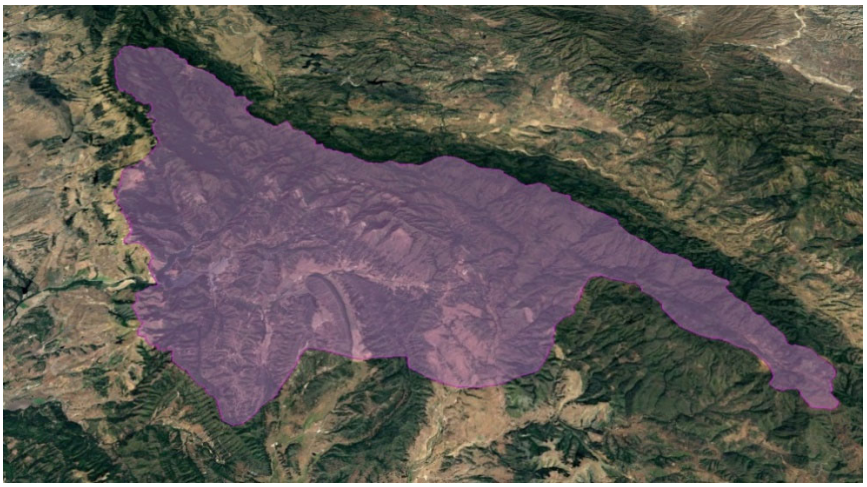

Figure 1. **Lake Lopez Watershed as defined in the original feasibility and design study.**

The updated watershed map is provided (Figure 2.) for visual reference, and a KMZ files is available upon request.

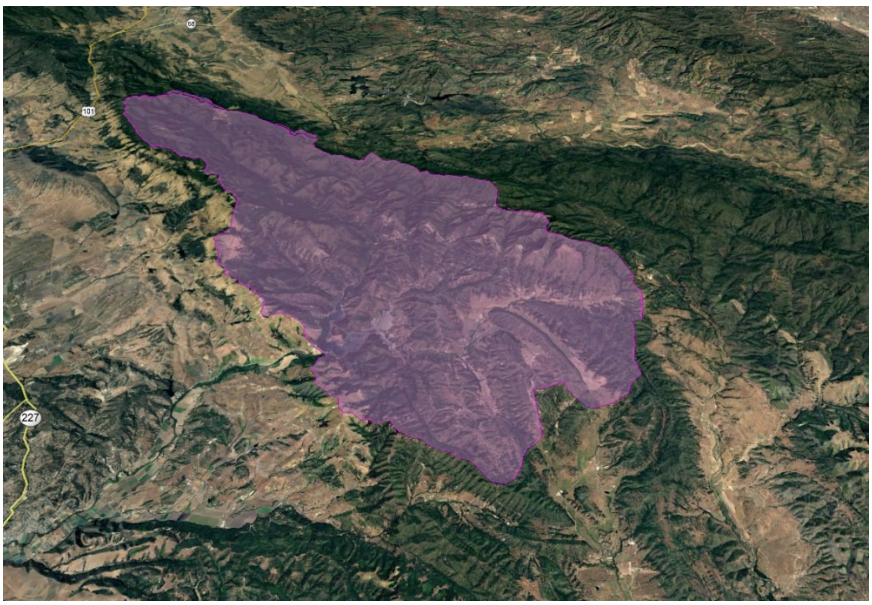

Figure 2. **Updated map of the Lake Lopez Watershed.**

Watershed Runoff Patterns

For evaluation purposes, NAWC has divided the watershed into three drainage zones based on significant topographical features and runoff patterns (Figure 3.). The primary boundary for the three zones is defined by a mountainous barrier that runs east/northeast across the central portions of the watershed. This geographical boundary extends from Lake Lopez to the northeastern boundary of the watershed, and is responsible for the lakes horseshoe-like appearance. Zones 1 and 2 produce runoff that enters the northern portion of Lake Lopez while zone 3 produces inflow into the southern portions of the lake. Zone 1 is the only source of *metered* inflow into Lake Lopez through Lopez Creek. The other 2 zones produce runoff through various unmetered and unregulated canyons, channels and creek beds.

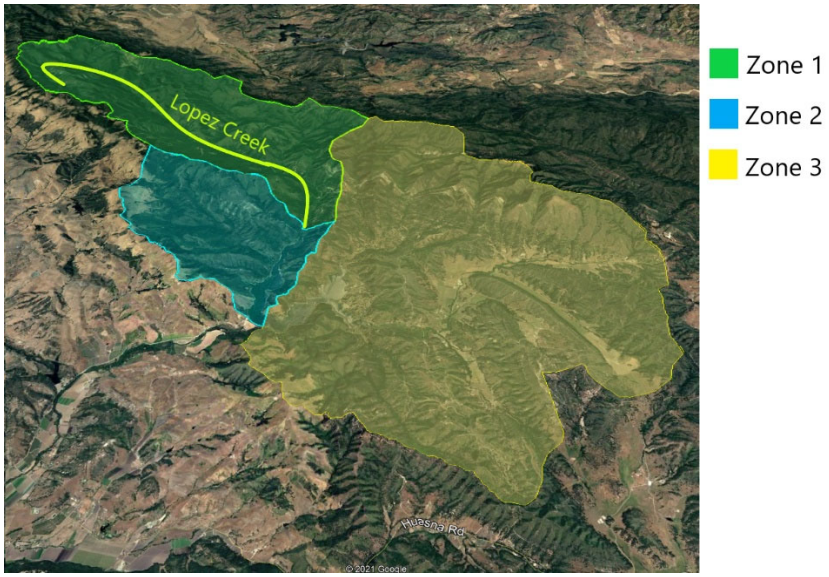

Figure 3. **Drainage zones for the Lake Lopez Watershed.**

ESTIMATING RUNOFF AND RAINFALL

Lopez Creek Inflow Estimates

During a typical year, total inflow numbers for Lopez Lake from Lopez Creek can be estimated using stream gage data. For the 2020 Water Year NAWC has been unable to locate data sufficient for determining seasonal stream flow totals from the USGS. Daily data is charted online but is insufficient for a reliable seasonal estimate. Using Total inflow estimates provided by SLO County, and a regression derived from a multi-year evaluation NAWC estimates that 1452 AF of inflow occurred through Lopez Creek.

Though the Lopez Creek Drainage only accounts for roughly 1/3 of the Lopez Lake Watershed (by areal representation), historical records indicate that this creek is responsible for just shy of 50% of the total inflow into Lopez Lake.

During the design and feasibility study, it was determined that the average inflow from Lopez Creek into Lopez Lake (from 1969 through 2009) is 6,606 acre-feet, suggesting that runoff for the 2020 Water Year was only 22% of average. During the seeding period of January – April of 2020, rainfall at Lopez Dam was measured at close to 80% of average, suggesting that precipitation fared far better than runoff during this period. This is not unusual for watersheds experiencing below average precipitation, as dry soil conditions can require substantial amounts of rainfall before measurable runoff occurs.

Additional Inflow

Depending on weather patterns and soil conditions Zones 2 and 3 have historically accounted for 50-60% of the inflow into Lake Lopez. Given the soil conditions that permeated that the watershed last year NAWC would predict that contributions from Zone 3 (particularly from the more southerly portions of Zone 3) represented a smaller percentage of total inflow into Lake Lopez. This correlates well with our estimates for Lopez Creek runoff of roughly 1500 AF and SLO Counties estimates for total inflow equaling just over 3,000 AF.

Determining the source of inflow isn't critical to NAWC's calculations for total increase estimates. This information does, however, play a role in our planning and operations.

RUNOFF AND RAINFALL INCREASE ESTIMATES

Runoff and Inflow Increase Estimates

Two precipitation gauges (Lopez Dam and Lopez Recreation Area) were correlated with runoff from Lopez Creek. Precipitation data were available online for these sites going back to the 2008 Water Year. Another gauge (Upper Lopez) which is located further inside the target area, was established more recently in early 2020. Rainfall data was compared to radar derived rainfall estimates for one seeding event in March 2020 to help verify the representativeness of these gauge sites to the target area as a whole.

Regressions conducted using recent precipitation data from the Lopez Dam and the Recreation Area sites concluded that a 10% seasonal increase in precipitation (due to seeding operations) would produce runoff increases of 13-17% with the more correlated of the gauges (Lopez Dam) indicating a 17% increase in runoff. In the original SLO program feasibility study, a 9% precipitation increase resulted in a roughly 13% increase in Lopez Creek runoff and a roughly 18% increase in Lopez Lake inflow. From these analyses NAWC determined that an overall 10% increase in precipitation in the watershed would yield a 15% to 18% increase in the total inflow to Lopez Lake for the 2020 water year.

Increases in runoff are generally higher (in terms of percentages) than increases in precipitation, due to the fact some precipitation is usually lost to recharging soil moisture before runoff begins. Thus, additional precipitation (due to seeding) tends to increase the overall efficiency of runoff a multiplicative or even exponential rate, especially in dry years.

Under the right conditions, a 10% increase in **individual** storm productivity will be the difference between little to no runoff and measurable runoff. During storms of sufficient magnitude, all or portions of the 10% increase will fall after soil conditions have met saturation thresholds and runoff is occurring. These storms result in a very high efficiency between storm seeding increases and runoff increases.

Using the total Lopez Lake inflow value of 3,098 AF in 2020 and applying the derived increase estimates (based on multi-year historical data analysis) cloud seeding in the Lopez Lake Watershed resulted in an estimated **468 AF** inflow (to Lopez Lake) increase.

Note that the results of work performed most recently for the Santa Barbara cloud seeding program suggest precipitation increases closer to 17% for convective storms, which would corelate to a more than 25% increase in runoff. NAWC used a significantly more conservative value of just over 10% for the purpose of this study as portions of the 2020 water year relied on 1 AHOGS installation for seeding. With the establishment of a 2nd AHOGS installation for the 2021 water year, NAWC predicts a significant improvement in seeding efficiency.

Rainfall Increase Estimates

In addition to calculating runoff increases, NAWC also considered the total precipitation that occurred during the program's operational period to estimate the increase in rainfall (Table 1). Precipitation totals for each of the seeded storms can be found below in Table 2.

Table 1

Seasonal Rainfall Estimates

March – April 2020 Total rainfall at Upper Lopez	**8.54 inches**
Estimated natural (non-seeded) rainfall based on a 10% increase assumed due to seeding	**7.76 inches**
Difference (assumed seeding increase) representative of target area	**0.78 inches**

Table 2

Seeded Storm Period Rainfall

Storm period	Upper Lopez rainfall (inches)	Lopez Rec Area rainfall (inches)
March 9-11	1.45	1.68
March 15-16	1.81	1.65
March 22-23	0.99	0.75
April 5-6	1.63	1.76

NAWC determined that the Upper Lopez Rain Gauge would be most representative of the watershed, given its elevation and geographic location. Using the precipitation totals from this gauge **NAWC estimated that a total of 30,000 AF of precipitation occurred over the watershed during the storms that were seeded for rain enhancement**. With a minimum expected increase of 10% and a maximum expected increase of 17% we estimate a total increase in rainfall of 3,200 AF.

From NAWC's inflow estimates and runoff calculations, NAWC estimates that 15% of the augmented rainfall contributed directly to Lopez Lake inflow, with the remaining portion being absorbed by the pervasively dry soil. Though we do not ascribe a dollar value to water that is absorbed by the soil,

this water does play a significant role in recharging ground water and in supporting vegetation and numerous animal species in the area.

To validate our rainfall estimates, NAWC performed a High-Resolution Radar analysis for the storm that occurred from March 15-16. This HRR analysis uses radar data to recreate the storm events that occurred during that calendar period, calculating estimated precipitation durations and intensities across the watershed and the surrounding areas. The results of this analysis are represented in a rainfall contour map (see Figure 4.).

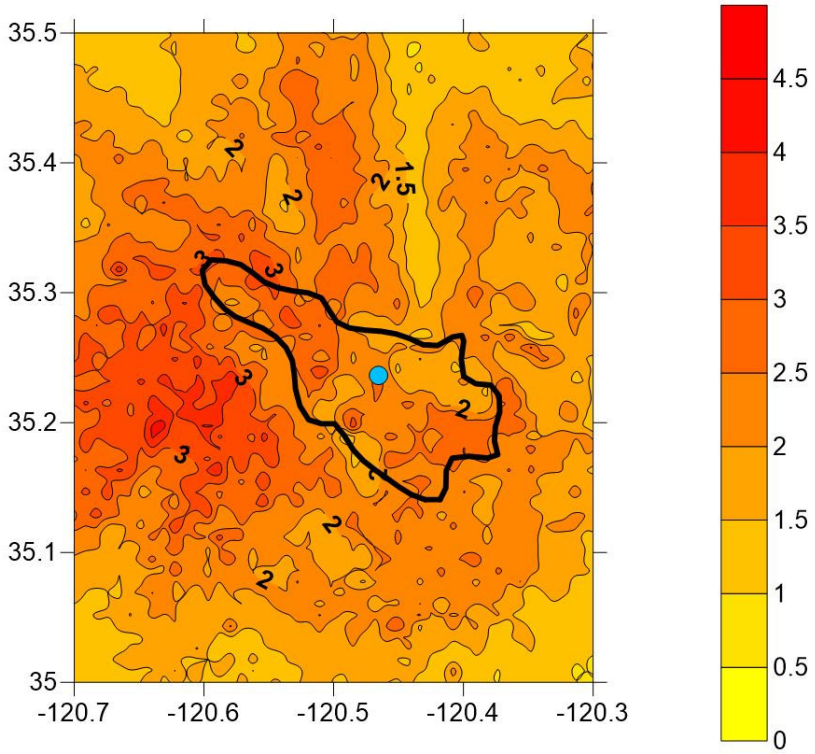

Figure 4. **Total precipitation contour map for the series of rainfall events that occurred beginning on March 15th 2020.**

Using the KMZ output file type, spatial representations for each rainfall contour can be ascribed, and a weighted average for total rainfall in the watershed can then be derived. This process is recorded in Table 3. The results of the HRR analysis suggest an average precipitation value of 2.3" across the watershed, occurring between the 15th and 16th of March 2020. This number is slightly higher than the rainfall that was measured at Upper Lopez Rainfall Gauge Site, suggesting that our total rainfall estimates were likely conservative.

Table 3.

Derivation Data for Total Precipitation from March 15th to March 16th 2020

Contour Line	Area 1 (AF)	Area 2 (AF)	Total (AF)	Percentage	Avg Precip (Inches)
1.5	6608	3187	9795	23.77%	1.75
2	16491		16491	40.02%	2.25
2.5	5629	7882	13511	32.79%	2.75
3	1406		1406	3.41%	3
		Total	41203		

Weighted Average (Inches)
2.32

Stream flow and runoff calculations were derived independently of rainfall estimates and are not dependent on these calculations. NAWC asserts that the estimated increase of 468 AF of inflow into Lake Lopez is as accurate as the somewhat limited data sources in the region permit.