CLOUD SEEDING PROGRAM

INCREASE ESTIMATES

2021 WATER YEAR

PREPARED BY:
NAWC INC

PREPARED FOR:
SAN LUIS OBISPO COUNTY

SUMMARY OF RESULTS

The 2021 Water Year was characterized by one wet month (January) with other months considered drier than average. For the 2021 Water Year, NAWC conducted a "ground-only" seeding program.

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 very promising results. A thorough investigation of the benefits of cloud seeding on precipitation in the Central Coast region, completed in 2015, demonstrated seasonal increases of up to 20% resulting from seeding efforts.

After the first year of operating in the Lopez Lake Drainage NAWC attempted to perform a rainfall increase study (like the broader 2015 study referenced above) focused exclusively on the Lopez Lake Drainage. Due to the lack of sufficient historic rainfall and corresponding runoff data, it was determined that the data sample was insufficient to derive a statistically significant increase estimate for the Lopez Drainage exclusively. NAWC therefore determined to use increase estimates from the broader Central Coast evaluation performed in 2015. As the drainage could not be independently evaluated NAWC used a conservative 10% increase in precipitation for the purposes of this runoff evaluation.

Table 1.
Summary of Results

Measure	Total for Seedable Period (AF)	Increase Attributed to Seeding (AF)	Cost per Acre Foot ($)
Runoff	2,632	382	419
Precipitation	33,303	3,028	53

The seeding program performed by NAWC for the 2021 Water Year cost a total of roughly $160,000 and resulted in a calculated inflow (runoff captured by Lake Lopez) increase of an estimated 382 acre-feet (AF) of additional water into the lake (assuming only a 10% increase in precipitation). This equates to an estimated cost per acre-foot of $419, which is significantly less than other sources of water in the region.

PROGRAM TARGET AREA

Updating the Target Area and Drainage Maps

To provide an accurate estimate of the total rainfall and runoff that benefitted Lopez Lake, NAWC in 2020 undertook a topographical review of the Lopez Lake Watershed. NAWC examined the KMZ files of the Lopez Lake Drainage 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 seeding 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. The remaining area (an estimated 42,650 acres) does drain into Lopez Lake. Comparison with CNRFC basin boundaries confirmed NAWC's findings.

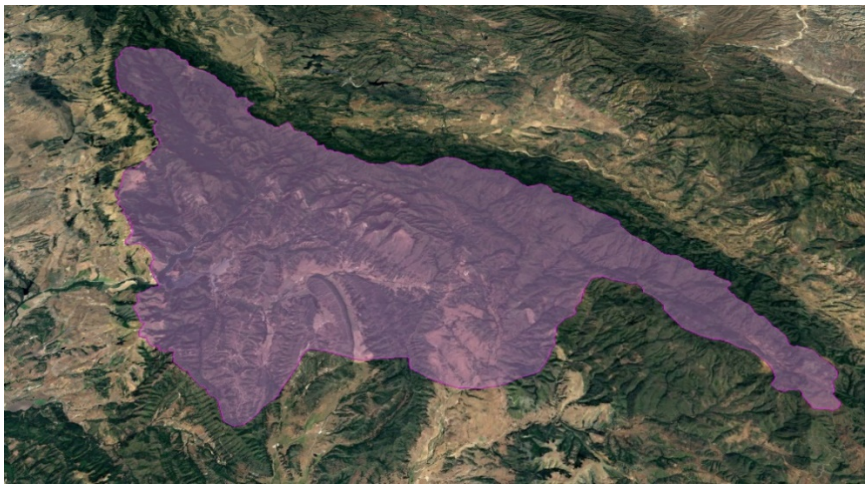

Figure 1. **Lake Lopez Watershed as defined in the original feasibility and design study.**

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

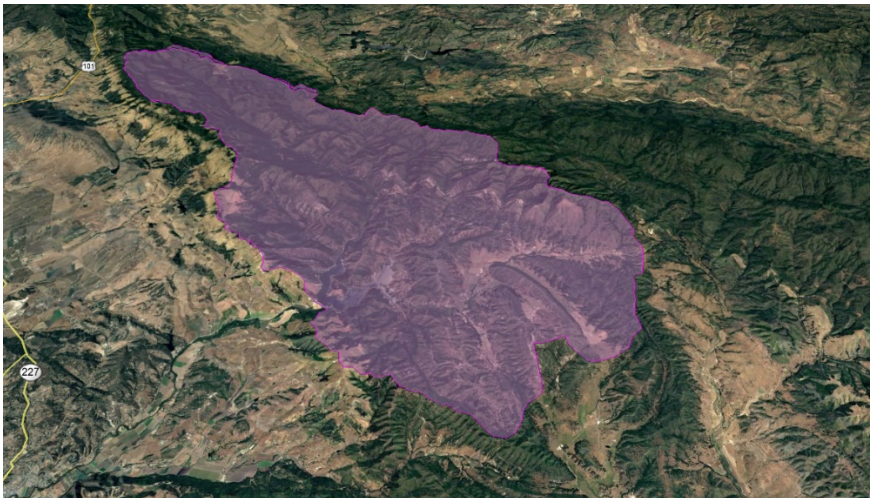

Figure 2. **Updated map of the Lake Lopez Watershed.**

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.

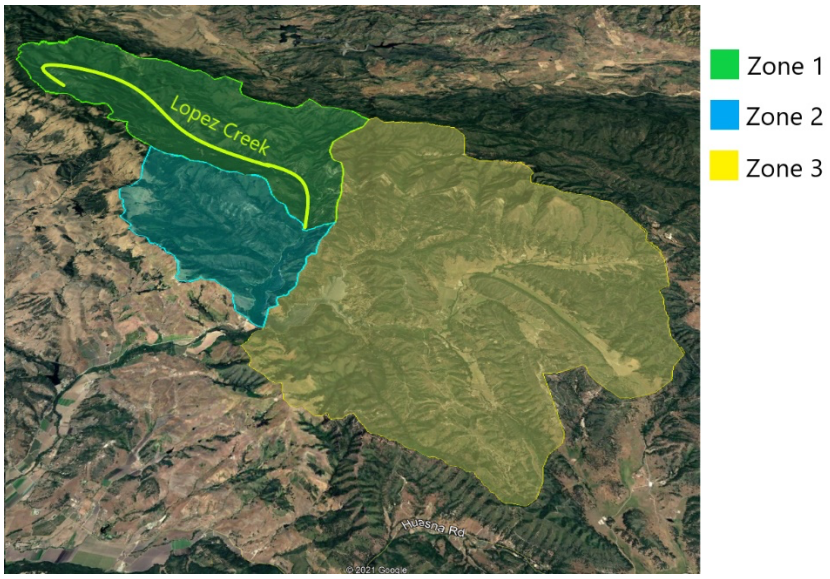

Figure 3. **Drainage zones for the Lake Lopez Watershed.**

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. Due to the insufficiency of this data online, SLO County provided inflow data to Lopez Lake for use in this calculation. The estimate uses these inflow estimates provided by SLO County, and a regression derived from a multi-year evaluation that suggests a roughly 17% streamflow increase from a 10% seasonal precipitation increase in a typical year.

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 under 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 2021 Water Year was only about 20% of average. During the seeding season of November 2020 to April 2021, rainfall at Lopez Dam was measured at close to 53% of average, which makes it evident that precipitation again fared far better (percentage wise) than did runoff during the season. 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 (Figure 3) have historically accounted for 50-60% of the inflow into Lake Lopez. Given the dry soil conditions that characterized the watershed in recent seasons, 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 reflects our estimates for Lopez Creek runoff of roughly 1300 AF in 2021 and SLO Counties estimates for total inflow equaling over 2,600 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. During the previous season, 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.

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 2,632 AF in 2021 and applying the derived increase estimates (based on multi-year historical data analysis) cloud seeding in the Lopez Lake Watershed resulted in an estimated **382 AF** inflow (to Lopez Lake) increase.

Note that the results of work performed for the Santa Barbara cloud seeding program suggest precipitation increases closer to 17% for convective storms, which would correlate to a more than 25% increase in runoff. NAWC used a significantly more conservative value of 10% for a precipitation increase, which would result in about a 17% average increase in runoff based on regressions between the observed historical data. With the establishment of additional AHOGS sites, the seeding effects could possibly be greater than this estimate.

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 2).

Table 2

Seasonal Rainfall Estimates

November – April 2021 Total rainfall at Upper Lopez	9.37 inches
Estimated natural (non-seeded) rainfall based on a 10% increase assumed due to seeding	8.52 inches
Difference (assumed seeding increase) representative of target area	0.85 inches

NAWC has determined that the Upper Lopez Rain Gauge would be most representative of the watershed, given its elevation and geographic location. Using the precipitation total from this gauge (9.37") and runoff area of 42,650 acres yields at total of just over 33,000 AF of precipitation over the watershed during the November – April seasonal period. Assuming that this total precipitation volume was increased by 10% due to seeding (over its natural value) yields a total of 3,028 AF potential additional precipitation. Comparing these total volume numbers (Table 1) for precipitation to the Lake Lopez inflow data (2,632/33,303 AF) implies that less than 10% of the total precipitation volume was converted into runoff. However, a somewhat larger percentage (382/3,028 AF, or 12.6%) of the estimated increase due to seeding was likely converted into runoff, based on these estimates. This is due to the fact that additional precipitation added to the watershed over and above the natural amount (in at least some cases, after the soil saturation requirements have been satisfied) is expected to contribute proportionally more runoff than the base (natural) amount as a whole.

From NAWC's inflow estimates and runoff calculations, it is estimated that over 12% of the augmented rainfall contributed directly to Lopez Lake inflow, with the remaining portion being absorbed by the pervasively dry soil in the 2020-2021 season. 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.