1. Introduction

1.1 NID service area

The Nevada Irrigation District (NID), established in 1921 under the California Irrigation District Act of 1897, provides water for nearly 25,000 homes, businesses, municipalities, and agricultural lands in Nevada, Yuba, and Placer counties. The NID service area encompasses 287,000 acres in the western foothills of the Sierras, with about 30,000 of those acres (~11%) being irrigated land (**Figure 1a**). Approximately 90% of NID's demand is raw water and agricultural demand supplied during the irrigation season (HDR & NID, 2020a). NID's water supply comes from four main sources: natural runoff/snowmelt from the contributing watershed areas, reservoir carryover storage, contract water purchases from PG&E, and recycled water. It is important to note that groundwater supply is limited, as most of the below ground natural aquifer system in the area consists of fractured rock (USGS, 1984); therefore, the District does not utilize groundwater as a supply source and is not aware of any growers supplementing water supply through private wells (NID 2021a). NID currently has a water supply network and storage facilities located in four major watersheds: 1) the Middle Yuba River; 2) tributaries of the South Yuba River; 3) Deer Creek; and 4) the Bear River; the last two of which include the major distribution and storage systems that fall within the NID service area. The District operates and maintain 9 major reservoirs that provide a combined storage total of 280,085 acre-feet (AF) (**Table 1**). Water is conveyed and delivered through a 484-mile labyrinth of canals, pipes, and tunnels, many of which are unlined and were constructed during the Gold Rush era (**Table 2**). Finally, instream minimum flow requirements (referred to as "Environmental Use" below) are set for the Middle Yuba River below Milton Diversion, Canyon Creek below Bowman Reservoir, and the Bear River below Combie Reservoir.

1.2 Proposed Centennial Dam

In 2017, NID proposed adding a new 275-foot, 110,000 AF capacity dam that would be constructed between Combie and Rollins reservoirs (**Figure 1b**). The project was set to begin this year (2021) and would be called Centennial Dam to commemorate the district's 100-year anniversary. Local communities and grassroots organizations such as the South Yuba River Citizen's League and the Foothills Water Network have criticized dam construction, as it would inundate the last 6-miles of free-flowing stream along the Bear River, including native Nisenan villages and burial grounds, popular recreational sites, and ~2,200 acres of mature riparian and oak woodland. The NID has cited concerns of decreased snowpack as well as earlier and more intense watershed runoff under its 50-year projection scenarios (HDR & NID, 2020b). Centennial Dam would represent a 40% increase in overall reservoir storage capacity.

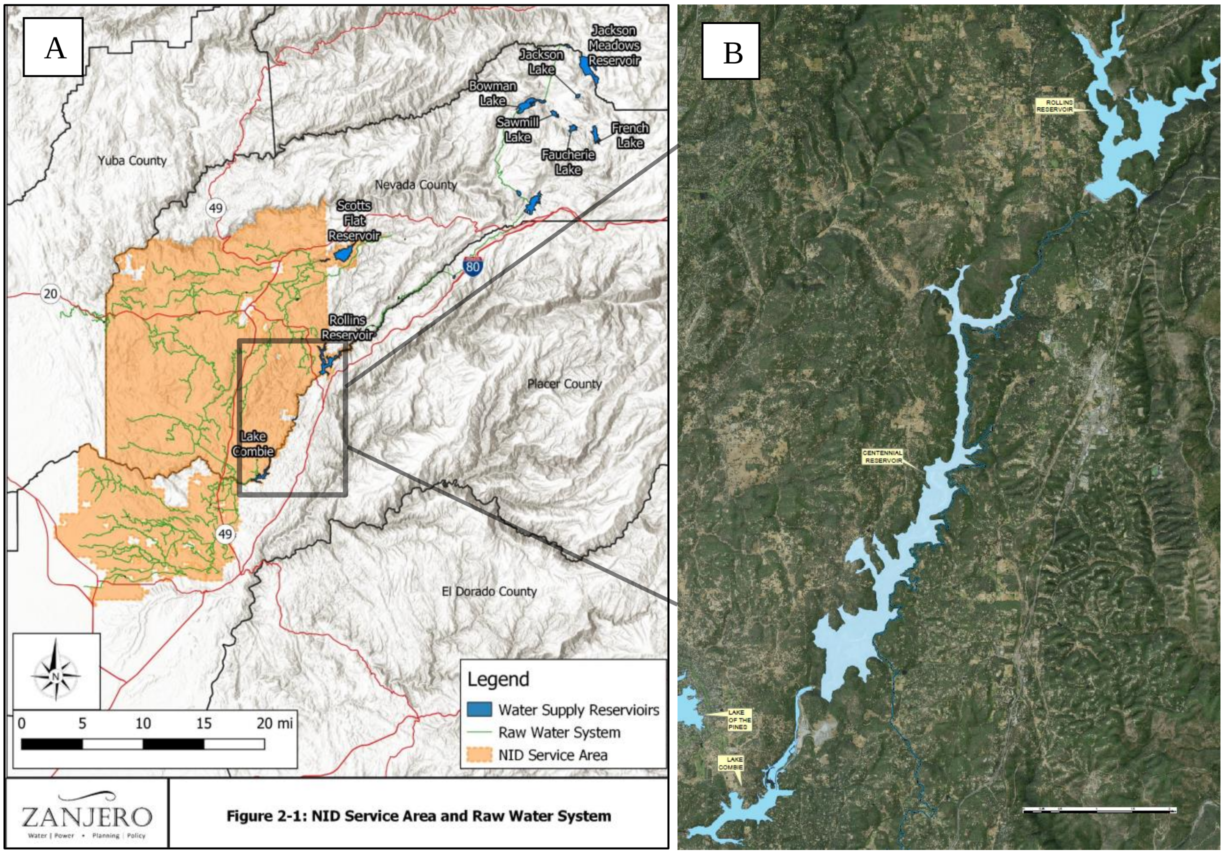

Figure 1. A) Map of the NID service area relative to major river networks in the Central Valley (HDR & NID, 2020a). B) Proposed Centennial Dam location on the Bear River (NID, 2018).

Table 1. List of NID reservoirs and their capacity (NID 2021a).

Reservoir	Capacity, AF
Jackson Meadows	69,205
Bowman	68,510
Jackson Lake	1,330
Sawmill	3,030
Faucherie	3,980
French	13,940
Rollins	65,988
Scotts Flat	48,547
Combie	5,555
Total Capacity	280,085

Table 2. Water conveyance and delivery systems (NID 2021a).

System Used	Number of Miles
Canal	340
Flume	9
Penstock	1
Other/Creek	35
Siphon/Pipe	91
Tunnel	8
Total	484

2. Objectives

To answer the question of whether the NID really needs yet another dam in the Yuba-Bear watershed system, as opposed to implementing changes in management, I proposed two main study questions:

1) How reliable is the current system based on supply and demand of water resources?
2) Where is NID water primarily going (i.e., where can management efforts be focused to make an impact)?

3. Data Sources

- NID water supply and current and future demands:
  - 2015 and 2020 Agricultural Water Management Plans (NID, 2021a; NID, 2021b)
  - Hydrologic Analysis Technical Memorandum (HDR & NID, 2020a)
  - Water Supply Analysis Technical Memorandum (HDR & NID, 2020b)
  - Water Demand Projection Model Update (HDR & NID, 2020c).
- Stream gage flows and reservoir storage changes in the river network (sub-annual):
  - California Data Exchange Center (CDEC, 2021)
  - USGS online gage data (USGS, 2021)

4. Methods and Assumptions

Water supply and demands were compiled primarily using reported values from the NID's 5-year 2015 and 2020 Agricultural Water Management Plans (AWMPs). Using the summaries provided in the 2015 and 2020 AWMPs, I compiled annual supply and demand for the 10 year period between 2011 and 2020, as this would provide a long-term comparison of water budgets between drought (~2012-2016) and wet (~2017-2019) periods. The values for the

2015 year were not reported in these plans, but is most likely contained in the 2016 year. Effective precipitation and recycled water were not included in supply considerations as these did not provide significant amounts of water. As stated in the introduction, the NID is not aware of groundwater supplementation in the service area and so groundwater contribution is assumed to be negligible, with 100% of water demand supplied from surface water sources. Watershed runoff, which is the main source of water in the District, does not represent actual supply available due to temporal differences between runoff and water rights; further, water rights for the NID are restricted to 450,000 AFY (NID, 2021b). The NID documents did not specify whether the runoff is modeled using a rainfall-runoff simulation model combined with stream gage data or is purely measured flow within streams that drain into the service area, but did clarify that watershed runoff was quantified only in watersheds where NID has water rights: Middle Yuba River, South Yuba River, Bear River, Deer Creek, Wolf Creek, Coon Creek, and Auburn Ravine (HDR & NID, 2020b).

5. Calculations/Results

Question 1: Supply, Demand, and Reliability

Between 2011 and 2020, the majority of water in the District was supplied by watershed runoff (68%, on average) (**Figure 2**). Runoff varied greatly in dry and wet years, with 100,000 AF supplied during 2013, the driest year, and 500,000 AF in the wettest year of 2017. Carryover storage within the NID reservoirs provided a steady secondary supply source (39%, on average). Small contract supplies were provided by PG&E 2011-2014.

Water uses and demands were quite steady between 2011 and 2020, even during wet and dry periods (**Figure 3**). The average total demand in any one year is 161,205 AF of water. Agricultural use (water applied for irrigation) comprises most of NID’s water use, at an average of 68% of annual water. The NID estimates that an average 11% of their supply is lost each year to canal seepage, evapotranspiration (ET), and percolation. On average, 9% goes to municipal and industrial uses, 6% is allocated for environmental needs such as instream flows, and 4% goes to recreational uses such as ponds and man-made water structures.

Considering these reported values for water supply and demand, supply-demand ratios were calculated for each year (**Table 3**). This revealed that on average, the NID has roughly 2.25 times the supply needed to meet the demands within its service area. Next, storage-demand ratio was calculated using two different methods (**Equations 1 and 2**). The first evaluates the potential storage relative to demand, if all reservoirs are completely full at capacity (280,085 AF); in this scenario, total storage is about 1.74 times annual demand. However, a more conservative approach based on current reservoir operations policies is to calculate the ratio of the average carryover storage to demand. This ratio comes out to 0.89, indicating a 10% deficit if demand was supplied purely by reservoir storage alone.

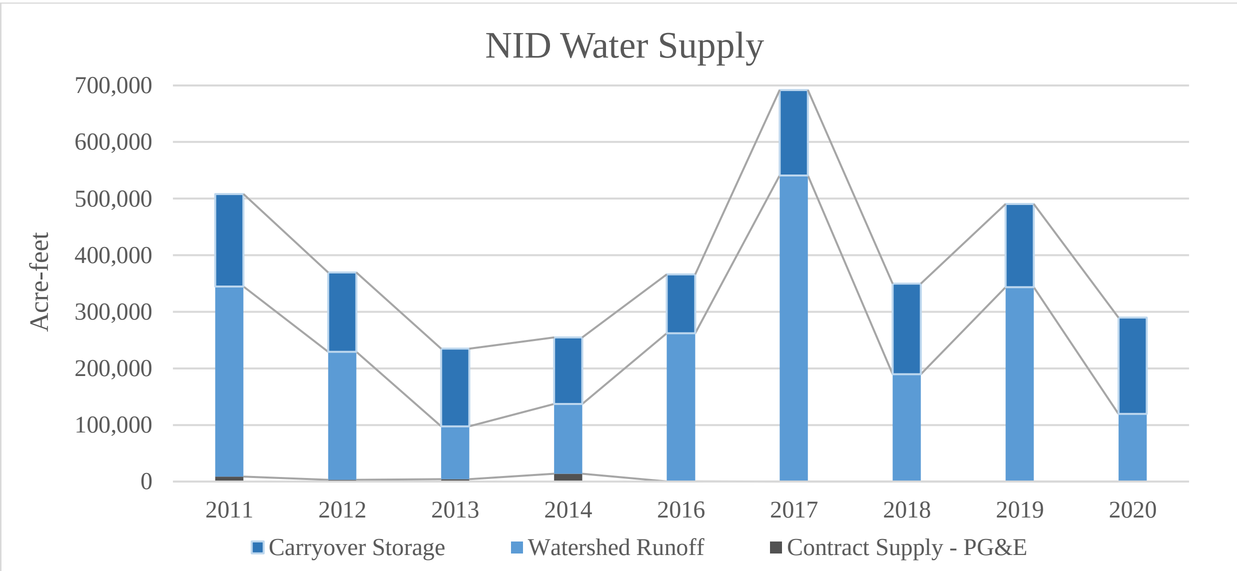

Figure 2. Surface water supplies, 2011-2020 (Brown & Caldwell, 2016; NID, 2021b).

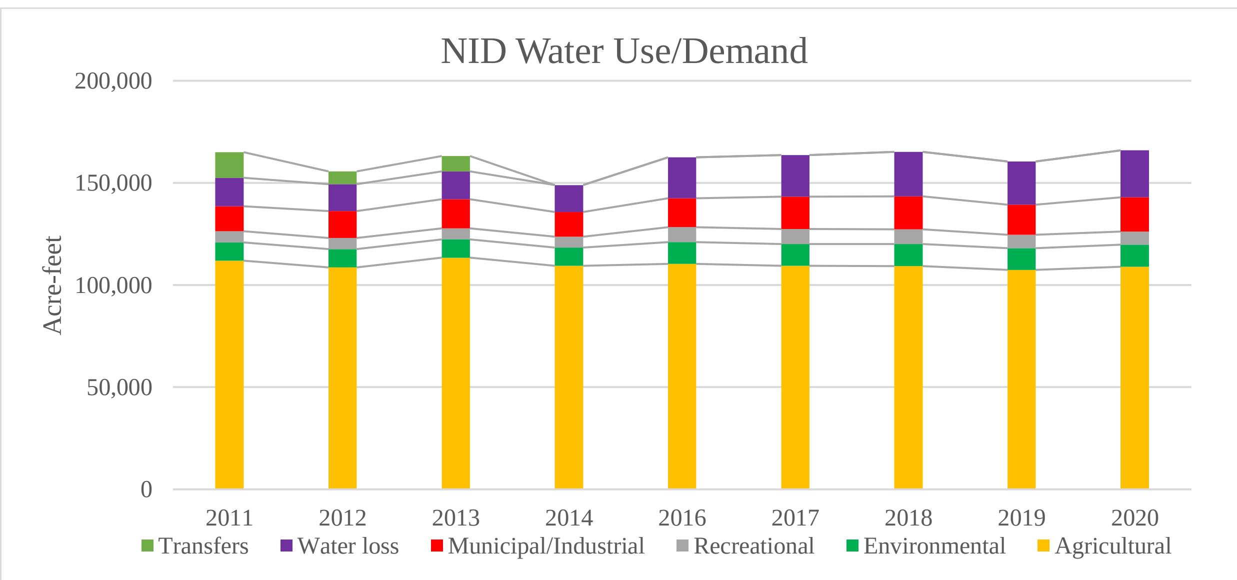

Figure 3. Total water uses, 2011-2020 (Brown & Caldwell, 2016; NID, 2021b).

Table 3. Supply-Demand Ratio (Annual total supply divided by the annual total demand).

Year	2011	2012	2013	2014	2016	2017	2018	2019	2020	*Average*
Supply-Demand Ratio	3.08	2.38	1.44	1.71	2.25	2.75	2.12	2.80	1.74	2.25

Storage-Demand Ratios:

$$(1)\ \frac{Total\ Reservoir\ Storage}{Average\ Demand} = \frac{280{,}085\ AF}{161{,}205\ AF} = \mathbf{1.74}$$

$$(2)\ \frac{Average\ Carryover\ Storage}{Average\ Demand} = \frac{143{,}386\ AF}{161{,}205\ AF} = \mathbf{0.89}$$

Question 2: Primary water use

The primary water use in the NID service area is listed as “agricultural”—this refers to any outdoor irrigated land. Total irrigated acres averaged 31,707 acres between 2016 and 2020 and includes cereal crops, forage crops, fruits, nurseries, cannabis (as of 2017), nuts, golf courses, parks, family gardens/orchards, and ponds (**Figure 4**). On average, between 2016 and 2020, irrigated pasture for forage use (hay, alfalfa, hobby farms) accounted for the majority of crop lands at 65% of those total acres. Family gardens/orchards account for 20%. Fruit crops, when combined, account for ~6% of total acreage, and 35% of those acres are for winegrapes. Golf courses accounted for 3% of irrigated acreage while all other uses accounted for <3% each.

Applied water was estimated using the metered sales of water to owners of these agricultural lands after subtracting estimated ET. The NID final draft of the AWMP (NID, 2021b, Appendix H) estimated ET for irrigated land types by determining the monthly Crop ET for each crop type based on California Polytechnic Irrigation Center data (2021). Effective Crop ET is equal to the Crop ET minus Effective Precipitation. The crop consumptive use fraction was determined by dividing the Effective Crop ET by the estimated total applied water (**Table 4**). The crop consumptive use fraction varied greatly between 65% and 83% depending on whether the year was considered wet, typical, or dry.

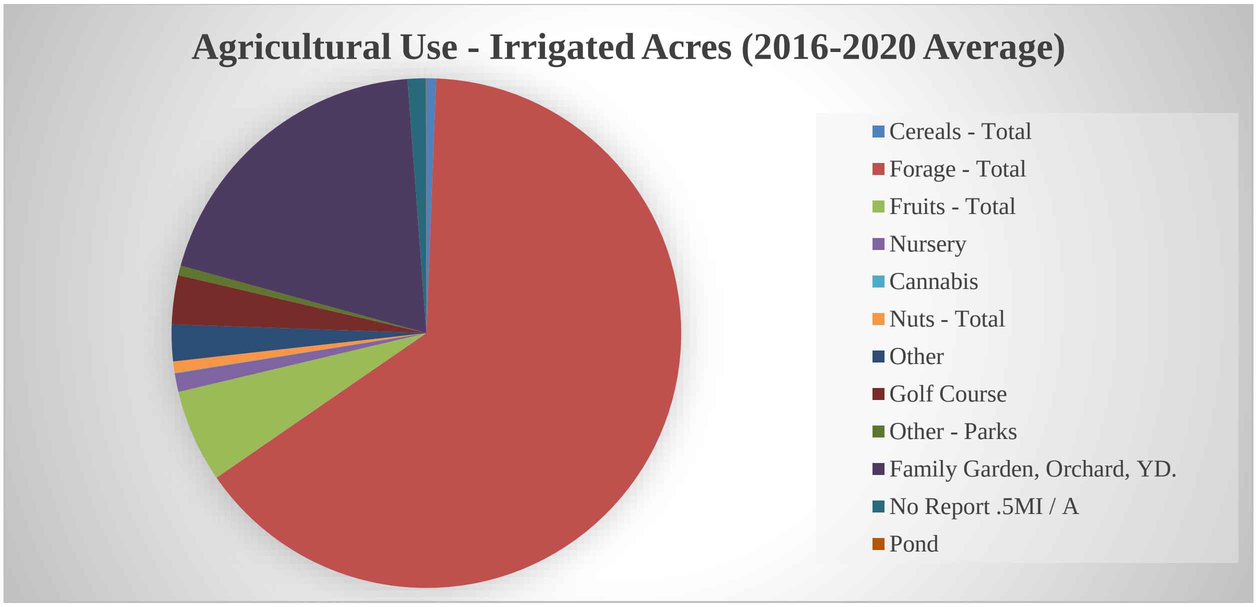

Figure 4. Irrigated acres, averaged across 2016-2020. Percent land use out of 31,707 acres (NID 2021b).

Table 4. Total annual Effective Crop ET (ET (crop consumptive)-effective precipitation), Applied Water, and Crop Consumptive Use (Effective Crop ET/AW) (modified from NID 2021b).

	2016	2017	2018	2019	2020
Year Type	'typical'	'wet'	'typical'	'wet'	'dry'
Effective Crop ET (AF/year)	88,703	70,717	90,006	76,276	90,660
Applied Water (AW) (AF/year)	110,356	109,476	109,343	107,439	109,016
Crop Consumptive Use	80%	65%	82%	71%	83%

6. Conclusions

Using trends in water usage over 10 years in the NID service area, the robustness of the NID water supply system was determined, with supply always exceeding demand. In most years, demand may be met almost entirely using only reservoir carryover storage. Further, the NID calculations did not account for the percent of instream flows that are currently met with reservoir spill, so the ratio between storage and demand may be even higher. One surprising result obtained was that water usage/demand did not greatly differ between wet and dry periods. NID water is primarily supplied to agricultural and irrigated lands, particularly forage and pasture.

7. Recommendations/Limitations

This study was limited by the sparse availability of flow and reservoir storage data from CDEC and USGS gages. Independent flow data was gathered from these sources, but it was infeasible to attempt to replicate the NID models. Further, to replicate the model(s) also requires a strong familiarity with the complexity of the conveyance system, water rights, operations, hydropower systems, and water transfers. Nonetheless, the findings support the following recommendations:

- Increased management and tracking of water used for pasture and forage lands (which are often flood irrigated) as well as reduction of water intensive grasses and winegrape crops.
- The NID ET and applied water calculations were derived solely from water sales and reported acreage. Water sold may not accurately reflect these metrics as it does not represent users' irrigation patterns, strategies, or actual application. Improved agricultural efficiencies should be explored as well as improved tracking of water usage and applied water.
- NID amended their 2020 AWMP to note that while it is unaware of users supplementing with groundwater, it currently does not track this and that it would "coordinate with the counties in the future to better understand private groundwater use" (NID, 2021b). The author supports this along with implementing groundwater monitoring and accounting.
- A watershed assessment in the Bear River watershed to determine the value of ecosystem services that could be provided by setting aside or restoring the ecosystem in place of building Centennial Dam. For example, quantifying the carbon sequestration, water retention, and flood mitigation provided by upstream meadows.

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