An Evaluation of the Northern Integrated Supply Project: Feasibility of Filling Glade Reservoir

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Abstract. The Northern Integrated Supply Project (NISP) aims to develop much needed water storage along the Front Range of Colorado. A primary component of this effort is the construction of Glade Reservoir, which has a proposed capacity of 170,000 acre-feet and an estimated annual yield of 40,000 acre-feet. Water allocation in Colorado is governed by the Doctrine of Prior Appropriation, which requires that all historical water users receive their decreed streamflow water right before any water can be diverted by new water users. NISP intends to fill Glade Reservoir with excess streamflows from the Cache la Poudre River, which refers to streamflow that has not yet been allocated to senior water users. The MODSIM River Basin Management Decision Support System developed at Colorado State University is applied to simulating the filling of Glade Reservoir using historic streamflow and diversion data for the past 50 years to determine if this project is capable of required water deliveries of the project for satisfying the projected demand. Several additional simulations were executed in MODSIM in which the reservoir size and annual yield were altered in order to provide decision-makers with additional options regarding the construction of this storage project.

1.0 Introduction

The Northern Integrated Supply Project (NISP) aims to increase water supply for stakeholders in Colorado's Front Range area by building two reservoirs that would provide additional storage capacity in the region. Glade Reservoir, with a proposed capacity of 170,000 acre-feet, would divert water from the Cache la Poudre River (Poudre River) through the existing Poudre Valley Canal. Galeton Reservoir has a proposed capacity of 40,000 acre-feet and would divert water from the South Platte River. The Northern Colorado Water Conservancy District (Northern Water) is coordinating the efforts of 15 Front Range water providers to facilitate this project; however, there are a number of opponents to the project who are concerned with the environmental impact that will be caused by the construction and operation of these reservoirs. Projections of future population growth and increasing agriculture demand necessitate additional water supply in the region, but the best way to secure this water supply is still up for debate.

2.0 Background

Northern Water is a public agency, originally founded in 1937 in conjunction with Colorado-Big Thompson Project (C-BT Project). Through the C-BT Project, Northern Water is responsible for bringing supplemental water to 860,000 people and 640,000 irrigated acres of land in Colorado's Front Range area[2]. Northern Water is a leader in providing reliable water supply to an area with high population and high agriculture development, but few natural water resources.

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Of the 16 million acre-feet of water generated by Colorado's river systems each year, 80% of the water flows to the western slope while 20% naturally flows to the eastern slope. In additional, 2/3 of that total water supply is required to flow out of the state according to Interstate Compacts. Reverse of Colorado's water portfolio, 80% of Colorado's population lives on the eastern slope, with 20% on the western slope. Agriculture makes up an even larger Eastern Colorado water demand as approximately 75% of irrigated acreage is located in the Eastern Slope, while overall agriculture received 90% all of water resources allocated within the state. Figure 1 provides a depiction of Colorado's water resources and demands[3].

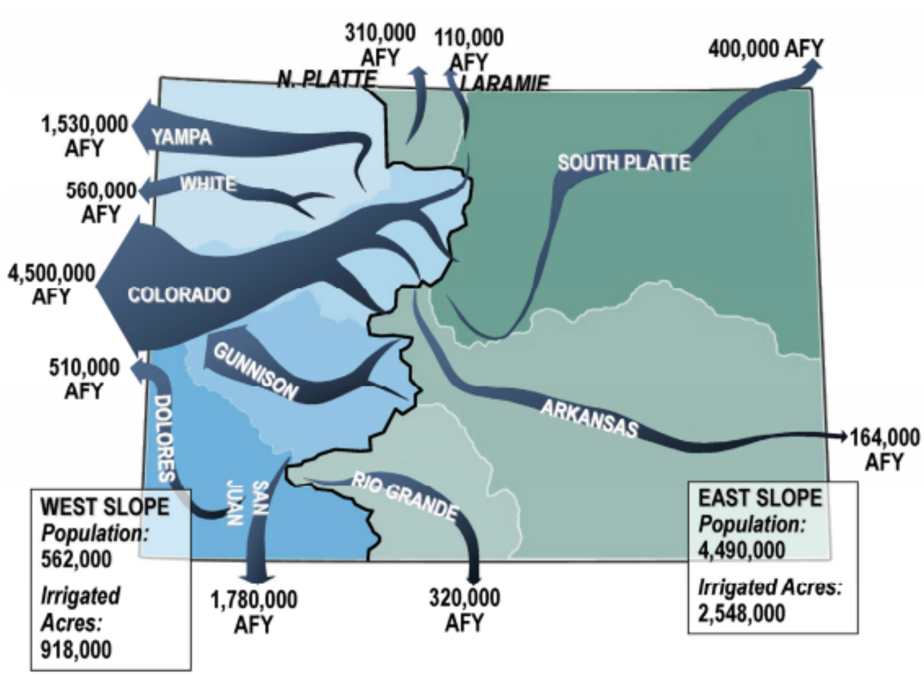

Figure 1: Colorado Population, Irrigated Acreage and Flows- 2010 SWSI Report

In addition to the challenge of simply securing a water supply, the amount of water supply needed varies according the time of year. The summer months typically have high water demands due to lawn and farm irrigation, while the demand drops in the winter months. River water supply alone is not sufficient or dependable enough to meet the peak summertime demands, thus in an arid, populated region like the Front Range, water storage is essential to providing reliable water supplies to all water users. External pressures such as population growth and climate change further exacerbate the need for additional water storage in the Front Range area.

Specific to the NISP project, the 15 water providers the NISP project would benefit currently serve a population of 200,000 people. That number is expected to increase to 400,000 people by 2030. In conjunction with concern for water supply, it is estimated that 60,000 acres of irrigated land would dry up without NISP, amounting to a $27 million

[3] http://cwcb.state.co.us/water-management/water-supply-planning/Documents/SWSI2010/SWSI2010ExecutiveSummary_v2.pdf

dollar loss in crop production annually[4]. NISP recognizes the need for additional water supply to meet 2030 projected water demands. NISP is currently undergoing evaluation by the Army Corp of Engineers (COE), the organization that is responsible for producing an Environmental Impact Statement (EIS) required by the United States' Environmental Protection Agency (EPA) under the National Environmental Policy Act (NEPA). Under NEPA, federal agencies are required to "integrate environmental values into their decision making processes by considering the environmental impacts of their proposed action and reasonable alternatives to those actions."[5] The COE released a draft EIS in 2008, but due to the large number of comments received on the report, the COE decided to conduct further analyses and produce a supplemental EIS report. The final decision regarding NISP has yet to be decided, and Front Range stakeholders currently await the release of the supplement report, scheduled for 2014.

Another important aspect of NISP is its setting within Colorado Water Law, which is based on the Doctrine of Prior Appropriation. Water from the Poudre River is not free for the taking. The right to water is gained from the ownership of a water right. A water right prioritizes a water user's right to divert water chronologically, thus, water right holders with the earliest appropriation date have the most secure water supplies, while water right holders with later appropriation dates have less secure water supplies and may not receive water in drought years. The implication of the Doctrine of Prior Appropriation on NISP is that Glade Reservoir would have low priority water rights; NISP would only be able to divert water that exceeds the amount already allocated to the senior water right holders. In the evaluation of NISP, it must be determined that the Poudre River possesses sufficient streamflow to meet the supply needed to fill Glade Reservoir. Determining if the water supply exist in the Poudre River is the basis for this report.

3.0 Project Objective

The primary objective of this project is to conduct a feasibility study regarding the filling of Glade Reservoir. Glade Reservoir has a planned capacity of 170,000 acre-feet and an annual yield of 40,000 acre-feet. Northern Water intends to fill the reservoir with excess Poudre River water in times of "high flow."[6] To conduct this analysis, 50 years of historical streamflow and demand data were compiled and entered into the MODSIM simulation model. The analysis was based on the assumption that this data was representative of future climate conditions. As a secondary objective, the model would be used to simulate values of the reservoir's storage volume when attributes of the original Glade Reservoir designed are altered. Alternations that are made to the original design include a reduction of reservoir size and increases in the annual yield volumes. For both the simulations of the original design and altered designs, the model would be run with the target of filling the reservoir to 80% (to allow room for flood control) as well as to 100% to see how the reservoir would function at full capacity.

[4] http://www.northernwater.org/docs/NISP/NISPHome/NISPKeyStats_2.pdf
[5] http://www.epa.gov/compliance/basics/nepa.html
[6] http://www.northernwater.org/docs/NISP/MapsDocuments/ExecSummNispDeisApr08.pdf

4.0 Methodology

4.1 Model Description

MODSIM, a network flow simulation model developed at Colorado State University was used to simulate the filling of Glade Reservoir. Historical streamflow and diversion data was inputted into the model, and MODSIM simulated reservoir volume responses to these variable conditions. For the model setup, a node network was built that represented the actual Glade Reservoir system using an original Poudre River Model acquired from Dr. John Labadie at Colorado State University. The scope of the project focused on a small stream reach between the Poudre Valley Canal and the mouth of the Poudre Canyon (MOC). Upstream and downstream components of the model that did not pertain to this analysis were removed. Additional explanation for the model's reduction is explained in the Assumptions section of this paper. A flow through demand node was created that represented the available water for the Glade Reservoir, which was composed of historic monthly streamflow minus the historic monthly demands. Glade Reservoir was incorporated into model as an outflow to a flow through demand node that represented annual yield, with adjusted seasonal allocation percentages (Table 1).

The historic demand node was positioned downstream of the Poudre Valley Canal diversion node and given a higher priority than the Glade Reservoir node. Under this setup, the Poudre Valley Canal node only diverted streamflow that was available after the historical demands were met. The model was run monthly using historical data from January 1, 1964 until September 30, 2013, 49.75 years total.

4.2 Assumptions

For this report, several assumptions were made to simplify the simulation given the limited timeframe for this project's completion. In terms of data acquisition, an approximately 50 year period of streamflow data was gathered to represent possible future river conditions, although weather variability would impact the actual streamflow and the speed with which the reservoir would be filled. The period of historical data encompassed both wet and dry years so extreme weather events were incorporated into the simulation. The demands on the system were assumed to encompass all of the historical demands on the Poudre River, and their aggregation was assumed to be representative of their removal from the river. The MOC streamgage was positioned downstream of the Poudre Valley Canal and served as a check point to verify sufficient water was in the stream to supply historical demands. Only water in excess of the historical demand total was removed upstream of the streamgage by the Poudre Valley Canal.

In terms of losses, it was assumed that there would be negligible groundwater seepage from the Glade Reservoir site and negligible channel conveyance loss. It was assumed that the Glade Reservoir site and the Poudre Valley Canal would be designed to minimize storage and conveyance losses in an effort to maximize the water diverted from the Poudre River. Evaporation losses were incorporated into this analysis by basing evaporation rates on pan evaporation data for the City of Fort Collins. It was assumed that the city's proximity to the Glade Reservoir site would result in similar evaporation rates. The data was gathered from the HydroBase database, which cites its data source as the National Oceanic and Atmospheric Administration.

Table 1. Distribution of Annual Yield Volumes

Month	Percent Yield
January	4%
February	5%
March	6%
April	7%
May	10%
June	12%
July	16%
August	12%
September	10%
October	7%
November	6%
December	5%

The final assumptions made for this analysis were in regards to reservoir operations. The NISP General Fact Sheet states Glade Reservoir will yield 40,000 acre-feet per year, and it was assumed that release distribution throughout the course of a year would be consistent for all years within the simulation. Table 1 provides the releases percentages used to determine how the total 40,000 acre-feet would be distributed throughout each year. More water would be released in the summer months to supply the peak demands, while less water would be released in the winter when demands are low. Finally, it was decided to enable Glade Reservoir to start releasing water as soon as Poudre River inflows accumulated to a volume of approximately 25% of total capacity. A total capacity of 25% was chosen as a trigger point for release because the reservoir requires a minimum volume to maintain dead storage water uses, which include recreational use and water needed to maintain wildlife habitats and produce a health ecosystem. A common volume percentage for dead storage was determined during the research phase, a conservative value was selected to input into the model.

4.3 Data Acquisition

A combination of publically available tools and resources were used in the data acquisition process for the Glade Reservoir analysis. Data for the report was obtained from HydroBase, a database managed by the Colorado Division of Natural Resources. HydroBase is a Colorado Decision Support System (CDSS) tool and serves as a central database to house Colorado climate and water data. Data from HydroBase was gathered using another CDSS tool, called TSTool. TSTool stands for “Time Series Tool,” and works by pulling in time series data from HydroBase and other sources and processing the data. Using TStool was advantageous because it allowed us to interface with other readily available tools, such as Excel and Google Maps. Once data was obtained from HydroBase, TStool wrote the data to an Excel workbook, and that data could then be pulled into the MODSIM simulation. Google Map was used as a basic mapping tool that assisted us visualizing the system.

The two types of data needed for this project were historic Poudre River streamflow data and historic Front Range demand data. Using TSTool, data was gathered from HydroBase for historic monthly streamflow data on the Poudre River from 1964 through 2014. Streamgages were identified using the Poudre River's HUC code, 10190007. HydroBase returned data for numerous streamgages that are located on the river, and the streamgage located at the mouth of the Poudre Canyon (identified as MOC= Mouth of Canyon) was selected due to its proximity to the proposed diversion location from the Poudre River to the Glade Reservoir site. Northern Water plans to divert water to Glade Reservoir through the Poudre Valley Canal, which can be identified by its Water District Identifier (WDID) 0300907. The locations of the Poudre Supply Canal headgate and the MOC streamgage were determined using metadata provided by HydroBase. HydroBase provide longitudinal and latitudinal data coordinates, and using TSTool, those coordinates can be written to a KML file that can then be opened using Google Maps. Figure 2 shows the locations of the Poudre Supply Canal and the MOC streamgage. Historic Front Range demand data was also used in the Glade Reservoir analysis. To simplify the analysis, historic Front Range demands from the Poudre River were aggregated as a single demand node downstream of the MOC streamgage. The premise of filling Glade Reservoir under NISP was to fill it with "high flows" on the river. It was assumed that high flows refers to streamflows that exceed the water that is already allocated to other users under the Prior Appropriation system. To determine demands, key diversion structures in the vicinity of the streamgage were determined in the research phase and the Poudre Valley Canal. Key structures were identified using information gathering from memoranda prepared in 2005 for the South Platte Decision Support System (SPDSS). SPDSS memoranda were prepared for each of the major municipal and agricultural water providers in the South Platte River Basin and delivered to the Colorado Water Conservancy Board. Table 2 provides a list of diversion structures considered for this analysis.

Figure 2: Map displaying Poudre River Streamgage and Poudre Valley Canal Headgate

Monthly diversion records for structures located on the stream reach between the MOC streamgage and to a point just north of the town of Laporte were aggregated as a single node. Laporte was chosen as an end point for the stream reach based on the assumption that Laporte would add additional flows to the river from urban runoff and wastewater returns that would be more difficult to account for and would add additional uncertainty to this analysis.

Using the WDID of each structure, monthly diversion data was obtained similarly to the streamgage data using TSTool. The diversion data that is housed in the HydroBase database is pulled into TSTool and then written to a KML file. The KML file was opened using Google Maps and additional work was performed to color code diversion structured based on whether or not they are located within the stream reach. The diversion structures are marked on the map with push pins; yellow push pins designate diversion structures within the stream reach and red push pins designate diversion structures outside of the stream reach. The MOC steamgage is shown as a green pushpin. Figure 3 displays this map image.

The final list of demand nodes that were included for this analysis are New Mercer Ditch (0300913), Pleasant Valley and Lake Canal (0300910), Larimer County Ditch No. 2 (0300914), Greeley Filters Pipeline (0300908), Little Cache la Poudre Ditch (0300915), and the Larimer County Canal (0300911). These demands are represent historic demands from the City of Fort Collins, City of Greeley, Larimer and Weld Irrigation Company, and the Water Supply and Storage Company.

Table 2. Historic Front Ranges Demands

Water Provider	Structure	WDID
Fort Collins	Fort Collins Pipeline	300906
Fort Collins	Chaffee Ditch	300925
Fort Collins	New Mercer Ditch	300913
Fort Collins	Pleasant Valley and Lake Canal	300910
Fort Collins	Larimer County No. 2 Ditch	300914
Fort Collins	Arthur Ditch	300918
Greeley	Greeley Filters Pipeline	300908
Greeley	Canal No. 3	300934
Larimer Weld Company	Poudre Valley Canal	300907
Larimer Weld Company	Little Cache la Poudre Ditch	300915
Larimer Weld Company	Larimer Weld Irrigation Canal	300919
NPIC	North Poudre Canal	300994
NPIC	Munroe Gravity Canal	300905
WSSC	Larimer County Canal	300911
New Cache Company	Greeley No. 2 Ditch	300929

5.0 Model Results and Discussion

In total, MODSIM simulations were run for four primary scenarios for which the size and annual yield of Glade Reservoir was varied. Two scenarios were run with a reservoir capacity of 170,000 acre-feet, the size of the original design of Glade Reservoir, and two scenarios were run with a reduced reservoir capacity of 120,000 acre-feet. For each reservoir size, simulations were run for filling the reservoir to 80% capacity and 100% capacity. Filling the reservoir to 80% capacity would allow room for flood control, and filling the reservoir to 100% capacity revealed how the reservoir would operate if flood control was not a consideration. Finally, within each scenario, multiple simulation runs were performed varying the annual yield volume that the reservoir was capable of producing. The purpose of varying the annual yield was to determine if the reservoir was capable of producing the target annual yield that was outlined by NISP as well as to determine if the reservoir could produce excess yield in the instance that it was needed in the future. The purpose of varying the annual yield was to determine if the reservoir was capable of producing the target annual yield that was outlined by NISP as well as to determine if the reservoir could produce excess yield in the instance that it was needed in the future. Any year in which the annual yield could not be met is defined as a "shortfall." Table 3 summarizes the scenarios and runs that were performed in this analysis.

Figure 3: Selection of Diversion Structures for Historic Demand

In Scenarios 1 and 2, the reservoir capacity was set to 170,000 acre-feet. As stated in the assumptions, as soon as the reservoir's storage volume reaches 40,000 acre-feet (approximately 25% of total capacity), water can be released for use. Based on this parameter, Glade Reservoir began yielding on May 1, 1965, just one year and five months after it began in both of these simulations.

In Scenario 1, the target capacity of the reservoir was set to 80% to account for flood control. For an annual yield of 40,000 acre-feet, the simulation did not produce any water supply shortages. The annual yield of 50,000 acre-feet resulted in a shortage when the reservoir level fell to 35,883 acre-feet during only the most extreme months of the simulation, which is displayed in Figure 4. As indicated in the graph, all demands were met for the remainder of the simulation.

Table 3: Glade Reservoir MODSIM Simulation Scenarios

Reservoir Capacity: 170,000 acre-feet	Reservoir Capacity: 120,000 acre-feet
Scenario 1: Filling to 80% Capacity	Scenario 3: Filling to 80% Capacity
Annual Yield (acre-feet):	Annual Yield (acre-feet):
40	40
50	50
60	N/A
Scenario 2: Filling to 100% Capacity	Scenario 4: Filling to 100% Capacity
Annual Yield (acre-feet):	Annual Yield (acre-feet):
40	40
50	50
60	N/A

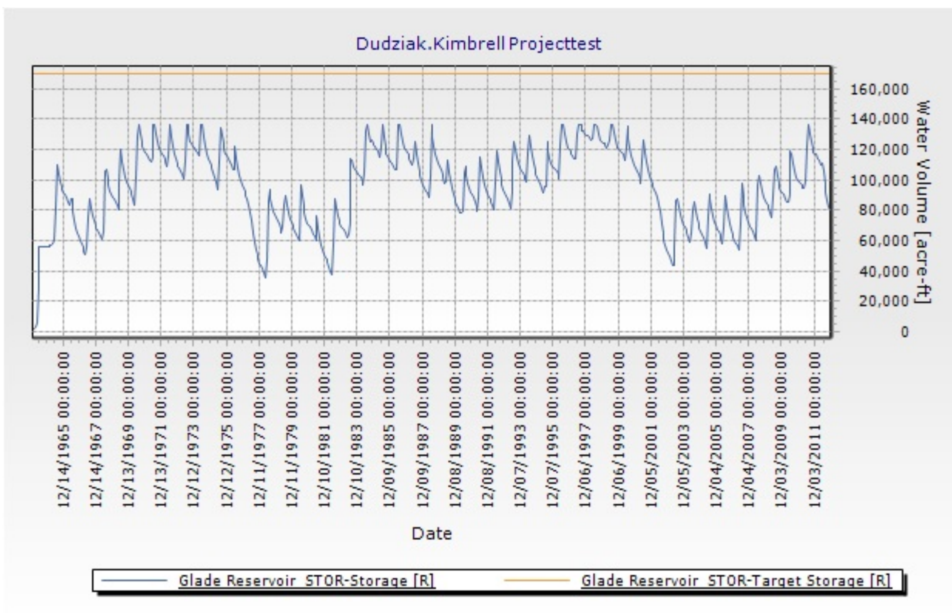

Figure 4: Glade Reservoir Storage Levels. Reservoir Size: 170,000 AF, Fill: 80%, Annual Yield: 50,000 AF

In Scenario 2, the target capacity of the reservoir was set to 100%. Under this condition, the historical Poudre River streamflows filled Glade Reservoir to full capacity on July 1, 1971, or 7.5 years after it began to fill. With a 40,000 acre-feet annual yield, the reservoir would reach 100% capacity 49 times in the nearly 50 year period, which is shown in Figure 5.

There were no shortfalls in this simulation. Next, the same simulation was run with a set annual yield of 50,000 acre-feet, which produced similar results to the previous simulation. This simulation did not experience shortfalls, and the reservoir filled to maximum capacity 19 times. Finally, the annual yield was set to 60,000 acre-feet, but that annual yield proved to exceed the maximum annual yield that the system could handle as the simulation produced several shortfalls and Glade Reservoir never reached full capacity within the 50 year time period.

In Scenarios 3 and 4, the size of Glade Reservoir was reduced to 120,000 acre-feet under the assumption that this might reduce construction costs and decrease the impact on the environment. In Scenario 3, the target capacity of the reservoir was set to 80% total capacity. The simulation was run while holding the annual yield at 40,000 acre-feet and assigned a minimum reservoir volume of 30,000 acre-feet to account for dead storage. The reservoir was able to supply water for the system's demand in all but 5 months of the simulation. The shortage occurred in the most extreme drought period in 1978, and the about 75% of demand was left unmet. Figure 6 displays the results of this simulation.

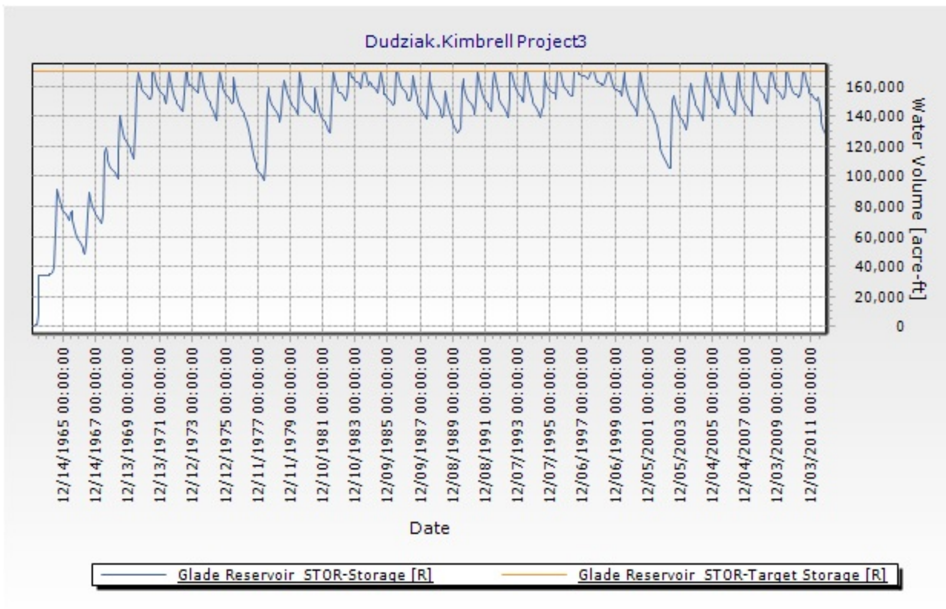

Figure 5: Glade Reservoir Storage Levels. Reservoir Size: 170,000 AF, Fill: 100%, Annual Yield: 50,000 AF

Next, the annual yield was set to 50,000 acre-feet to see how the model would handle the larger demand. Running the simulation with a minimum volume of 30,000 acre-feet, MODSIM produced two periods where no water could be released from the reservoir. In 1977, the reservoir did not yield any water for a five month period, followed by five months of shortages before demand was fully supplied. In 2002, the model predicted a five month period in which no yield occurred, followed by four months of shortages. Both of these time periods correspond with extreme drought events in the historical time period. Despite these periods of shortages, the reservoir was still able to meet the full system demands 97% of the time, as shown in Figure 7.

In Scenario 4, the size of the reservoir was set to 120,000 acre-feet with the maximum capacity set to 100%. When the annual yield was set to 40,000 acre-feet and the minimum volume set to 30,000 acre-feet, the MODSIM simulation did not produce any shortages. When the annual yield was set to 50,000 acre-feet and the minimum volume set to 30,000 acre-feet, the model produced 5 months of shortages during the drought of 1977-78 and 2 months of shortages during the 2002 drought. Overall, shortages during these two periods represented a significant reduction in meeting the demand, but a very small percentage chance of shortages occurring. If the water manager is willing to take a 3% risk to save a large amount of money, the 120,000 AF reservoir would be the preferred solution.

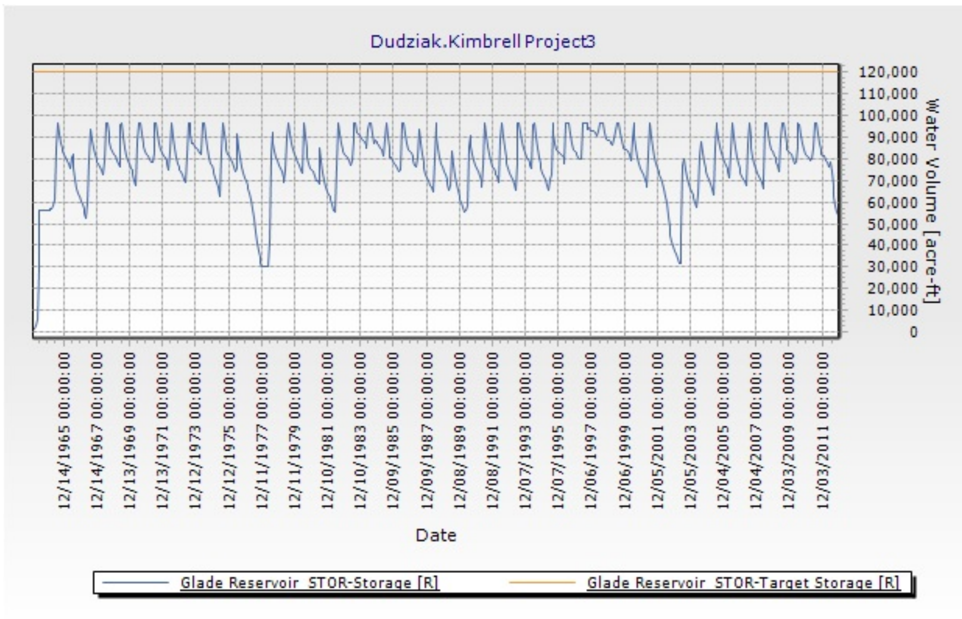

Figure 6: Glade Reservoir Storage Levels. Reservoir Size: 120,000 AF, Fill: 80%, Annual Yield: 40,000 AF

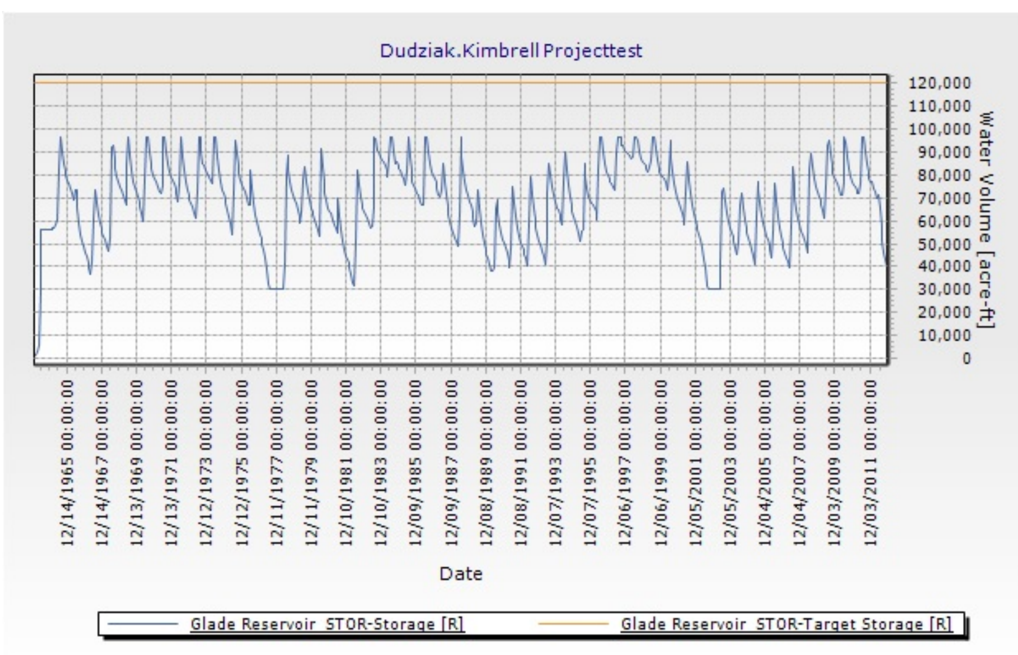

Figure 7: Glade Reservoir Storage Levels. Reservoir Size: 120,000 AF, Fill: 80%, Annual Yield: 50,000 AF

6.0 Conclusions

The overall objective of this project was to determine the adequacy of Glade Reservoir to supply a sufficient water supply to the projected 2030 demands outlined by NISP. The results of this analysis revealed that a storage capacity of 170,000 acre-feet was larger than needed to supply an annual yield of 40,000 acre-feet. Four scenarios were modeled in this analysis, and those results can be presented to and analyzed by decision-makers to determine if the current Glade Reservoir sizing of 170,000 acre-feet to supply an annual yield of 40,000 acre-feet is truly the optimal option. This report shows that the reservoir size could be reduced to 120,000 acre-feet and would be capable of supplying annual yields of both 40,000 and 50,000 acre-feet. The reduction of the reservoir size would reduce construction costs and environmental impacts, which may be a more appealing option to the opponents of this project. The option to increase the annual yield from 40,000 to 50,000 acre-feet would provide room for demand growth in the Front Range area, although the environmental impacts of that decision would need to be evaluated to be sure it was viable.

MODSIM proved to be a suitable tool for this analysis as it allowed for quick simulation iterations with a variety of parameters, and it provided accessible results in graphical and tabular formats. Because a number of simplifications were made due to the timeline of this analysis, the primary area of future work on this project would be to enhance the model setup by incorporating a complete set of historical demands and expanding the model system beyond the city of Laporte. Additionally, incorporation of channel losses, return flows to the river, and inflows to the river from other sources, such as municipal and industrial wastewater returns, are mass balance components needed to improve the accuracy to this model. Once this model was complete, it could be used conjunction with dynamic programing to develop operating rules for the reservoir. The scenarios considered highlighted a number of time periods in which water supply shortages occurred due to extreme drought events, and for this reason, this model could also be used to help water providers develop Drought Response Plans. Despite the assumptions made for this model, we believe the model is capable of providing a realistic glimpse of future Glade Reservoir operations, and it provides confidence that Glade Reservoir could serve a reliable water source for the Front Range area.

7.0 References

Only nonstandard references were used in this paper and are included in-text as footnotes.