Final Report

Missouri River Water Allotment Study for Future Use Water Permit 1443-2

Prepared for

West Dakota Water Development District
Rapid City, South Dakota

Prepared by:

Kurt W. Katzenstein, Ph. D., P.E.
Arden D. Davis, Ph. D., P.E.
Scott J. Kenner, Ph. D., P.E.
Mark T. Anderson
Alvis Lisenbee, Ph. D. (deceased)
Kaleb Hedman
Haley Noteboom
Regan Wess

South Dakota School of Mines and Technology
501 East St. Joseph Street
Rapid City, South Dakota, 57701

December, 2019

In memory of Dr. Alvis Lisenbee

Executive Summary

Since 1976, the West Dakota Water Development District (WDWDD) has renewed every 7 years Future Use Permit #1443-2, which allocates up to 10,000 acre-feet per year of Missouri River water for "future municipal, industrial, commercial, and rural water system use" (SD DENR, 2019). The City of Rapid City also holds a similar but larger permit (#1492-2) allowing for the allotment of up to 66,000 acre-feet of water per year. This study investigated (i) if and when new sources of water will be needed in western Pennington County based on current available water sources relative to predicted population growth, (ii) whether or not WDWDD should continue to retain its future use permit, and (iii) the estimated cost and type of infrastructure that would be needed in order to convey water from the Missouri River to Pennington County should water demands in the future warrant the use.

Results show that local supplies currently meet demand, and the region is not presently in critical need of new sources of water during years of average or above-average precipitation. However, during periods of prolonged drought (similar to those that occurred in the late 1980s and early 1990s, as well as the early 2000s), this study indicates that the region's ability to utilize its local water resources to meet demand is less certain and will continue to be reduced as population in the region expands in the future, putting additional stress on existing water resources. Therefore, future sources of water such as that provided by Permit 1443-2 should be retained.

This study provides an example of a route, the physical infrastructure and its cost that would be necessary to convey 10,000 acre-feet or 76,000 acre-feet of water annually from the Missouri River to western Pennington County. The estimated cost for a 3-foot diameter pipeline that could deliver 10,000 acre-feet/year is approximately $555,000,000. The current (2019 dollars) estimated cost for a 6-foot pipeline for 76,000 acre-feet/year is approximately $1,870,000,000.

Background and Purpose

Securing a reliable source of water, both in quality and quantity, is one of the most critical challenges facing municipalities and rural areas today. This is of particular importance in the western half of the United States where the climate is more arid. Many cities in the western U.S. are utilizing their water resources at rates greater than replenishment and now face serious sustainability challenges (Anderson and Woosley, 2005).

The region of interest for this work comprises western Pennington County including Rapid City and surrounding communities (Figure 1). Water sources have historically been obtained locally, including both groundwater and surface water. In the past, these water sources have been able to meet water demands in the past. However, as the population in the region continues to grow, the demand placed on these existing water sources eventually will exceed supply, at which time additional sources of water will be required.

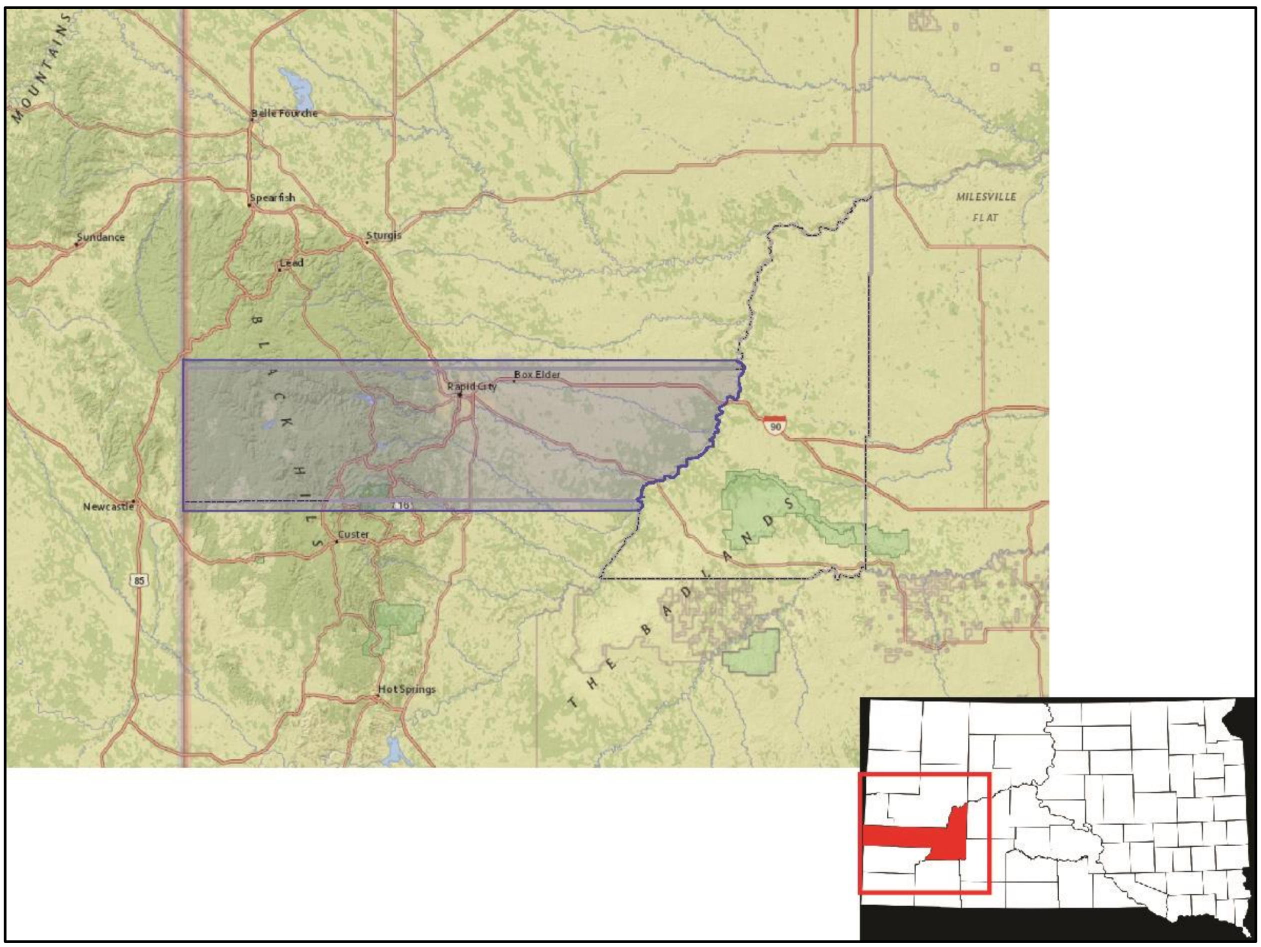


Figure 1. The approximate study area is represented by the shaded blue region.

One potential source of additional water for this region is the Missouri River. In 1976, the West Dakota Water Development District (WDWDD) applied for and was granted Future Use Permit #1443-2, which entitles the district to up to 10,000 acre-feet of Missouri River water per year.

The City of Rapid City also holds a similar but larger future use permit in the amount of 66,000 acre-feet of water per year. These permits remain active today but require periodic renewals (every 7 years) at a cost of about $895 per renewal application. This study was funded by WDWDD to investigate potential need to retain the permit and potential options for the use of Missouri River water in the region. The three main goals of the study were:

- Development of a clear understanding of current and projected water demands for Pennington County based on past water use and population projections.

- Documentation of the available volume of current water supplies, including currently utilized groundwater and surface-water sources.

- Investigation into the development of the use of Missouri River water including possible pipeline alignments, as well as the required infrastructure and its cost.

Results

Current and Projected Water Demands

There are multiple users of water within the study area. These include domestic, commercial, and agricultural entities. Although some information about total water use in the region exists (Driscoll et al., 2002; Carter et al., 2002; Carter and Driscoll, 2000; City of Rapid City, 2014), data delineating the magnitude of use from each of these entities throughout time are sparse. Long and Putnam (2002) provided an estimate of the share of groundwater that is used by each of the above-mentioned users in the late 1980s and early 1990s, but similar information for surface-water use does not appear to be available. As such, total historic water use in the region was evaluated against historic population in order to develop a relationship that could be projected into the future. This relationship only holds true so long as the proportion of use between the three factions (domestic, commercial and agricultural) remains similar in the future. This assumption is reasonable, however, if drastic shifts do not occur.

Population data from the U.S. Census Bureau were utilized to evaluate the historic population within the study area. Although the general study area focused on western Pennington County, it is likely that smaller burgeoning communities in Meade County adjacent to the study area (such as Black Hawk, Summerset, and Piedmont) also will have an interest in any long-term sustainable water use. As such, U.S. Census data for those communities were included in all population and water demand analyses. Therefore, this study evaluated trends in U.S. Census data that encompass Pennington County (excluding Wall, South Dakota, in order to focus on western Pennington County) as well as the neighboring communities mentioned above. The resulting historic population data are shown in Figure 2 (U.S. Census Bureau, 2018). This figure displays census data collected every 10 years since 1900, plus an estimate of “current” population in late 2018. As shown on Figure 2, the study area has experienced continuous and relatively steady growth since 1900.

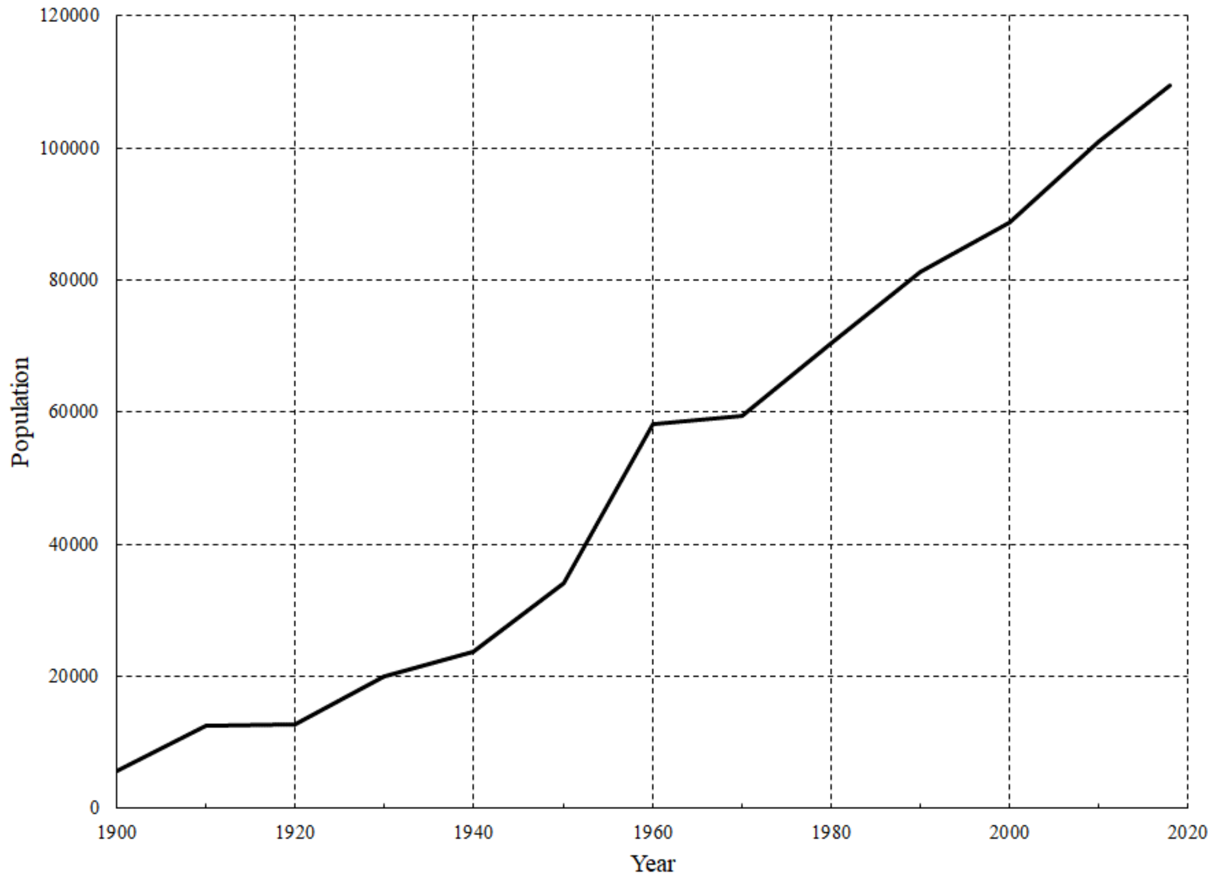


Figure 2. Historic population growth in the greater study area.

In order to provide a range of future population estimates within the study area, multiple assumptions were used for population projections. Figure 3 displays the results of these population projections. The solid black line represents the historic population within the study area, as originally shown on Figure 2. The dotted blue line represents a simple linear forecast based upon the historic data. The dotted orange line represents a population forecast based on a second-order polynomial fit to the historic data. The dotted purple line represents a forecast that compares the year-over-year percentage increase of population in Minnehaha County in eastern South Dakota to the historic population increase in the study area. The assumption in this case is that growth in western South Dakota has lagged behind that of eastern South Dakota but will mimic that of eastern South Dakota because of similar economic conditions. The dotted red line represents the predicted population within the study area based upon a logistic growth curve in which historic population was mathematically fit to a curve (Gupta, 2008) such that population could be predicted. The dotted green line represents population predictions from the City of Rapid City's utility master plan population employment projections (Dan Coon, 2018). Finally, the dashed black line represents an average of the all population projections from this study.

These population projections provide a wide range of population scenarios with increasing uncertainty further into the future. The population projections were forecast to 2120 (about 100 years from now), with the exception of the data from Rapid City, which were forecast to 2115.

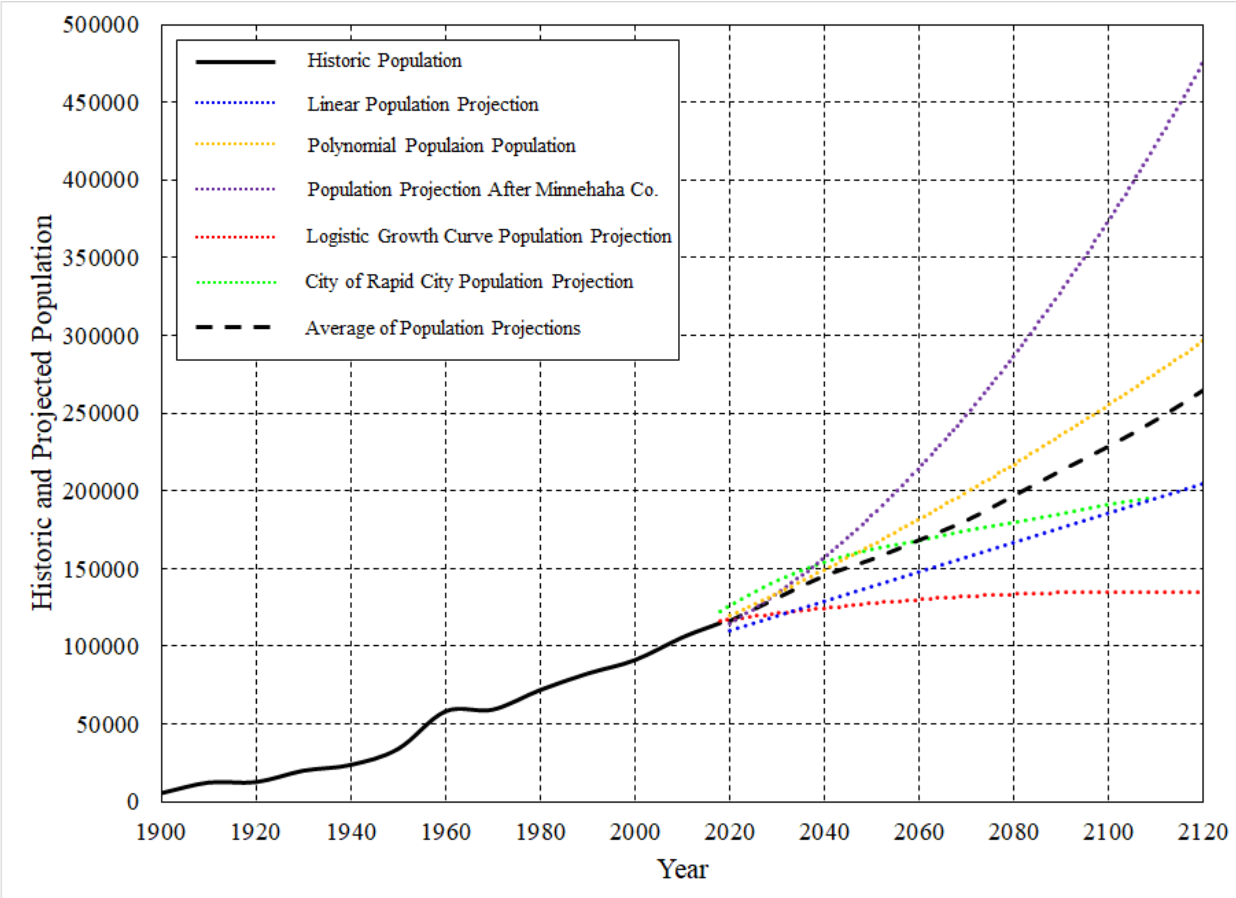


Figure 3. Population projections for the study area.

However, analyses of water use and demand discussed later in this report required that projections be evaluated beyond 2120. As such, the all population projections were extended to 2200. For simplicity, the average, minimum and maximum predictions, as well as the range of uncertainty of our population projections (gray shaded area) are shown in Figure 4. This represents the assumed population projection for the remainder of discussion in this study.

In order to assess future water demand, a relationship between population and water demand was used. Long and Putnam (2002) observed that per capita water use in Rapid City in 1997 was 123 gallons per day during the winter and 177 gallons per day in the summer. This study used the average of these two numbers (150 gallons per day) in order to project water demand based upon the population predictions developed above. To check the validity of this relationship, historic population was multiplied by this per-capita usage estimate and was compared to known historic water use during several years between 1950 and 2000. This comparison is shown in Figure 5 and indicates that this average usage per capita is reasonable. Therefore, this assumption of 150 gallons per day was applied in Figure 6 to the historic and forecasted population previously shown on Figure 4.

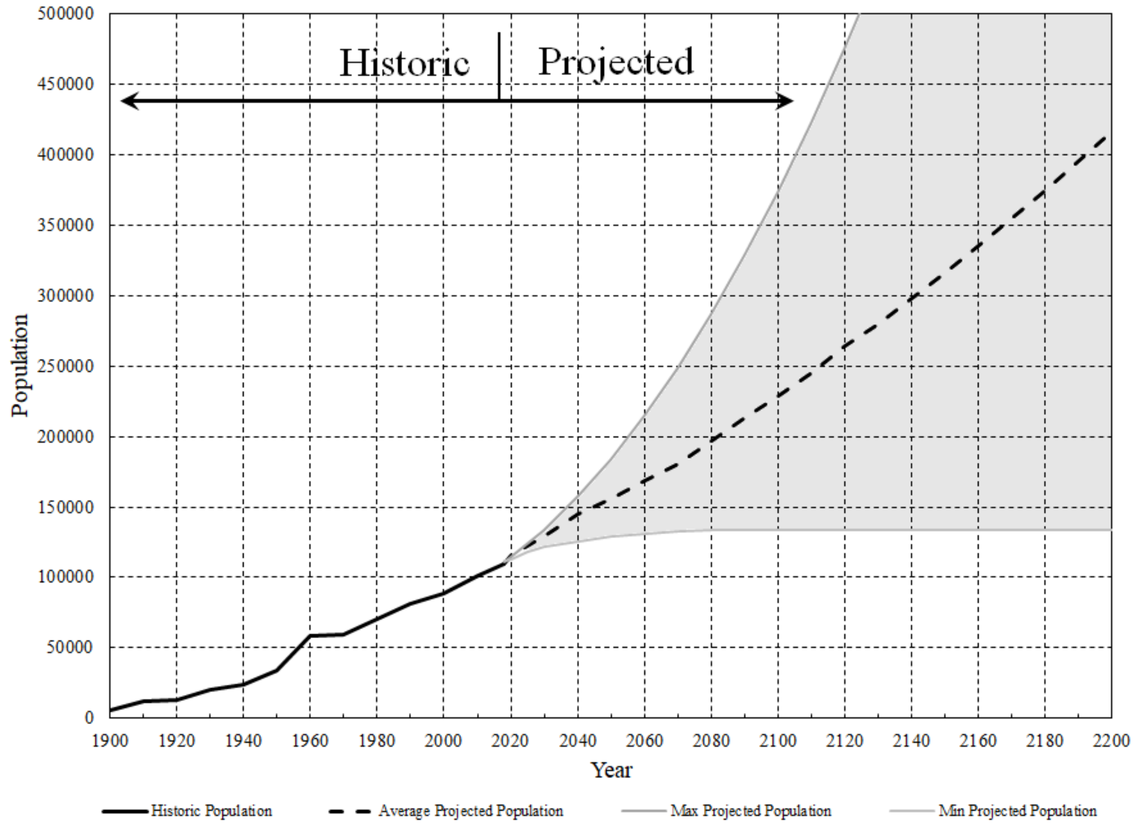


Figure 4. Historic population and assumed population forecast for this study. The solid black line represents the historic population; the dashed black line represents the average of all population projections. The two gray lines represent the maximum and minimum projected population estimates with the gray area representing the range of uncertainty between those estimates.

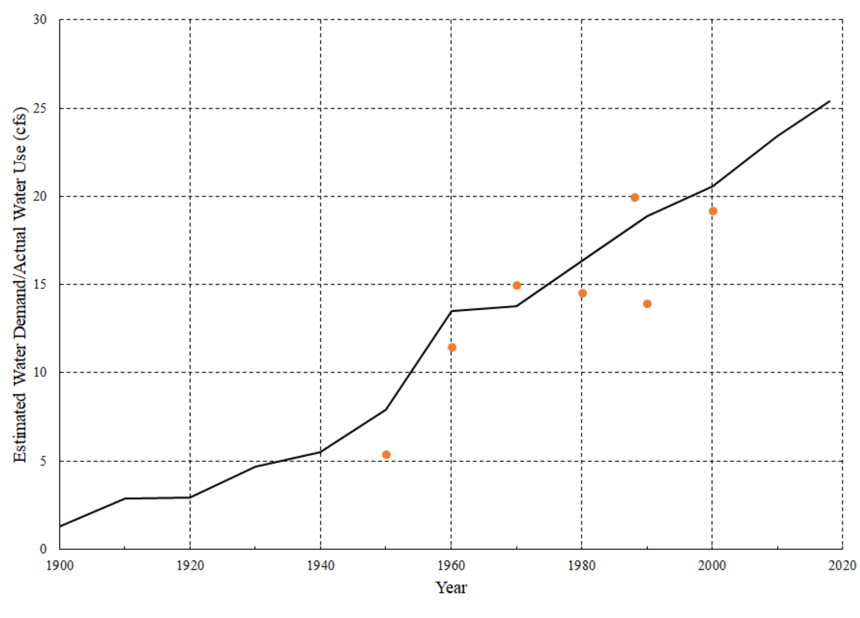


Figure 5. Comparison of estimated historic water demand based on the assumed per-capita use rate of 150 gallons per day (black line) with actual historic use (orange points).

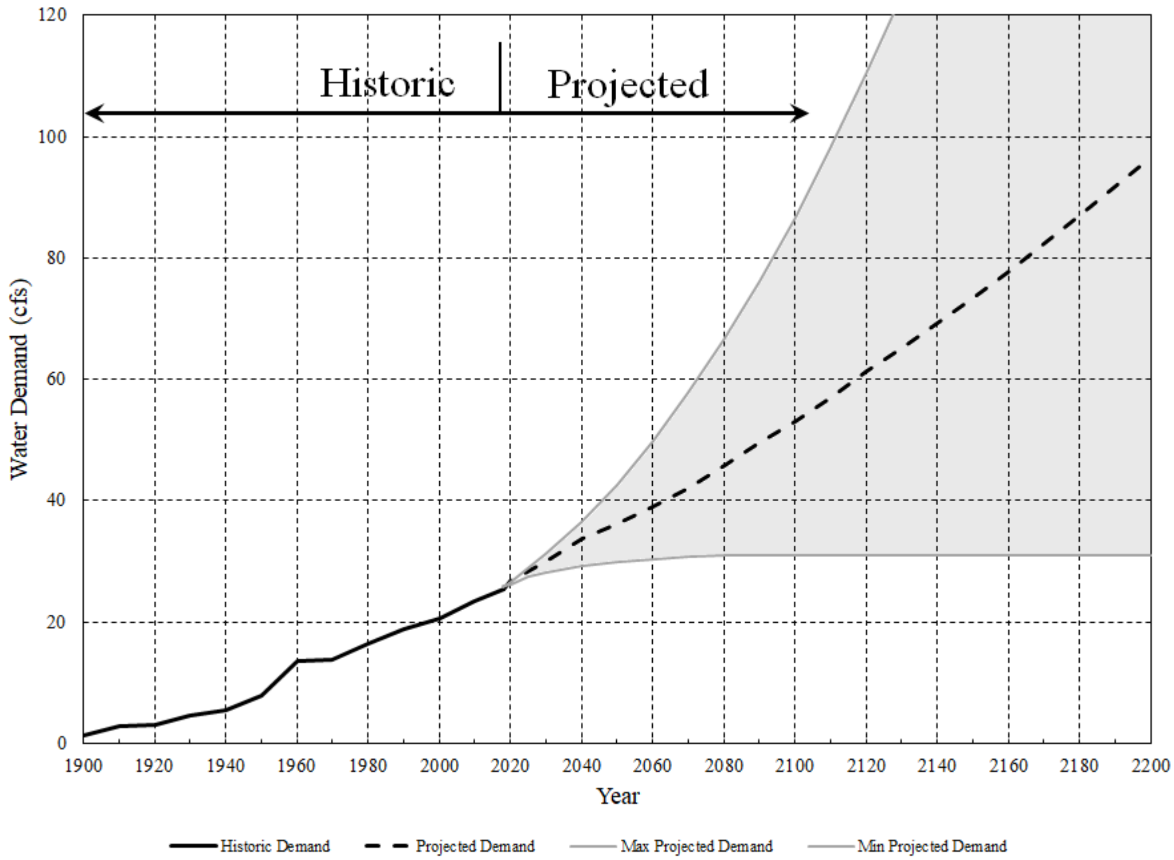


Figure 6. Historic and projected water demand based on a per-capita use of 150 gallons per day.

Current Water Supplies

As mentioned, historically, water used within the study area is supplied by both groundwater and surface-water sources. The amount of water that can be extracted from these sources is limited by hydrologic parameters as well as annual precipitation. Furthermore, the allocation of both surface water and groundwater within the study area is complex. For the purposes of this study, the total amount of usable water from each source was evaluated with the caveat that the actual appropriation, based on existing water rights, would need to be considered and potentially renegotiated in the future in order to maximize the use of available water resources in an efficient way. Usable water is the amount that is available for use without negatively affecting the long-term viability of the water source.

The use of groundwater as a source of water is very common throughout the western United States. However, many states in this area have operated for long periods of time in overdraft conditions; that is, they are extracting more water from their aquifers than is naturally replenished. This has led to areas of groundwater mining and associated water-level decline, reduction in storage conditions, land subsidence, saltwater intrusion, and oxidation of organic materials (Galloway et al., 1999).

The two major aquifers utilized within the study area (the Minnelusa and Madison) generally are permeable and have fluctuating amounts of groundwater in storage. The amount of groundwater available for consumption during any given year in the study area is strongly influenced by precipitation and the aquifers' connection to surface water in the Black Hills (Downey and Dinwiddie, 1988; Rahn and Gries, 1973; Hortness and Driscoll, 1999; Carter and Driscoll, 2000). The most pertinent study that provides insight into the amount of available groundwater for use within the study area was by Long and Putnam (2002). They evaluated groundwater availability during drought (1987 - 1993), wet (1993 – 1997), and an average of those periods (1987 – 1997) to determine the budget of available groundwater in the area (Figure 7).

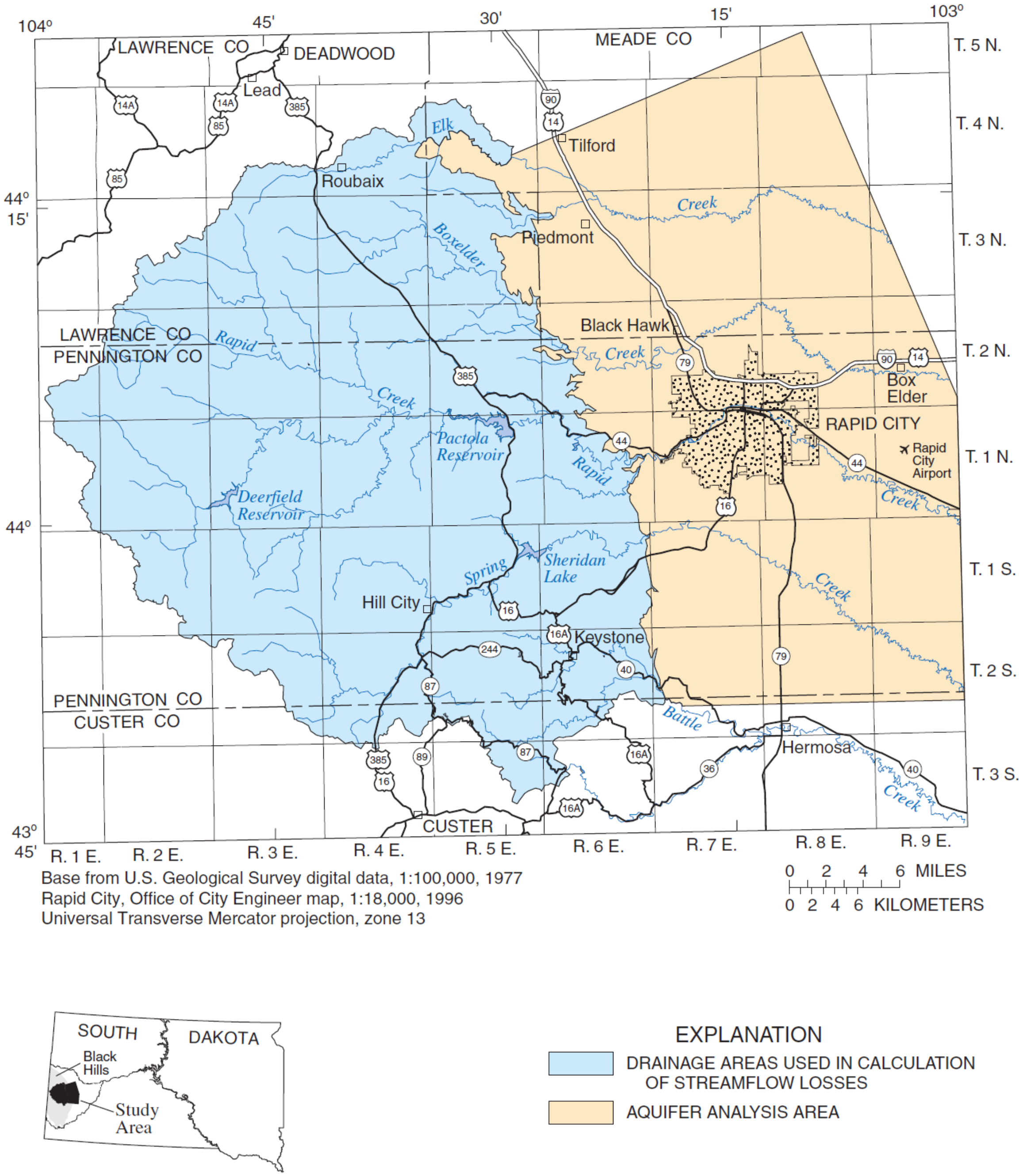


Figure 7. Study area of Long and Putnam (2002) from which estimates of available groundwater were obtained.

Figure 8 shows the variability of the annual precipitation recorded at the National Weather Service weather station at the Rapid City Regional Airport. Annual precipitation magnitudes are shown in blue, while the long-term average annual precipitation is signified by the red line, and a four-year running average is shown in orange in order to better visualize drought periods (long-term dips below the average) and wet periods (long-term periods above the average).

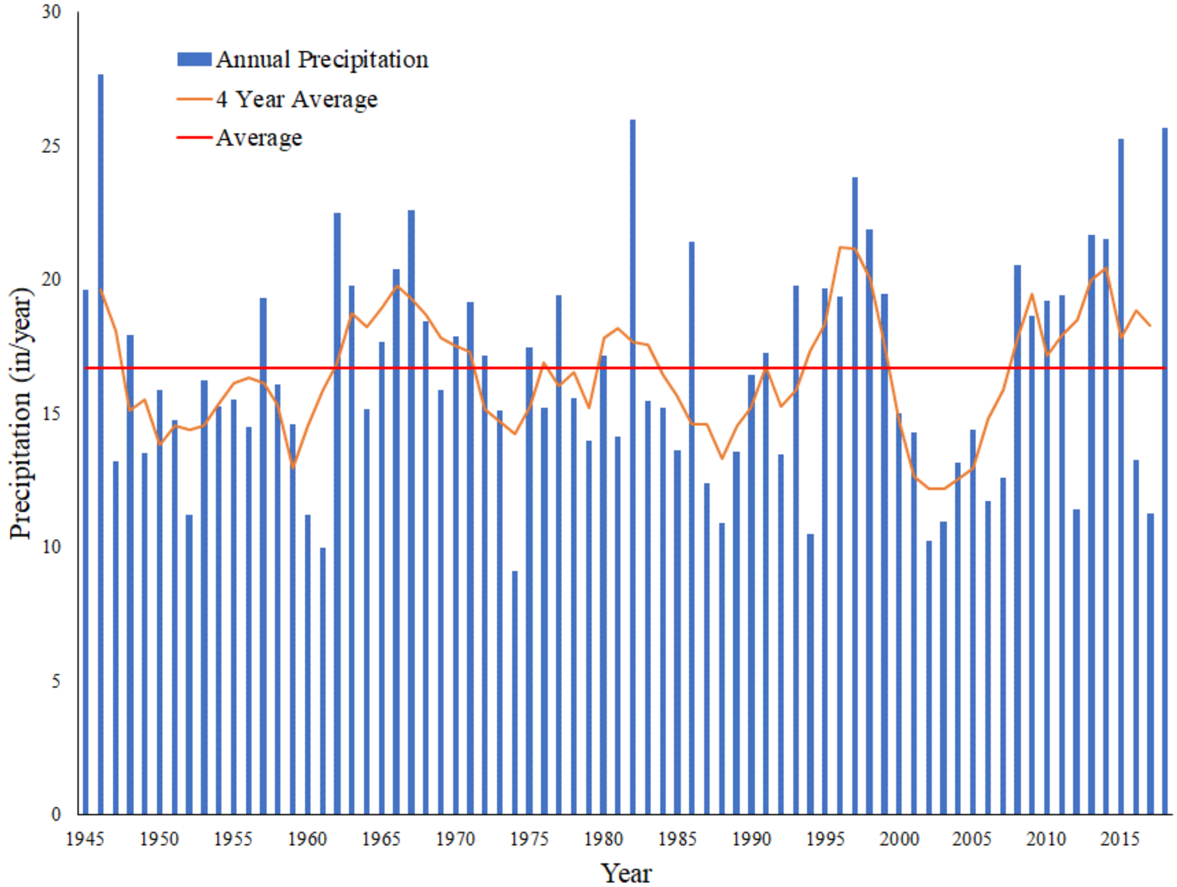


Figure 8. Annual precipitation at the Rapid City Regional Airport from 1945 – 2018, with long-term average and a four-year running average shown. Source: National Oceanic and Atmospheric Administration.

Long and Putnam (2002) found that inflow into the Madison and Minnelusa aquifers from precipitation directly on outcrops, streamflow losses, and leakage from the Deadwood aquifer in the study area ranges from 44.5 ft^3/sec, or cfs, (dry year) to 110.0 cfs (wet year), with an approximate average of 73.8 cfs. They estimated that the Minnelusa and Madison aquifers lost water to outflow from springs, and regional outflow at a rate of 47.5 cfs, 59.6 cfs, and 53.0 cfs during dry, wet, and average years respectively.

As such, for the purposes of this study, it was assumed that, in order to avoid an overdraft condition, groundwater budgets of 0 cfs (in actuality there is a 3.0 cfs deficit), 50.4 cfs, and 20.8 cfs are available for consumption during dry, wet, and average years, respectively. It is important to note that this assumes that we can effectively extract the maximum available water for use without negatively affecting areas around extraction wells.

In terms of surface-water availability for consumptive use, the lone historic source of surface water within the study area is Rapid Creek. Flows in Rapid Creek are strongly controlled by releases from Pactola Reservoir by the U.S. Bureau of Reclamation with input from the City of Rapid City. Because Pactola Reservoir is part of the Rapid Creek flow system, statistics garnered from evaluating historic flows observed at gaging stations in Rapid City are representative of flows that could be expected in the future. Gaging stations in Rapid City are below the known loss zones where surface water sinks into the Minnelusa and Madison aquifers below (Hortness and Driscoll, 1998; Anderson et al., 1999) and therefore represent the majority of water available for consumptive use. Water diverted from Cleghorn Spring prior to entering Rapid Creek is not included in the following discussion. Historically, water has been diverted from Cleghorn Spring for consumptive use, however it is difficult to say of this spring would continue to flow if groundwater resources are fully utilized at the rates discussed above. As such, this additional flow has been ignored in this assessment.

Figure 9 shows average annual streamflow for water years from 1964 – 2018 at U.S. Geological Survey gage 06414000 (Rapid Creek at Rapid City, SD). For the purposes of this study, average annual streamflows of 43.3 cfs, 82.5 cfs, and 60.7 cfs represent the 25th, 75th, and 50th percentile average annual flows. These were used as the available surface water flows for consumptive use for dry, wet, and average years respectively. However, these values must include a minimum amount of flow that remains in the creek to support aquatic life. Therefore, the water that is available for consumption will be less.

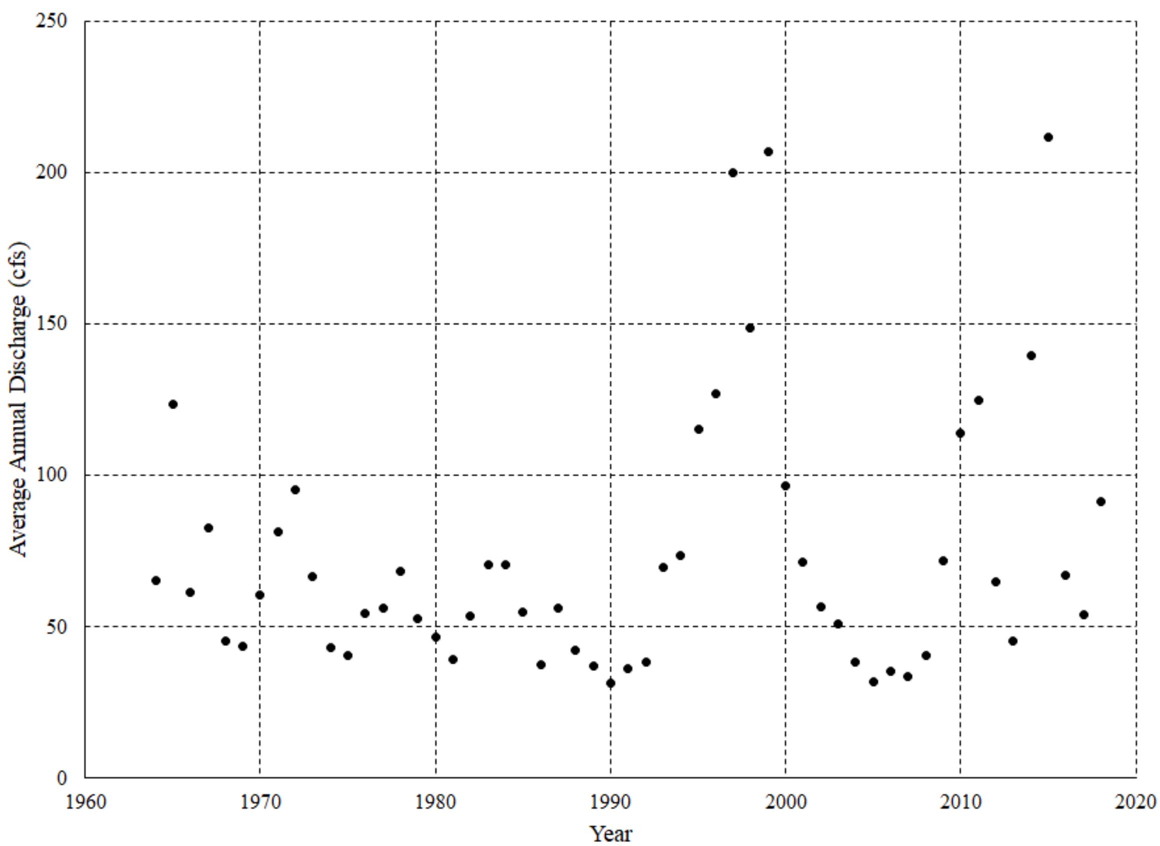


Figure 9. Mean annual discharge for gage 06414000 – Rapid Creek at Rapid City from 1964 – 2018. Source: U.S. Geological Survey.

Tennant (1975) stated that for "excellent" habitat, 60% of the annual mean stream discharge should be maintained. In this case, stream quality will not be altered, and the aquatic life will not be negatively affected. He stated that for a "good survival habitat," 30% of the mean flow of the stream should be maintained. Tennant stated that the absolute minimum flow that must be allotted in a stream is 10% of the mean annual discharge. However, he also noted that this flow magnitude should be short-lived. For our study, it was assumed that the goal would be to maintain a "good survival habitat." As such, a goal of 30% of the mean annual discharge should be maintained. The streamflow representing 30% of the mean annual discharge near the Rapid Creek and Rapid City gage is about 18.2 cfs. The absolute minimum flow that Tennant listed (10% mean annual discharge) for Rapid Creek near Rapid City would be 6.1 cfs.

Tessman (1980) modified Tennant's method by evaluating flows on monthly intervals. Tessman stated that:

- If the mean monthly flow is less than 40% of the mean annual flow, then the minimum allowable monthly flow equals the mean annual flow.

- If the mean monthly flow is greater than 40% of the mean annual flow, and 40% of the mean monthly flow is less than 40% of the mean annual flow, then the minimum allowable monthly flow equals 40% of the mean annual flow.

- If 40% of the mean monthly flow is greater than 40% of the mean annual flow, then the minimum allowable monthly flow equals 40% of the mean monthly flow.

Table 1 shows the mean monthly flows for gage 06414000 – Rapid Creek near Rapid City and the minimum monthly flows as recommended by Tessman (1980). It should be noted that 40% of the mean annual flow (50^{th} percentile of the average annual flow reported above) for Rapid Creek at this gage is 24.3 cfs.

Table 1. Minimum allowable monthly discharges after Tessman (1980) as determined by assessing mean monthly discharges between 1964 and 2018 at gage 06414000 – Rapid Creek near Rapid City, SD. Source: U.S. Geological Survey.

Month	Mean Monthly Discharge (cfs)	Minimum Allowable Monthly Discharge (cfs) per Tessman (1980)
January	40	24.3
February	40	24.3
March	49	24.3
April	72	28.8
May	130	52.0
June	161	64.4
July	109	43.6
August	80	32.0
September	60	24.3
October	48	24.3
November	44	24.3
December	42	24.3

Tessman's method provides more clarity with respect to managing streamflow magnitudes on a monthly basis. However, because the other data that have been analyzed in this study were based on annual statistics, Tessman's suggested streamflow magnitudes are difficult to apply. As a result, for this study, the 30% of the mean annual streamflow magnitude recommended by Tennant (18.2 cfs) was averaged with the minimum recommended flow for any month from Tessman (24.3 cfs). The resulting assumed value for minimum streamflow that must remain in order to maintain adequate stream habitat health is 21.3 cfs. It should be understood that while these values rate as acceptable flow conditions, they should be short lived as prolonged flow at this low of a discharge would likely have negative impacts on the stream ecosystem. When this averaged value was subtracted from the average annual streamflow values listed above, available surface water resources for consumptive use were 22.0 cfs, 61.2 cfs, and 39.4 cfs for dry, wet, and average climatic conditions.

In order to evaluate the availability of surface water for consumptive use over long-term periods, storage in Deerfield and Pactola reservoirs was ignored. However, these two reservoirs play an important role in the region's ability to moderate against decreased availability of surface and groundwater during times of drought. Figures 10 and 11 show historic reservoir elevations and dam outflows since the late 1950s (Squillace, 2019). These data show that water levels in Pactola Reservoir fluctuate more than at Deerfield, indicating that Pactola has historically been relied upon more to provide water during dry periods. In the early 1960s, water levels were also lowered to help chemically remove invasive fish species. Deerfield Reservoir's water levels throughout time have been relatively constant with a few exceptions. A dry period in the late 1950s and early 1960s, which occurred before and during the original impoundment of Pactola Reservoir (when Deerfield Reservoir would have been more susceptible to sizeable water level fluctuations), can be seen in Figure 10. The reservoir was drained in the early 1980s so maintenance could be performed on the dam. The only time when water levels were lowered significantly due to consumptive use since the impoundment of Pactola Reservoir occurred during the drought conditions that existed during the early to mid-2000s. However, useable storage in the reservoir never dropped below 75% during that time period.

Pactola Reservoir was also impacted by the drought in the late 1950s and 1960s even though it was not fully impounded yet. It has also been much more reactive to both short and long duration dry periods than Deerfield has. Most notably, useable storage in Pactola Reservoir was reduced to 42% and 49% of capacity during the drought periods occurring during the late 1980s through the early 1990s and the early to mid-2000s respectively. Total storage in the two reservoirs was reduced to about 51% and 55% of capacity during those two droughts respectively.

Projected Water Use

If the budgets for available groundwater and surface water are summed, this equates to total available water budgets within the study area of 22.0 cfs, 111.6 cfs, and 60.2 cfs for dry, wet, and average climatic conditions, respectively. Figure 12 shows how these values compare to the predicted water demand shown previously on Figure 6.

Figure 12 indicates that, in the next few decades, western Pennington County could face a water shortage if serious drought conditions occur and persist for several years or more. Conversely, if

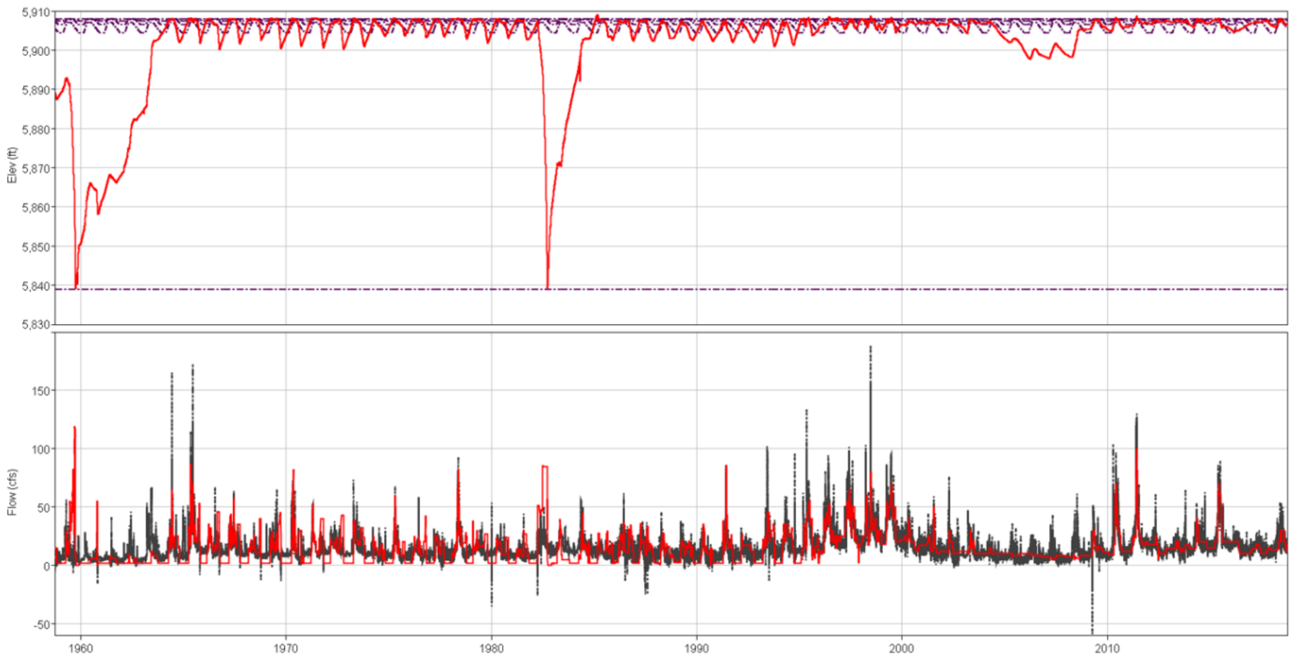


Figure 10. Historic water levels and dam outflows for Deerfield Reservoir (Squillace, 2019)

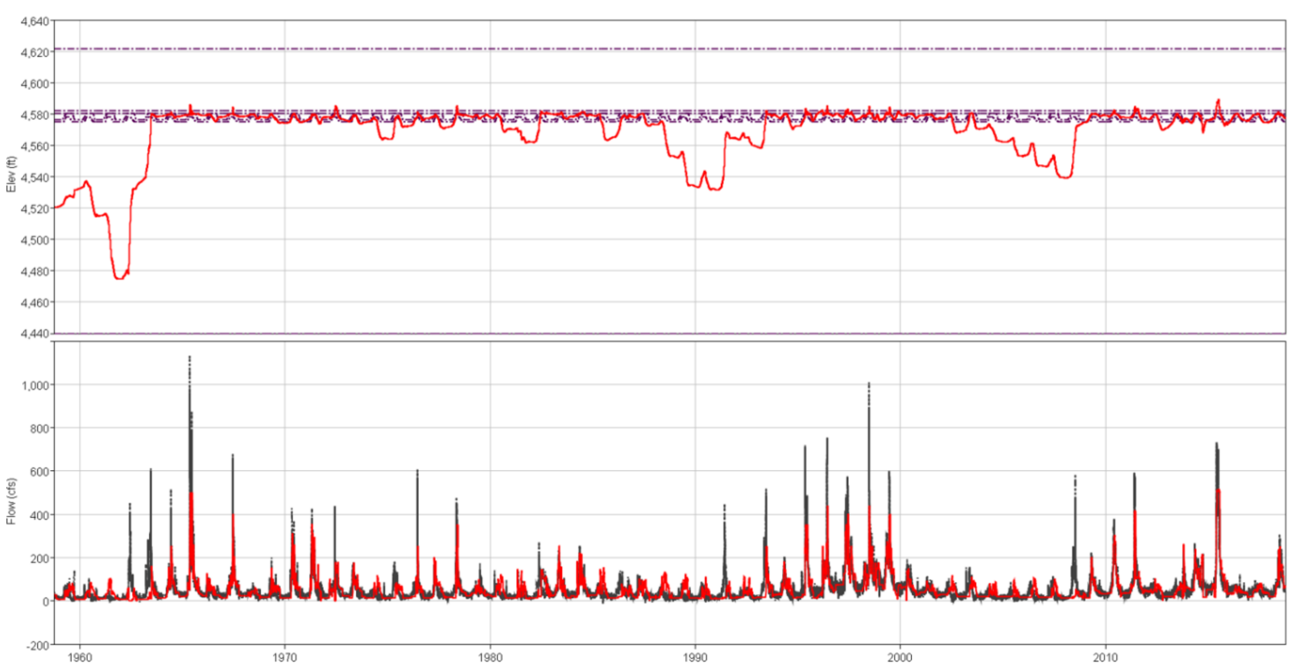


Figure 11. Historic water levels and dam outflows for Pactola Reservoir (Squillace, 2019).

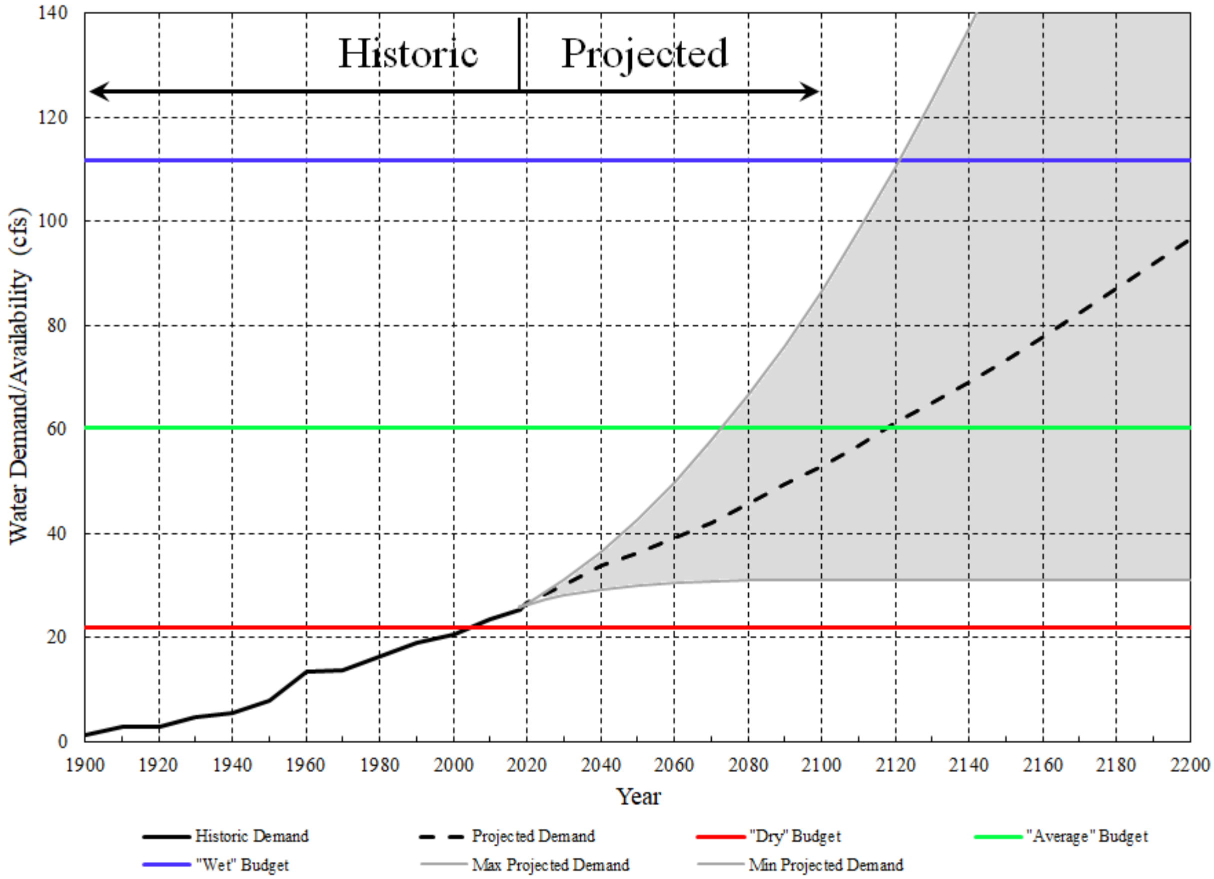


Figure 12. Historic and projected water demand based on a per-capita use of 150 gallons per day plotted with "dry", "wet," and "average" water budgets in this study.

the area enjoys average or above-average precipitation steadily during the next century, without significant droughts, current supplies could be adequate for several decades. Because much uncertainty is indicated by the various population projections utilized in this study (see the gray shaded area in Figures 4, 6, and 12), a wide range of future water-demand scenarios exist.

Development of Missouri Water Use

Should it be deemed necessary to exercise the right (10,000 acre-feet/year) provided by Future Use Permit #1443-2 and the need to transport water from the Missouri River to western Pennington County becomes paramount, it would be a significant task. Furthermore, if such a project were to be undertaken, it is likely that the WDWDD would need to form a partnership with the City of Rapid City in order to transport some or all of its allotment (66,000 acre-feet/year) as well. Partnerships with other communities and entities also should be sought and the help of our congressional delegation would be crucial.

It is difficult to know at this point how much water would be transported; therefore, in this study, the required pipe sizes for multiple volumetric flow rates and their associated flow velocities were calculated. Typically, pipelines are designed such that the average flow velocity within the pipe falls in a range from about 2 – 5 ft/sec. As such, a simple estimation of required pipe size can be done by determining the cross-sectional area of the pipe needed to pass a desired flow at a required velocity. Figure 13 provides pipeline size requirements for desired flow velocities between 2 – 5 ft/sec for flow volumes of 2,500; 5,000; 10,000; 20,000; 40,000; and 80,000 acre-feet/year. Preliminary pipeline designs needed to convey the full WDWDD allotment (10,000 acre-feet per year and both the WDWDD and Rapid City allotments (76,000 acre-feet per year) are discussed later.

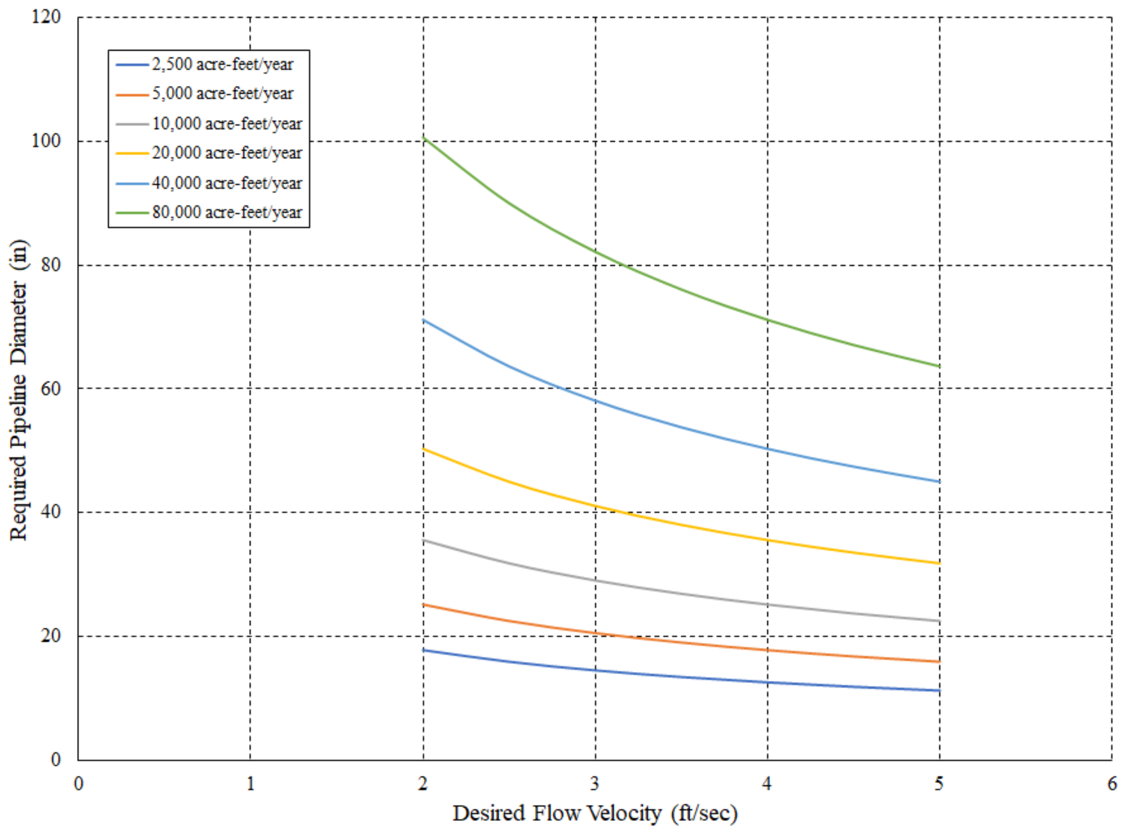


Figure 13. Required pipeline diameters relative to desired flow volumes and velocities.

As with any major pipeline project, designating an alignment for construction is one of the largest challenges. For the purposes of this study, three alignments are suggested (Figure 14). The red and blue alignments in Figure 14 show the two most likely scenarios because these alignments follow existing highways or interstates. These routes are assumed to be the least challenging for securing access/easements to install a pipeline. The green alignment, in contrast, utilizes almost entirely private land but is shorter in distance and preserves elevation as much as is possible between Lake Oahe and Rapid City. This alignment would reduce construction costs but would only be viable if the cost to acquire land for this route is less than the savings in infrastructure.

The elevation profiles along each alignment are shown on Figure 15. The change in elevation along the profile is a crucial design parameter because it represents the loss (or gain) of pressure head along the alignment. In addition to head loss related to elevation change, head also will be lost along the route due to pipe friction and passage through fittings, valves, bends in the pipe, etc. (known as minor head loss). This project would need to overcome about 1,560 ft of elevation head because of the differences in elevation between Oahe Reservoir and Rapid City. In order to evaluate the challenges related to the project, this study conducted a preliminary assessment of head loss associated with what was deemed as the most likely pipeline alignment, which is shown in red on Figure 14. This alignment follows the rights of way associated with Highways 34 and 14 before joining the Interstate 90 right of way. This was deemed the most likely route candidate because it is the shortest route between the desired points that follows all state or federal road alignments.

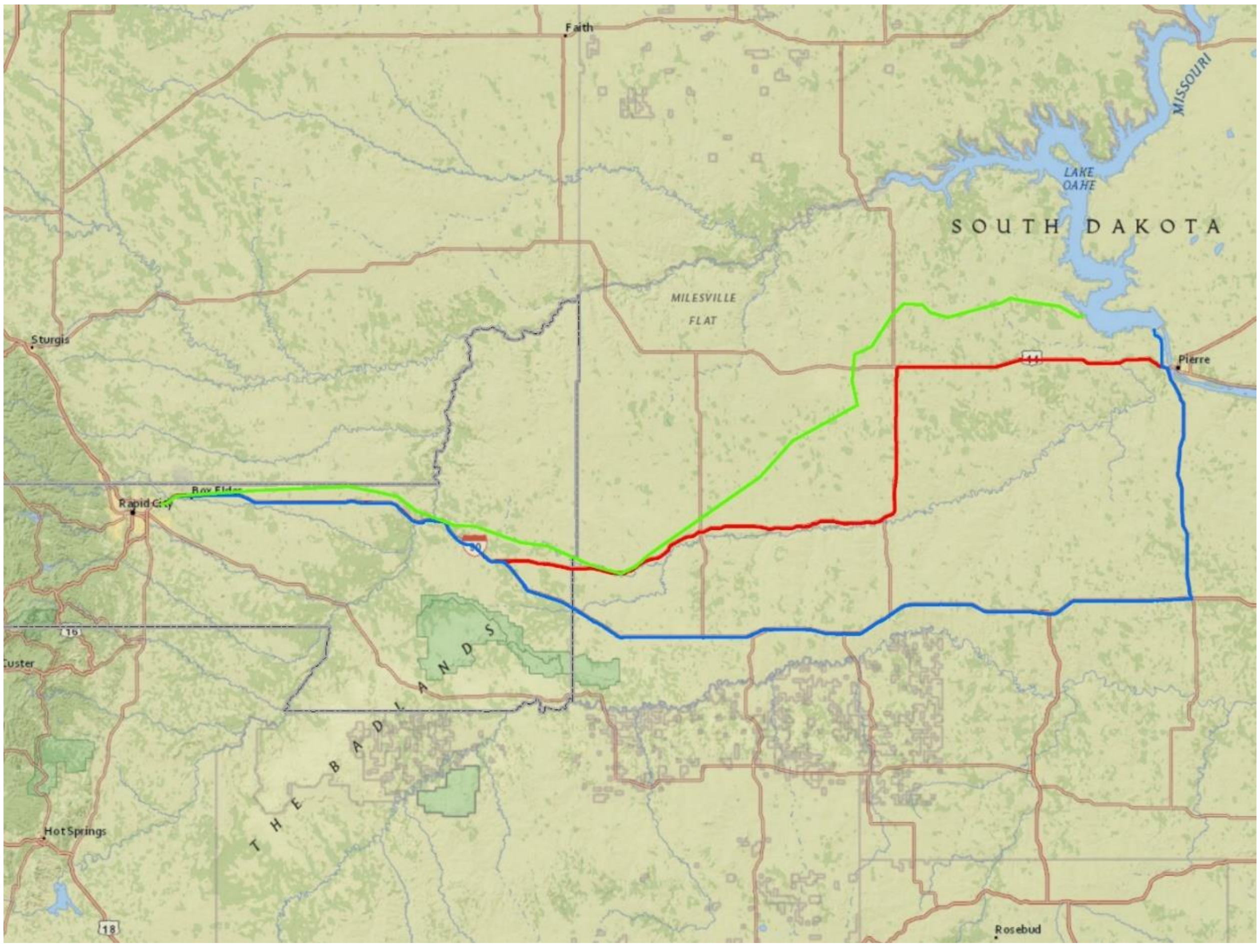


Figure 14. Possible alignments for a pipeline from Oahe Reservoir to Rapid City.

This study provides two design scenarios. The first assumed a pipeline designed to carry the full capacity of the WDWDD future use permit of 10,000 acre-feet/year. The second assumed a pipeline designed to carry the full allotments from both WDWDD and Rapid City totaling 76,000 acre-feet/year. After a few iterations it became clear that the first design would be most cost efficient if 3 foot diameter pipe was used. This design would result in the lowest allowable flow velocity of approximately 2 feet/second, but it would minimize the added head resulting from friction loss and, therefore, greatly reduce the number of pump stations needed (a major capital investment as well as a sizeable maintenance expense). For the second design, a pipe diameter of 6 feet was selected.

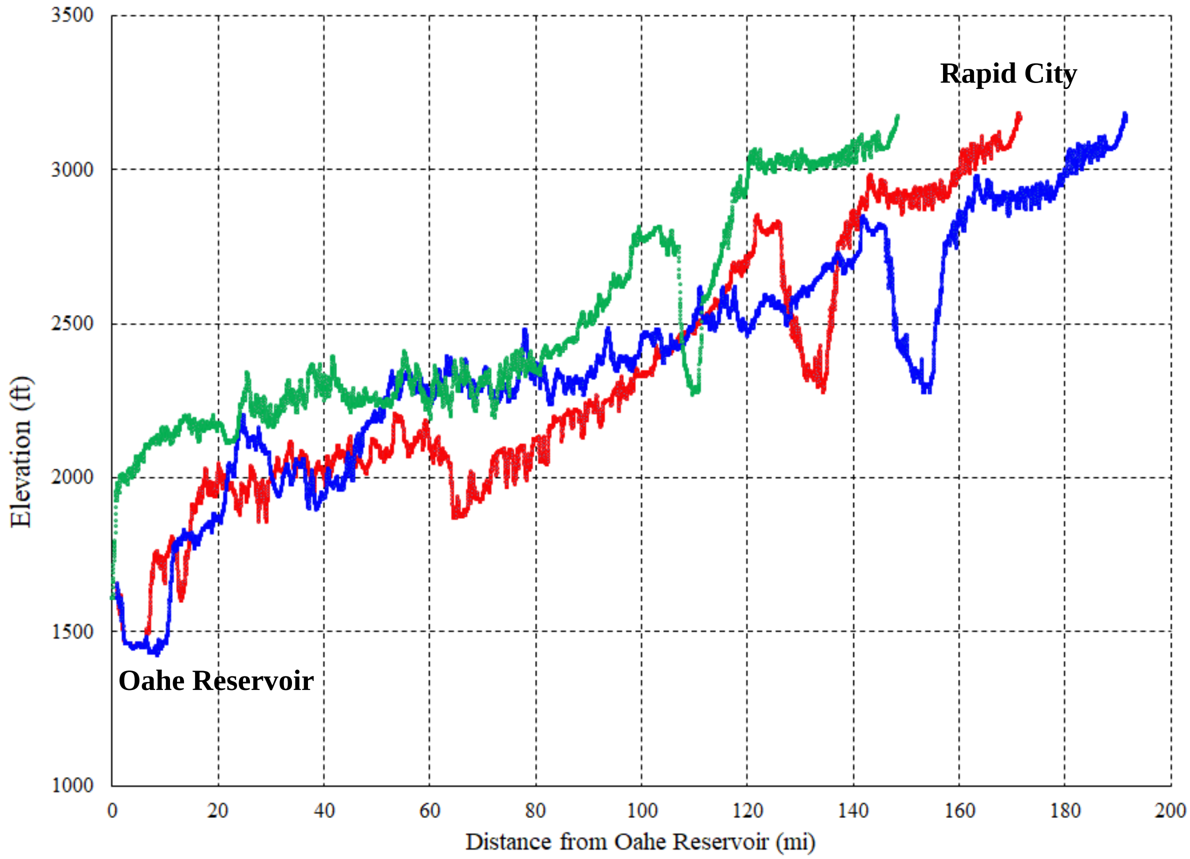


Figure 15. Elevation profiles along the three proposed pipeline alignments.

In order to calculate head loss due to pipe friction (*HLf*), the Darcy-Weisbach Equation was used:

$$HLf = f\ \frac{L}{D}\frac{V^2}{2g}$$

Where:
f = friction coefficient (unitless)
L = length of pipe (ft)
D = diameter of pipe (ft)
V = velocity of flow (ft/sec)
g = gravitational acceleration (ft/sec^2)

The friction coefficient (f) was estimated by using the Swamee-Jain equation:

$$f = \frac{0.25}{log\left(\frac{\frac{e}{D}}{3.7} + \frac{5.74}{\left(\frac{DV}{v}\right)^{0.9}}\right)^2}$$

Where: e = roughness coefficient (ft)
D = diameter of pipe (ft)
V = velocity of flow (ft/s)
υ = kinematic viscosity (ft^2s)

The head loss due to friction then was calculated at points along the entire alignment for both the 3 and 6-foot diameter pipelines. The total head loss due to friction for the 3 and 6-foot diameter pipelines was determined to be roughly 260 and 357 feet respectively.

Minor head losses (HLm) due to pipe fitting and valve characteristics were determined using the following equation:

$$HLm = (\#valves)K\left(\frac{V^2}{2g}\right)$$

Where: #valves = the number of valves needed (we assumed one valve every 5 miles)
K = correction factor for valve type (we assumed a swing type valve)
V = velocity of flow (ft/s)
g = gravitational acceleration (ft/sec^2)

The total minor head loss along the proposed alignment also was also calculated at points along the proposed alignment. Total minor head loss along the entire length of the 3 and 6-foot diameter pipelines was approximately 5 and 19 feet respectively.

The total head loss (when considering elevation head loss, friction head loss and minor head loss) for the 3 and 6-foot diameter pipelines was determined to be approximately 1825 feet and 1935 feet respectively. As such, multiple pump stations would be required in each design to boost head pressure along the alignment. For these hypothetical scenarios, pumps were specified for the required intake stations as well as boost stations for both of the pipeline designs (Lind, 2019). A summary of the pertinent pump characteristics is provided in Table 2 but detailed specifications for the proposed pumps are provided in Appendix 1.

Table 2. A summary of pertinent pump specifications for the two proposed pipeline designs (Lind, 2019).

Pump Station Type	Design Power Required (hp)	Pressure Head (ft)	Design Flow (gpm/cfs)	Efficiency (%)	Number of pumps
3’ Diameter Intake Station	269	453.2	2000/4.45	83.65	4
3’ Diameter Boost Station	308	330.0	3000/6068	81.14	3
6’ Diameter Intake Station	1993	452.0	15666/34.90	89.08	3
6’ Diameter Boost Station	1433	330.1	15666/34.90	91.02	3

In each case, the design would call of the use of three of the above-listed pumps at each station to provide the needed capacity (with the exception of the 3' diameter intake station which would require four pumps). It is suggested that each pump station have an additional pump available on standby in order to accommodate maintenance. In order to maintain positive head pressure due to the head losses described above for each design, 6 pump stations would be necessary for the 3-foot diameter pipeline and 7 pump stations would be necessary for the 6-foot diameter pipeline.

The locations of these pump stations were evaluated by calculating a cumulative head loss value (elevation head loss, head loss due to friction, and minor head loss) along the entirety of the alignment and installing pump stations where necessary to maintain positive head pressure (with roughly a 10% buffer considered). The proposed locations of pump stations for both pipeline sizes along the alignment and elevation profile are shown on Figures 16 and 17 respectively.

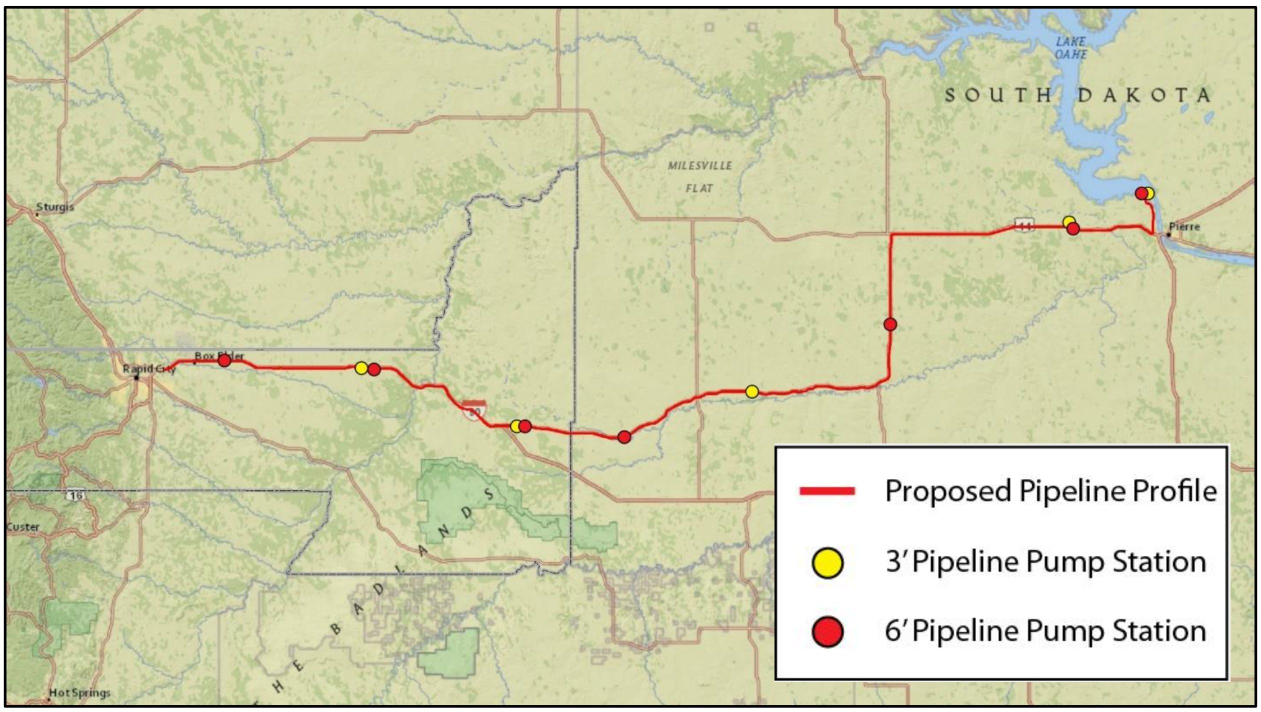


Figure 16. Locations of pump stations along the proposed pipeline alignment.

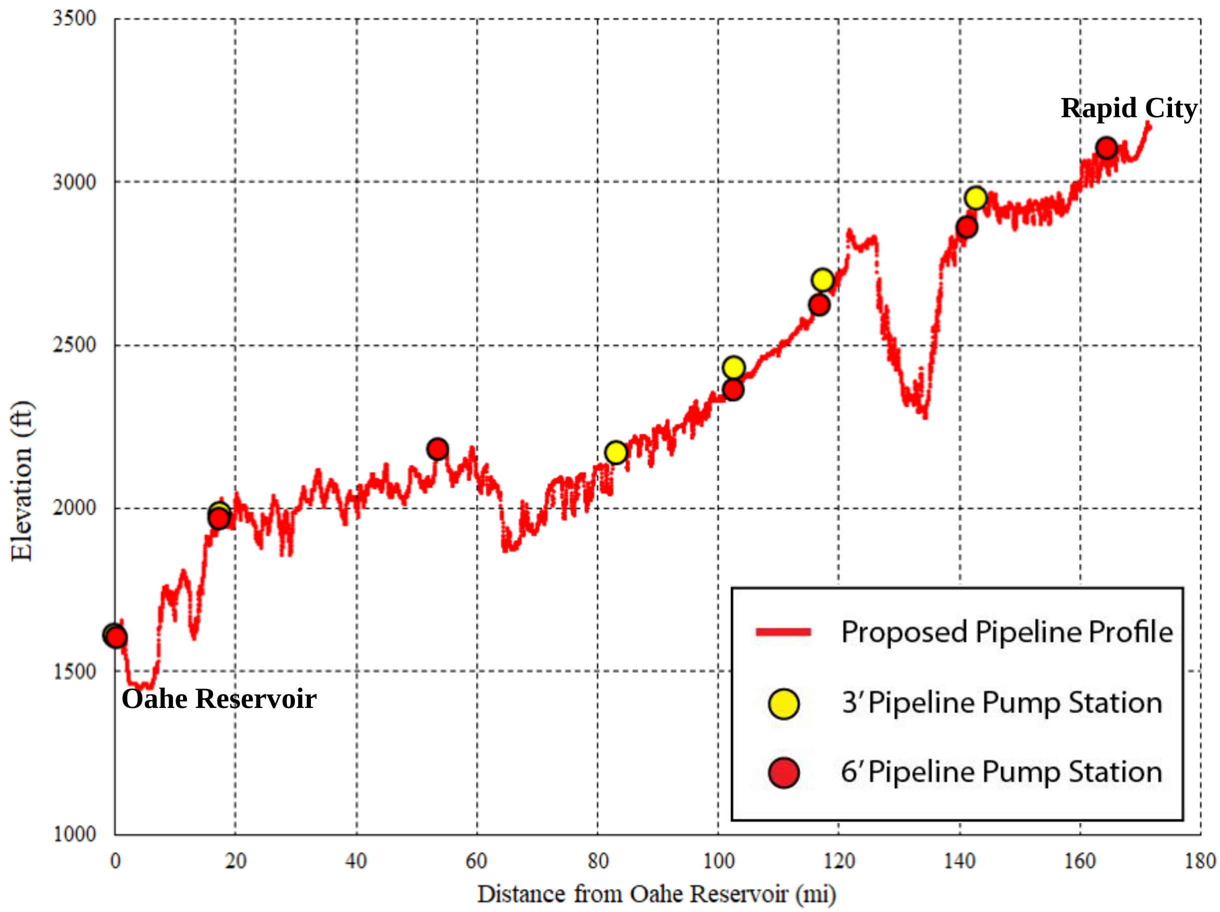


Figure 17. Pump station locations plotted on the elevation profile for the proposed pipeline alignment.

Additional engineering challenges and requirements related to the construction of the pipeline include the following:

- A pipeline such as this would require reservoirs (tanks or surface water) at each boost pump station to break pressure. Suggested minimum capacities for these reservoirs are 2 million gallons for the 3-foot pipeline and 10 million gallons for the 6-foot pipeline (Chorne, 2019).

- When the water reaches its destination in western Pennington County, it would need to be stored in a sizeable reservoir before it could be distributed into existing water systems. This would also allow multiple entities to tap into the new supply. It is likely that this would require a conventional surface reservoir, perhaps similar to the proposed Brennan Reservoir in Rapid Valley several decades ago (U.S. Bureau of Reclamation, 1985).

- Initial and final water quality at both the beginning and the end of the pipeline would need to be assessed. It is possible that untreated water could be conveyed to the final reservoir east of Rapid City and then treatment could occur there before distribution, but the impact of untreated water on pipeline infrastructure would need to be assessed. If treatment occurs at the source at Oahe Reservoir, the impact of the pipeline on water quality would then need to be considered.

Estimated Project Cost

As with the preliminary pipeline design considerations discussed above, a preliminary cost estimate has been completed for the construction of 3-foot and 6-foot diameter pipelines which would have the capability to convey 10,000 acre-feet/year and 76,000 acre-feet/year respectively. It is important to note that the cost estimate discussed here only includes the capital investment related to construction. The only operational expense that was estimated was the maximum electrical cost that might be expected for each pipeline. As such, a detailed analysis of operational costs would need to be completed. Cost estimates were conducted using generous guidance from Chorne (2019).

Estimates of construction costs included considerations for pipe materials and appurtenances, excavation, intake pump stations, boost pump stations (including the required electrical infrastructure that would be needed), engineering design, legal and administrative costs, environmental assessment, easement procurement, permits, and a contingency for unforeseen expenses which are common for projects such as these (Chorne, 2019). These estimated costs were, in some cases, aggregated together into categories as shown in Tables 3 and 4. The total estimated cost of the 3-foot diameter pipeline was approximately $555 million. The estimated cost of the 6-foot diameter pipeline was approximately $1.87 billion. A cost comparison of pipeline capacity evaluating the expense for each acre-foot delivered annually suggests values of $55,000 per acre-foot of pipeline capacity for the 3 foot diameter pipeline and about $26,000 per acre-foot of pipeline capacity for the 6 foot diameter pipeline. These cost discussions do not include annual maintenance costs although a brief discussion of energy costs is provided below.

Table 3. Cost estimate for the 3-foot diameter pipeline (Chorne, 2019).

Expense Category	Cost Estimate
Intake pump station (including electrical infrastructure)	$7,500,000
36” ductile iron pipe and appurtenances (includes excavation and pipe material, valves, borings, road crossings, air release valves, blow-off valves etc.)	$340/ft
Boost pump station (including 2,000,000 gallon reservoir)	$5,900,000
Engineering, legal, admin, environmental, easements, permits, etc.	35% total const. cost
Contingency estimate	25% total const. cost
Total	**$555,000,000**

Table 4. Cost estimate for the 6-foot diameter pipeline (Chorne, 2019).

Expense Category	Cost Estimate
Intake pump station (including electrical infrastructure)	$45,000,000
72" ductile iron pipe and appurtenances (includes excavation and pipe material, valves, borings, road crossings, air release valves, blow-off valves etc.)	$850/ft
Boost pump station (including 10,000,000 gallon reservoir)	$39,800,000
Engineering, legal, admin, environmental, easements, permits, etc.	25% total const. cost
Contingency estimate	25% total const. cost
Total	**$1,870,000,000**

Based on the required horsepower for each pump station and pump efficiency values, an estimate of the total electricity required to all the pump stations at capacity was completed for each pipeline. The power needed to run all the pump stations associated with the 3-foot and 6-foot diameter pipelines at capacity is approximately 5.2 and 26.2 Mw respectively. This equates to approximately 45.6 and 229.0 gigawatt-hours annually. As such, the annual estimated electrical costs for each pipeline assuming constant operation at full capacity would be approximately $1 – 1.5 million (3-foot pipeline) or $7 – 11.5 million (6-foot pipeline) and would be dependent upon the negotiated wholesale price of energy ($0.03 to $0.05 per kilowatt-hour assumed).

Discussion

As population continues to increase within the study area, additional sources of water will need to be developed. As shown on Figure 12, if the population projections derived from this study are accurate and current per-capita water use remains the same into the future, the current water supply that is afforded during an "average" year is projected to overcome average predicted demand around the year 2120. Currently, storage in Pactola and Deerfield reservoirs and storage in groundwater provide a buffer against drought conditions. However, the management/response of these two systems to the two most recent drought periods indicates that as populations continue to increase this buffer will be greatly reduced. Furthermore, if we enter a prolonged period of drought where the buffer provided by storage in Pactola and Deerfield reservoirs is exhausted, our current water supply would not be enough to provide water at a typical rate without negatively affecting our groundwater storage. Utilizing groundwater above the natural recharge rate is not a long-term planning strategy, as other communities in the western U.S. are discovering. As such, the region would benefit from long-term planning regarding water supply security. A severe and unexpected drought, if it continued for several years or longer, could cause an urgent need for water supplies much greater than could be supplied locally. Although the water from this proposed pipeline project might not be needed immediately or every year in the future, it is important to consider the lead time needed for a large-scale project. As an example, the Red River Pipeline Project in North Dakota is similar to this proposal in size and scope, and was begun in the 1990s. That project is nearing construction at the time of writing of this report, more than 20 years later.

If western Pennington County enjoys average or above-average precipitation in coming decades, future use of other sources of water closer to the project area would be favorable compared to transporting water from the Missouri River. Expanding the use of existing groundwater and surface water resources beyond that which is currently being utilized (i.e., broadening access to the Madison and Minnelusa aquifers farther from Rapid City and the use of other surface watersheds) could provide additional supplies. However, as growth continues within the study area, it is likely that the surrounding areas will experience similar growth and will be developing these water resources themselves. The largest surface water resource in the Black Hills region is the Cheyenne River, but the water rights associated with the Cheyenne River and the Angostura Reservoir are currently fully allocated to the Angostura Irrigation District, and the State is no longer issuing future use permits to those bodies of water (U.S. Department of the Interior, 2011). Any changes to this allocation would require far reaching renegotiations.

It should be stressed that the future use permit of the West Dakota Water Development District is not an actual license that would guarantee the use of water. In the future, political considerations at the state and national level could complicate development and eventual use of water from the Missouri River. In addition, policies of the U.S. Army Corps of Engineers could change with regard to management of the Missouri River. More populous downstream states in the Missouri River basin could exert political and economic influence for competing interests, including navigation, flood control, and water consumption.

The prospect of transporting water from the Missouri River to western Pennington County, while challenging, is feasible from an engineering perspective. However, this project would be extremely costly. Given the rough estimates of the cost of a project such as the one proposed in this report, it is unlikely that such a large cost could be borne solely by local entities in western Pennington County. As such, it is likely that state and federal support almost certainly would be necessary.

Conclusions

A strong need for new sources of water within the study area exists. As such WDWDD should continue to maintain Future Use Permit #1443-2, which would require renewal in 2024. If water is to be brought to western Pennington County via pipeline from the Missouri River, a project such as this would likely take decades to approve and construct. As population in the area increases, the need to ensure water security will grow ever greater. Therefore, local entities with a stake in our water security should pool their resources to ensure that they are proactive in securing future sources of water, one of which could involve water from the Missouri River.

Acknowledgements

Our group thanks the West Dakota Water Development District for its support in funding this study as well as for their thoughtful suggestions for improving the project as it progressed. We also thank Mr. Dan Coon and Mr. Jeff Crockett from the City of Rapid City for their insightful help on topics related to the project as well as their assistance providing our team access to previous studies commissioned by the City that pertain to this work. Additionally, the team would like to recognize Mr. Syed Huq, who also provided very helpful discussion regarding the required infrastructure and challenges related to constructing and operating a large pipeline system, as he has extensive experience operating the Mni Wiconi-Rosebud Rural Water System. Our preliminary pipeline design and cost estimates would not have been possible without the help of Will Lind from Dakota Pump, Inc., and Cory Chorne of AE2S.

References

Anderson, M.T., Driscoll, D.G., and Williamson, J.E., 1999, Ground-water and surface-water interactions along Rapid Creek near Rapid City, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 98-4214, 99 p.

Anderson, M.T., and Woosley, L.H., Jr., 2005, Water availability for the western United States – key scientific challenges: U.S. Geological Survey Circular 1261, 85 p.

Carter, J.M., Driscoll, D.G., and Williamson, J.E., 2002, Atlas of water resources in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-747, 120 p.

Carter, J. M., and Driscoll, D. G., 2000, Estimated recharge to the Madison and Minnelusa aquifers in the Black Hills area, South Dakota and Wyoming, Water Years 1931-98: U.S. Geological Survey Water-Resources Investigations Report 00-4278, 66 p.

Chorne, Cory, 2019, AE2S, Personal communication

City of Rapid City, 2014, Rapid City comprehensive plan, 473 p.

Coon, Dan, 2018, Personal communication, City of Rapid City.

Downey, J. S., and Dinwiddie, G. A., 1988, The regional aquifer system underlying the Northern Great Plains in parts of Montana, North Dakota, South Dakota, and Wyoming – summary: U.S. Geological Survey Professional Paper 1402-A, 64 p.

Driscoll, D.G., Carter, J.M., Williamson, J.E., and Putnam, L.D., 2002, Hydrology of the Black Hills area, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 02-4094, 150 p.

Galloway, D., Jones, D. R., and Ingebritsen, S. (editors), 1999, Land subsidence in the United States: U.S. Geological Survey Circular 1182, 177 p.

Gorman-Rupp, Centrifugal pumps. 04 Sept. 2019 <https://www.grpumps.com/pumptype/product/Centrifugal-Pumps>.

Gupta, R. S., 2008, Hydrology and hydraulic systems, Third Edition: Waveland Press.

Hortness, J. E., and Driscoll, D. G., 1998, Streamflow losses in the Black Hills of western South Dakota: U.S. Geological Survey Water-Resources Investigations Report 98-4116, 99 p.

Lind, Will, 2019, Dakota Pump, Inc., Personal communication.

Long, A. J., and Putnam, L. D., 2002, Flow-system analysis of the Madison and Minnelusa aquifers in the Rapid City area, South Dakota – conceptual model: U.S. Geological Survey Water-Resources Investigations Report 02-4185, 100 p.

Rahn, P. H., and Gries, J. P., 1973, Large springs in the Black Hills, South Dakota and Wyoming: South Dakota Geological Survey Report of Investigations No. 107, 46 p.

Squillace, Rosemary, 2019, Personal communication.

Tennant, D. L., 1976, Instream flow regimes for fish, wildlife, recreation, and related environmental resources: Fisheries, Vol. 1, p. 6 - 10.

Tessman, S. A., 1980, Environmental assessment. Technical Appendix E. Environmental use sector reconnaissance elements of the Western Dakotas Region of South Dakota study: Water Resources Research Institute, South Dakota State University, Brookings, SD.

South Dakota Department of Environment and Natural Resources, Water Resources Divison. 1 October, 2018, <https://denr.sd.gov/wrimage/wrinfo/wr_div2/1443-2.pdf>

United States Bureau of Reclamation, 1985, Rapid City water supply study, preliminary findings report: US Department of the Interior, Bureau of Reclamation, Upper Missouri Region, Billings, MT, 85 p.

United States Census Bureau, Data. 1 November 2018, <https://www.census.gov/data.html>

United States Department of the Interior, 2011, Southern Black Hills Water System appraisal report: Rural Water Supply Program, Dakotas Office, Great Plains Region, 41 p.

Appendix 1

Pump Specifications

Pump specifications for 3-foot diameter intake pump station:

GRUNDFOS PEERLESS PUMP Grundfos Quotation System 19.4.1

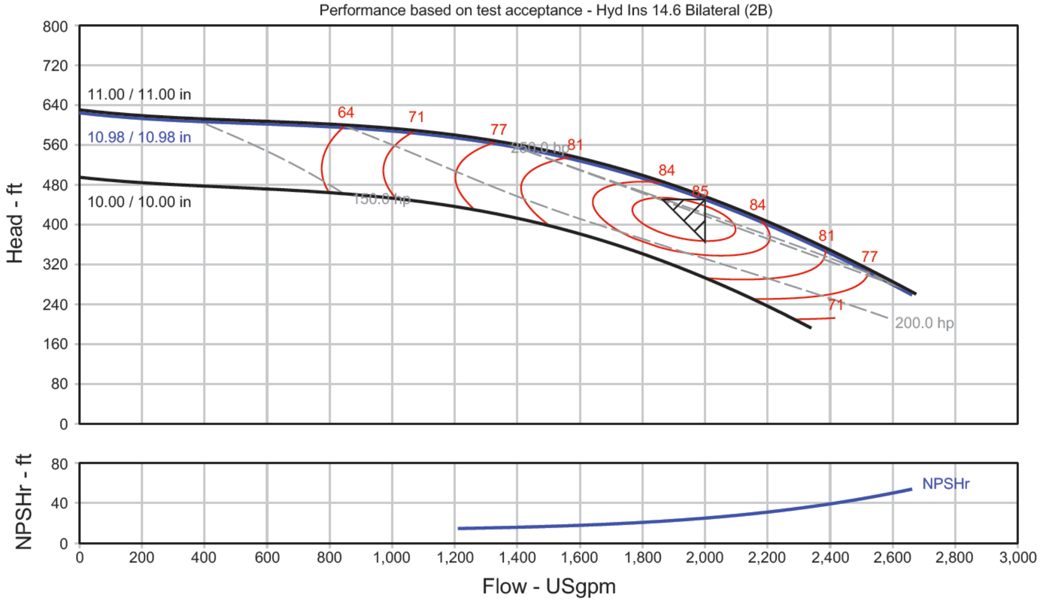
Pump Performance Datasheet

Customer	:	Quote Number / ID	: 528438
Customer ref. / PO	:	Peerless Model	: 15MA/LC
Tag Number	: 004	Stages	: 6
Service	:	Based on curve number	: 15MALC-2617049
Quantity	: 1	Date last saved	: 10/18/19 4:16 PM

Operating Conditions	
Flow, rated	: 2,000.0 USgpm
Differential head / pressure, rated (requested)	: 450.0 ft
Differential head / pressure, rated (actual)	: 453.2 ft
Suction pressure, rated / max	: 0.00 / 0.00 psi.g
NPSH available, rated	: Ample
Frequency	: 60 Hz
Performance	
Speed, rated	: 1760 rpm
Impeller diameter, rated	: 10.98 / 10.98 in
Impeller diameter, maximum	: 11.00 / 11.00 in
Impeller diameter, minimum	: 10.00 / 10.00 in
Efficiency (bowl / pump)	: 84.65 / 83.65 %
NPSH required / margin required	: 24.98 / 0.00 ft
Ns (imp. eye flow) / Nss (imp. eye flow)	: 3,115 / 6,949 US Units
MCSF	: 500.0 USgpm
Head, maximum, rated diameter	: 624.5 ft
Head rise to shutoff (bowl / pump)	: 38.69 / 39.88 %
Flow, best eff. point (bowl / pump)	: 2,021.1 / 1,995.2 USgpm
Flow ratio, rated / BEP (bowl / pump)	: 98.96 / 100.24 %
Diameter ratio (rated / max)	: 99.82 %
Head ratio (rated dia / max dia)	: 98.67 %
Cq/Ch/Ce/Cn [ANSI/HI 9.6.7-2010]	: 1.00 / 1.00 / 1.00 / 1.00
Selection status	: Near miss

Liquid	
Liquid type	: Cold Water
Additional liquid description	:
Solids diameter, max	: 0.00 in
Solids concentration, by volume	: 0.00 %
Temperature, max	: 68.00 deg F
Fluid density, rated / max	: 1.000 / 1.000 SG
Viscosity, rated	: 1.00 cP
Vapor pressure, rated	: 0.34 psi.a
Material	
Material selected	: Material Group, Standard
Pressure Data	
Maximum working pressure	: See the Additional Data page
Maximum allowable working pressure	: See the Additional Data page
Maximum allowable suction pressure	: N/A
Hydrostatic test pressure	: See the Additional Data page
Driver & Power Data (@Max density)	
Motor sizing specification	: Max power (non-overloading)
Margin over specification	: 0.00 %
Service factor	: 1.00
Power, hydraulic	: 227 hp
Power (bowl / pump)	: 269 / 269 hp
Max power (non-overloading)	: 270 hp
Nameplate motor rating	: 300 hp / 224 kW

Bowl performance. Adjusted for construction and viscosity.
The duty point represents the head at the bowl.
Performance based on test acceptance - Hyd Ins 14.6 Bilateral (2B)



Dakota Pump Inc.

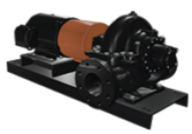
Pump specifications for 3-foot diameter boost pump station:

GRUNDFOS

SUBMITT

Grundfos Series KP - Horizontal Split Case Pump

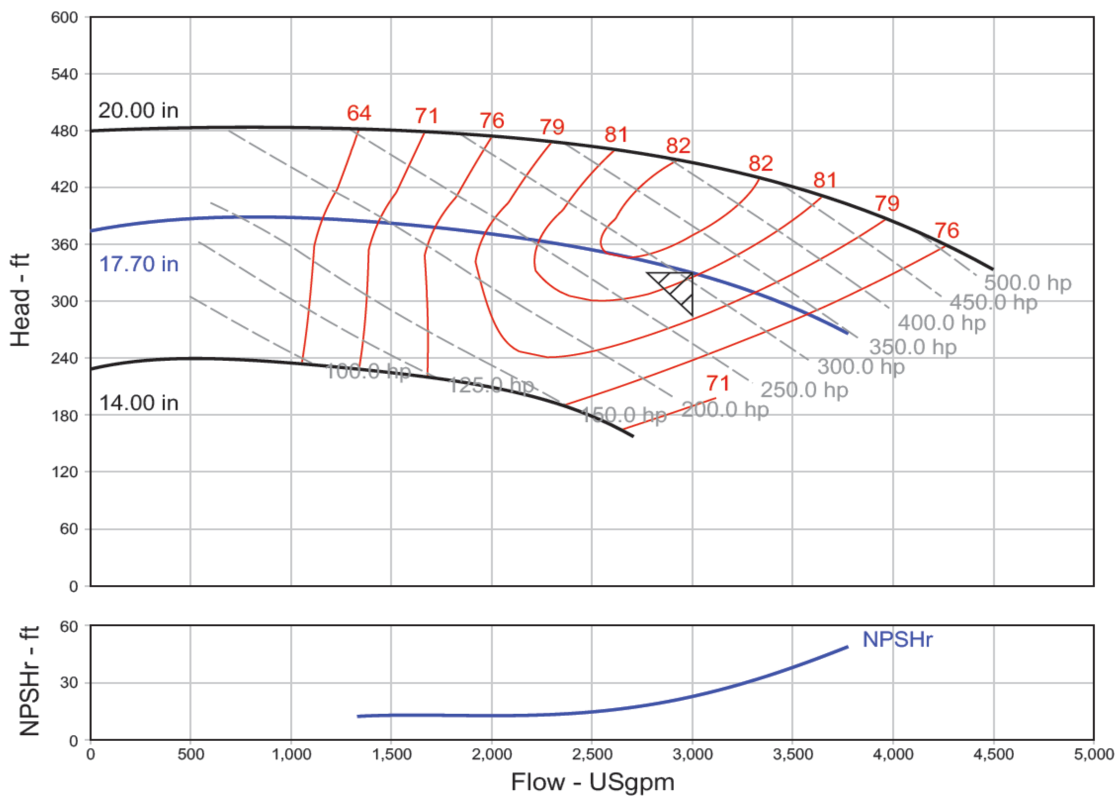
QUOTE NUMBER / ID 528438	UNIT TAG 004	QUANTITY 1
	SERVICE	
REPRESENTATIVE	SUBMITTED BY	DATE
ENGINEER	APPROVED BY	DATE
CONTRACTOR	ORDER #	DATE



KP 6020-3/4
1780 rpm

Part Number N/A

Conditions of Service		Pump Data		Motor Data	
Flow	3,000.0 USgpm	Impeller Diameter	17.70 in	Motor HP	350 HP
Head	330.0 ft	Max. Imp. Dia.	20.00 in	BHP	307.97
Liquid	Cold Water	Min. Imp. Dia.	14.00 in	Enclosure	ODP
Temperature	68.00 deg F	Efficiency	81.14 %	Voltage	230/460 V
NPSHr	22.77 ft	Suction	8 in.	Phase	3 Phase
Viscosity	1.00 cP	Discharge	6 in.	Cycle	60
Specific Gravity	1.000 SG			Frame Size	447T



Dakota Pump Inc.

Pump specifications for 6-foot diameter intake pump station:

GRUNDFOS PEERLESS PUMP Grundfos Quotation System 19.4.1

Pump Performance Datasheet

Customer	:
Customer ref. / PO	:
Tag Number	: 004
Service	:
Quantity	: 1

Quote Number / ID	: 528438
Peerless Model	: 26HH-OH
Stages	: 6
Based on curve number	: 26HHOH-2629638
Date last saved	: 10/18/19 4:48 PM

Operating Conditions	
Flow, rated	: 15,666.0 USgpm
Differential head / pressure, rated (requested)	: 450.0 ft
Differential head / pressure, rated (actual)	: 452.0 ft
Suction pressure, rated / max	: 0.00 / 0.00 psi.g
NPSH available, rated	: Ample
Frequency	: 60 Hz

Performance	
Speed, rated	: 1160 rpm
Impeller diameter, rated	: 19.88 / 15.19 in
Impeller diameter, maximum	: 19.95 / 15.34 in
Impeller diameter, minimum	: 18.50 / 11.56 in
Efficiency (bowl / pump)	: 89.81 / 89.08 %
NPSH required / margin required	: 26.42 / 0.00 ft
Ns (imp. eye flow) / Nss (imp. eye flow)	: 5,709 / 12,368 US Units
MCSF	: 8,000.0 USgpm
Head, maximum, rated diameter	: 873.4 ft
Head rise to shutoff (bowl / pump)	: 93.22 / 94.53 %
Flow, best eff. point (bowl / pump)	: 15,737.6 / 15,638.5 USgpm
Flow ratio, rated / BEP (bowl / pump)	: 99.55 / 100.18 %
Diameter ratio (rated / max)	: 99.16 %
Head ratio (rated dia / max dia)	: 97.74 %
Cq/Ch/Ce/Cn [ANSI/HI 9.6.7-2010]	: 1.00 / 1.00 / 1.00 / 1.00
Selection status	: Near miss

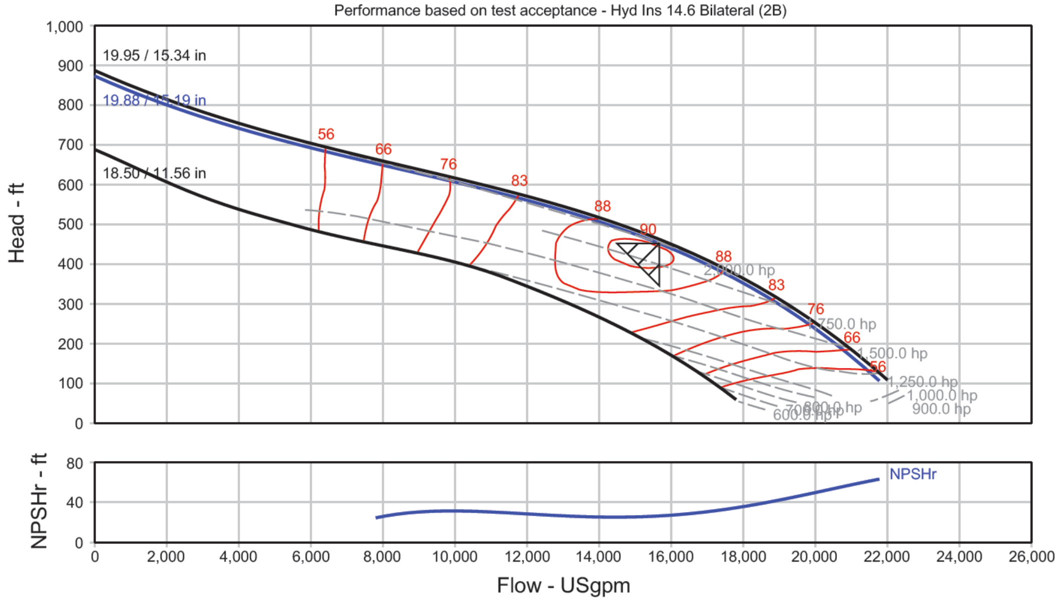
Liquid	
Liquid type	: Cold Water
Additional liquid description	:
Solids diameter, max	: 0.00 in
Solids concentration, by volume	: 0.00 %
Temperature, max	: 68.00 deg F
Fluid density, rated / max	: 1.000 / 1.000 SG
Viscosity, rated	: 1.00 cP
Vapor pressure, rated	: 0.34 psi.a

Material	
Material selected	: Material Group, Standard (DIE Bowl)

Pressure Data	
Maximum working pressure	: See the Additional Data page
Maximum allowable working pressure	: See the Additional Data page
Maximum allowable suction pressure	: N/A
Hydrostatic test pressure	: See the Additional Data page

Driver & Power Data (@Max density)	
Motor sizing specification	: Max power (non-overloading)
Margin over specification	: 0.00 %
Service factor	: 1.00
Power, hydraulic	: 1,788 hp
Power (bowl / pump)	: 1,991 / 1,993 hp
Max power (non-overloading)	: 2,201 hp
Nameplate motor rating	: 2,250 hp / 1,678 kW

Bowl performance. Adjusted for construction and viscosity.
The duty point represents the head at the bowl.
Performance based on test acceptance - Hyd Ins 14.6 Bilateral (2B)



Dakota Pump Inc.

Pump specifications for 6-foot diameter boost pump station:

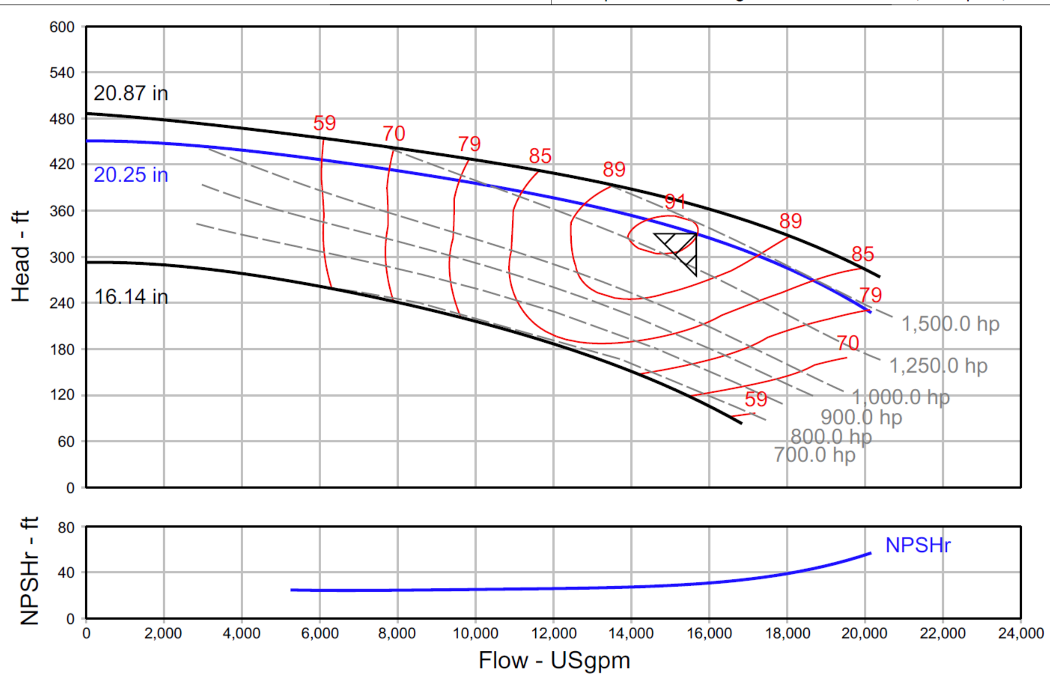
GRUNDFOS

Grundfos Quotation System 19.4.1

Pump Performance Datasheet

Customer	:	Quote Number / ID	: 528438
Customer ref. / PO	:	Model	: 1620-3/4 KP
Tag Number	: 004	Stages	: 1
Service	:	Based on curve number	: RC10242-SS Rev 0
Quantity	: 1	Date last saved	: 10/18/19 4:43 PM

Operating Conditions		Liquid	
Flow, rated	: 15,666.0 USgpm	Liquid type	: Cold Water
Differential head / pressure, rated (requested)	: 330.0 ft	Additional liquid description	:
Differential head / pressure, rated (actual)	: 330.1 ft	Solids diameter, max	: 0.00 in
Suction pressure, rated / max	: 0.00 / 0.00 psi.g	Solids concentration, by volume	: 0.00 %
NPSH available, rated	: Ample	Temperature, max	: 68.00 deg F
Frequency	: 60 Hz	Fluid density, rated / max	: 1.000 / 1.000 SG
Performance		Viscosity, rated	: 1.00 cP
Speed, rated	: 1785 rpm	Vapor pressure, rated	: 0.34 psi.a
Impeller diameter, rated	: 20.25 in	**Material**	
Impeller diameter, maximum	: 20.87 in	Material selected	: Cast Iron
Impeller diameter, minimum	: 16.14 in	**Pressure Data**	
Efficiency	: 91.02 %	Maximum working pressure	: 195.1 psi.g
NPSH required / margin required	: 30.05 / 0.00 ft	Maximum allowable working pressure	: 230.0 psi.g
Ns (imp. eye flow) / Nss (imp. eye flow)	: 1,900 / 12,727 US Units	Maximum allowable suction pressure	: 0.00 psi.g
MCSF	: 7,897.0 USgpm	Hydrostatic test pressure	: 348.0 psi.g
Head, maximum, rated diameter	: 450.8 ft	**Driver & Power Data (@Max density)**	
Head rise to shutoff	: 36.63 %	Motor sizing specification	: Max power (non-overloading)
Flow, best eff. point	: 15,060.0 USgpm	Margin over specification	: 0.00 %
Flow ratio, rated / BEP	: 104.02 %	Service factor	: 1.00
Diameter ratio (rated / max)	: 97.03 %	Power, hydraulic	: 1,305 hp
Head ratio (rated dia / max dia)	: 89.94 %	Rated power (based on duty point)	: 1,433 hp
Cq/Ch/Ce/Cn [ANSI/HI 9.6.7-2010]	: 1.00 / 1.00 / 1.00 / 1.00	Max power (non-overloading)	: 1,493 hp
Selection status	: Acceptable	Nameplate motor rating	: 1,500 hp / 1,119 kW



Dakota Pump Inc.