Southern Nevada Pipeline

by

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Abstract

In the last two years, the water level of the Colorado River has decreased significantly, and the states that utilize the river are preparing water rationing if the current drought continues. An alternate means of providing water to metropolitan areas served by the Colorado River is quite valuable. Desalinated water from the West Coast and pumped to Southern Nevada is a distinct possibility.

In order to conduct a cursory study for a water pipeline to serve Southern Nevada, the problem has to be bound and a scope of the study established. Therefore, three possible locations for the start of the pipeline were chosen from the Southern California Coast. Three main methods of seawater desalination were described. A pipeline model was analyzed for flow rates ranging from total replacement of the Las Vegas water use to fractions of the total use. The power required to pump the water from the coastal location to Las Vegas was then calculated. Power options were analyzed and ranked for the optimal power source.

The power required to pump total replacement of Las Vegas's water usage is shown as feasible with the assumed model of

the pipeline. The simplified model generated in this study the total water use could be pumped to substitute all water use for Las Vegas instead of the continued use from Lake Mead. After all the data and calculations were presented, a final design was recommended, based on the bounding of the system requirements.

Chapter 1- Introduction

In the last five years the Western United States has experienced declines in the overall water level of the Colorado River. This river supplies water resources to many high population areas of the Western and Southwestern United States. Cities, such as Las Vegas, depend on the river to provide water to their citizens. Since this is the only source of water, it is a single point of failure to the city, should the river level continue decrease or become polluted from agricultural, industrial, or government activities. The intent of this proposal is to analyze a pipeline system to supplement water resources for Southern Nevada. The design of this system will involve the requirements for desalination from the West Coast of Southern California and transport by pipeline to Southern Nevada. Such a system will have the capacity to supplement or replace the use of the Colorado River.

The literature review will require study of the technical aspects of three independent systems: desalination systems, nuclear systems for industry, and pipelines for transport. The focus of this study will combine the use of these independent systems to construct an overall water delivery system for the Southwestern United States. Desalination plants are used to convert ocean water into potable water. Potable water, considered safe for drinking, is created by separating the water from salts and other solids found in ocean water. Historically, the desalination method has been distillation by use of: 1) a heat source or 2) reduced pressure to boil water as a means of separation from its original form. These methods are referred to as Multi Stage Flash (MSF). There is a hybrid that uses a combination of these methods, know as Multiple Effect Distillation (MED). A contemporary desalination plant that uses a distillation method for creating potable water is the Ras Uhl power plant in Saudi Arabia. The other main method, which has received more attention in the last two decades, is membrane separation through Reverse Osmosis (RO). This method involves forcing ocean water through semi-permeable membranes, separating water from the dissolved solids and creating potable water in the process. This method has become popular in recent years due to process advances that allow reduced energy consumption compared to distillation. A contemporary plant of this design includes the Santa Barbara desalination plant near Ventura, California. Nuclear power systems have been used primarily as a means to generate electrical power, with some prototype applications for generating process heat for industry or desalination by distillation. A few Russian prototypes have used modified Russian naval nuclear plants mounted on floating barges to act as portable electric sources for desalination plants that can be relocated as needed to provide potable water for remote locations. Pipelines used to transport liquids have been in use for over a century, not including aqueducts which have been used for millennia for transporting water to large population areas. This study will focus on enclosed pipeline systems and the associated technical specifications of these systems. Literature used in review and research will include the Western Australian water scheme, The Great Manmade River in Northern Africa, and the Los Angeles aqueduct.

The methods used to research this system will be limited to fluid flow in pipes and current information for nuclear coupled desalination systems. Pipe flow will model laminar and turbulent flows, and determine the pumping requirements for the system. Multiple size pipes will be analyzed to determine optimal specifications. A combination nuclear desalination system will be determined by the amount of water that can be transported to Southern Nevada per unit of time.

The significance of this study will analyze potential options for desalination systems, and an overall system to supplement Southern Nevada with an alternate water source. Proposed designs for nuclear desalination have been analyzed for distillation methods, and a comparison or using nuclear power systems for membrane separation methods has not been examined. Such a system would be able to reduce greenhouse gas emissions from current distillation based desalination plants, as well as desalination plants that obtain electrical power from fossil fueled electric plants. The pipeline system to transport water from the California coast 300 miles inland over mountain passes and through desert conditions has only being designed once in history. The design required for this study will determine optimal configurations for a designated water flow rate.

Chapter 2- Pipeline Route and Topology

In order to minimize pumping power required to supplement the Southern Nevada Pipeline, the topology of the planned route will need to be chosen based on criteria consisting of the following: 1) minimize the overall length, 2) minimize the number of rises in elevation, 3) minimize the travel over national parks and populated areas. The areas that should be considered for the point of origin for the pipeline vary along the West Coast of the United States. However, to keep the shortest distance between the Pacific Ocean and Southern Nevada, the pipeline’s point of origin should be located close to Los Angeles, California. Three locations that would be ideal include Ventura, Long Beach, or Newport Beach, CA. The distances from these points to Las Vegas are 333 mi, 316 mi, and 307 mi respectively. Further selection should take into account the two Mountain Ranges that surround these locations in Southern California. The route starting in Ventura, CA, traverses the San Gabriel Mountain Range, and involves traveling through Soledad Pass at an elevation of 3,209 ft. The Long Beach route traverses the San Bernardino Mountain Range and travels through the Cajon Pass at an elevation of 4,190 ft. The third route, starting at Newport

Beach, CA, passes through the Santa Ana Canyon, elevation 679 ft., then continues along a route similar to the route from Long Beach, including travel through Cajon Pass. Once reaching Victorville, CA, elevation 2,726 ft, all three routes will continue along the same path to Las Vegas. Figures 2-1 through 2-3 map the three routes from their respective origins to Victorville, CA.

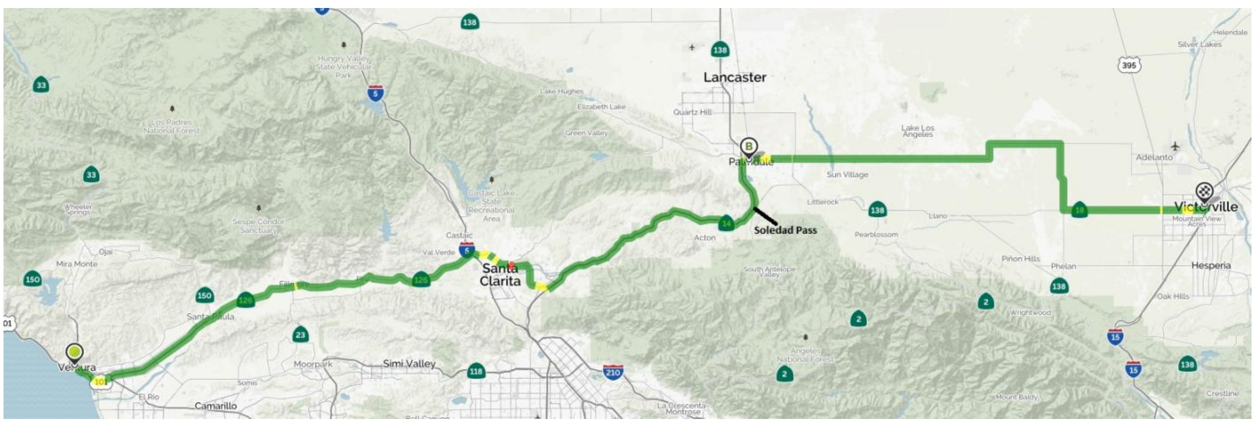

Figure 2-1 (Ventura, CA to Victorville, CA)

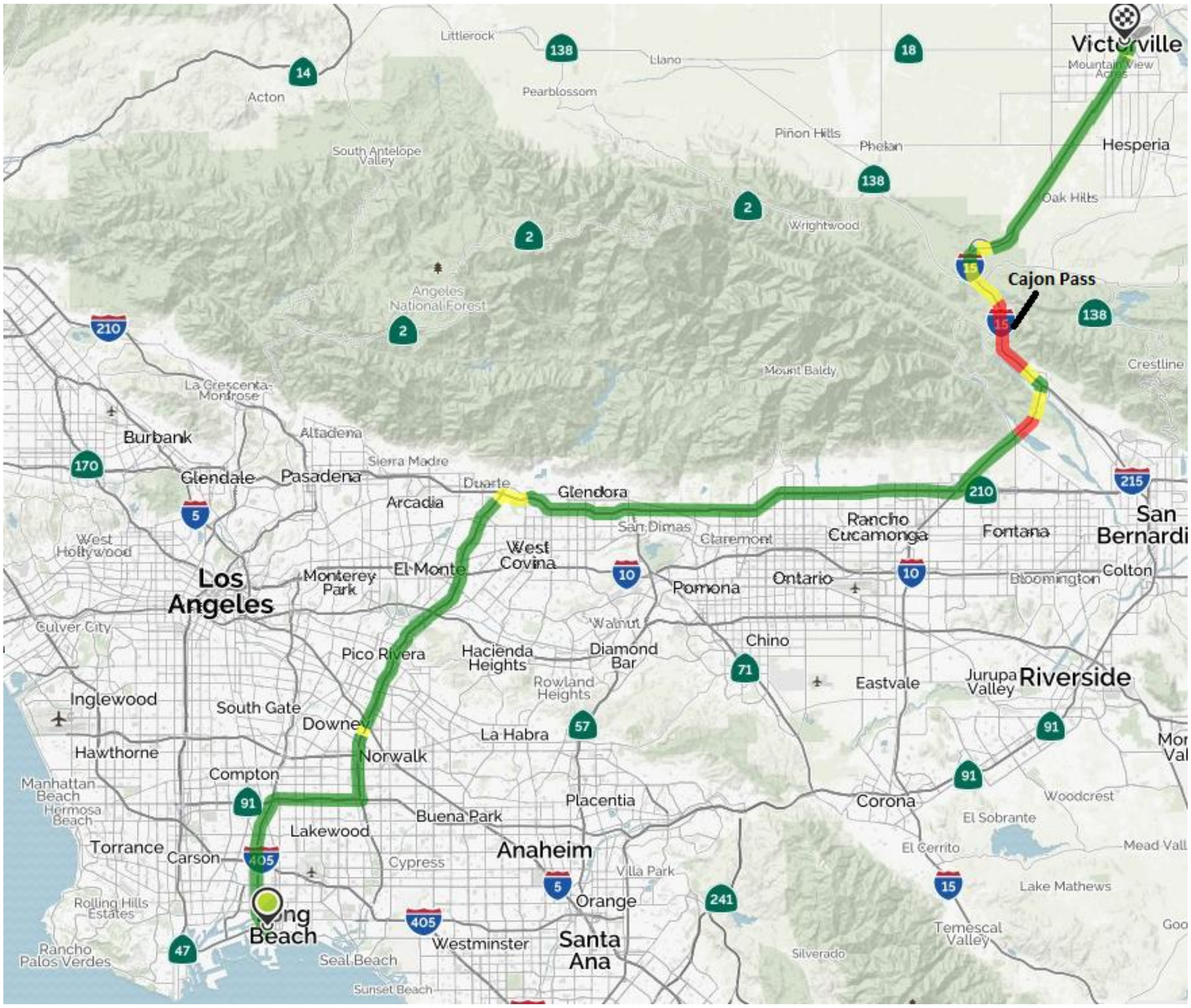

Figure 2-2 (Long Beach, CA to Victorville, CA)

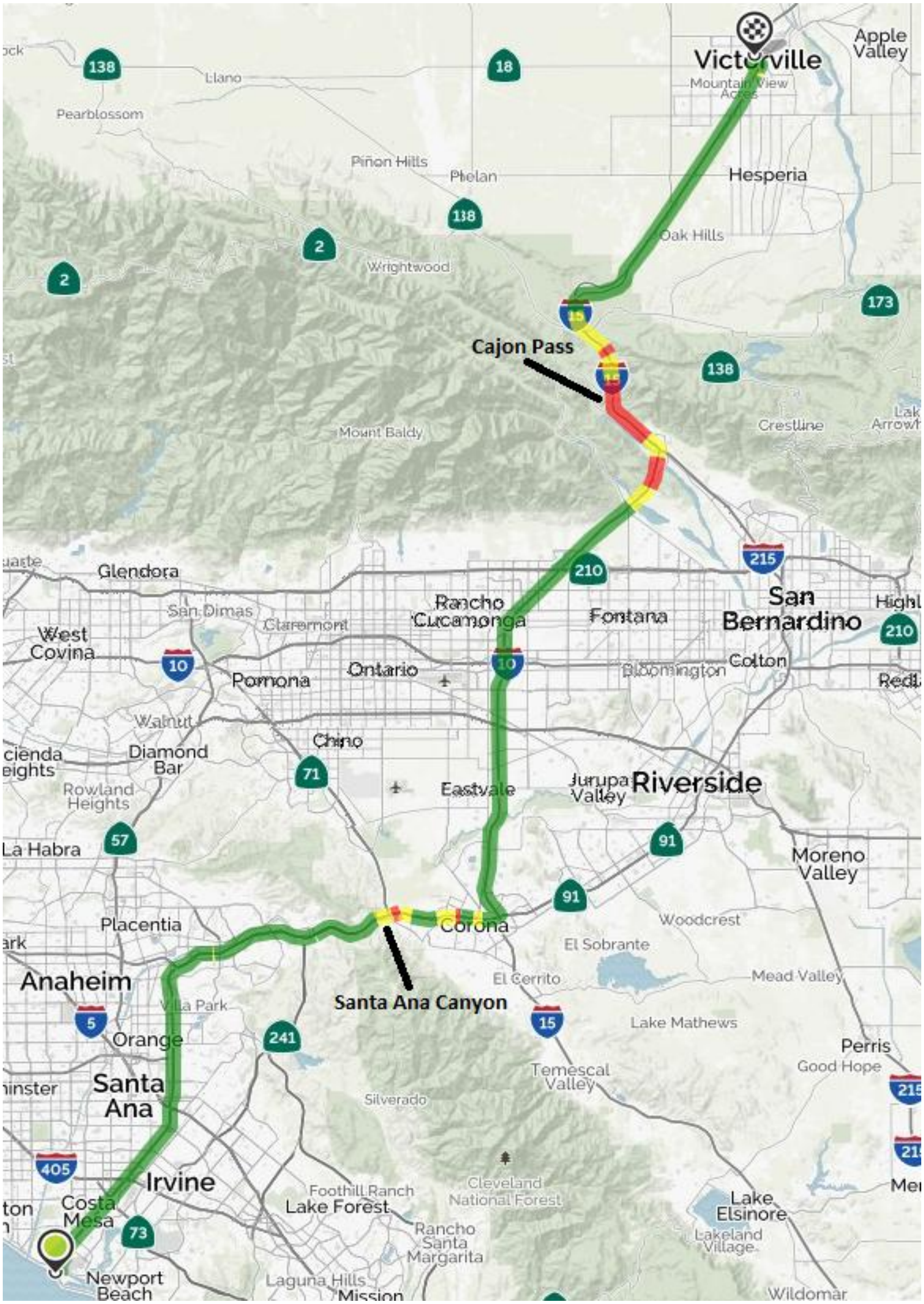

Figure 2-3 (Newport Beach, CA to Victorville, CA)

Upon reaching Victorville, CA, the pipeline would continue northeast, passing through the Southeastern California towns of Barstow (elevation 2,175 ft) and Baker (elevation 942 ft). This route is continued as shown in Figure 2-4.

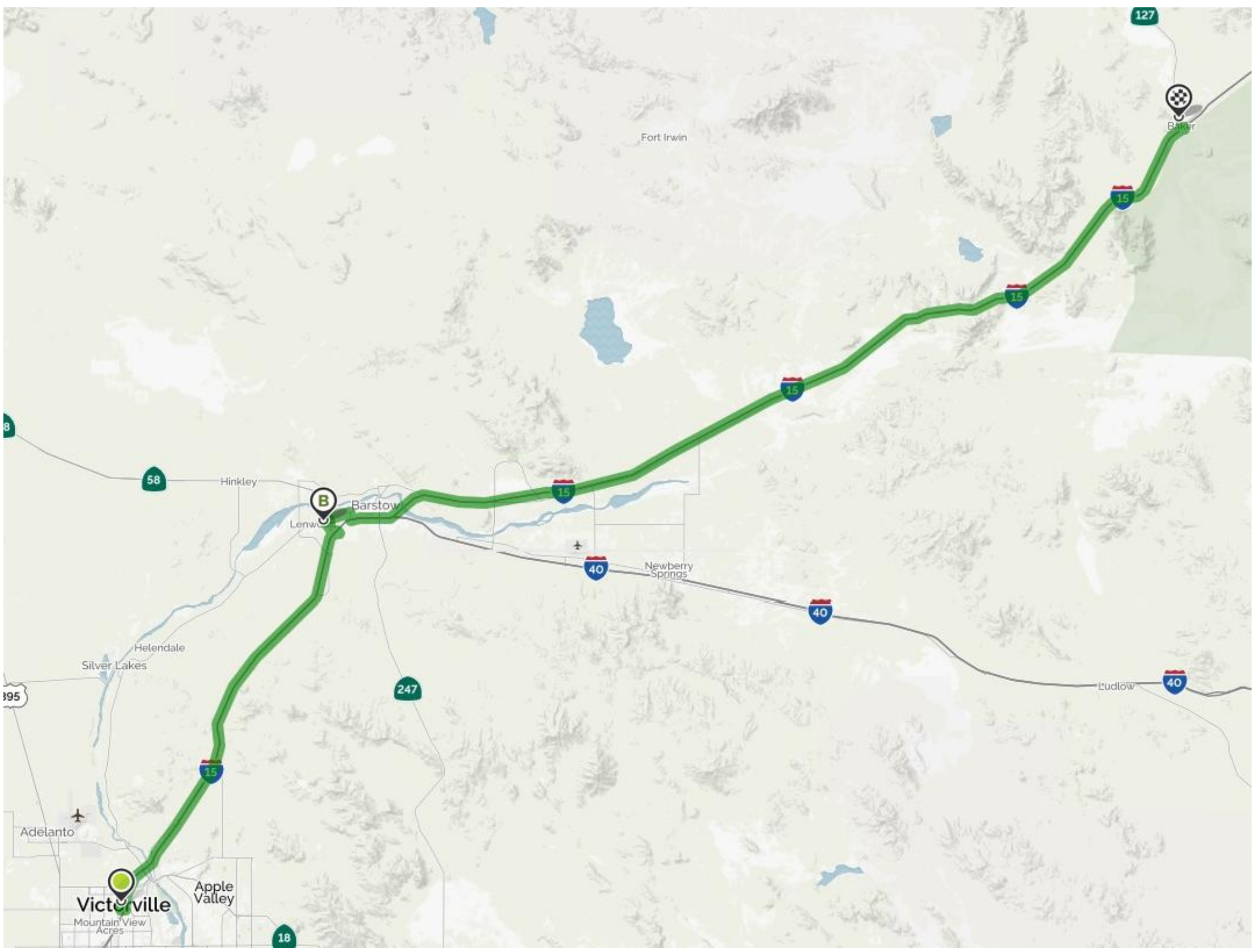

Figure 2-4 (Victorville, CA to Baker, CA)

After passing through Baker, CA, the pipeline would continue on through Mountain Pass, CA at an elevation of

4,728 ft. The route will cross the California/Nevada border at an elevation of 2,618 ft. The final leg of the pipeline continues north into southern Las Vegas, Nevada, elevation 2,001 ft. This is shown in Figure 2-5. Additionally, Figures 2-6 through 2-8 display each route with regard to distance and elevation (relative to sea level).

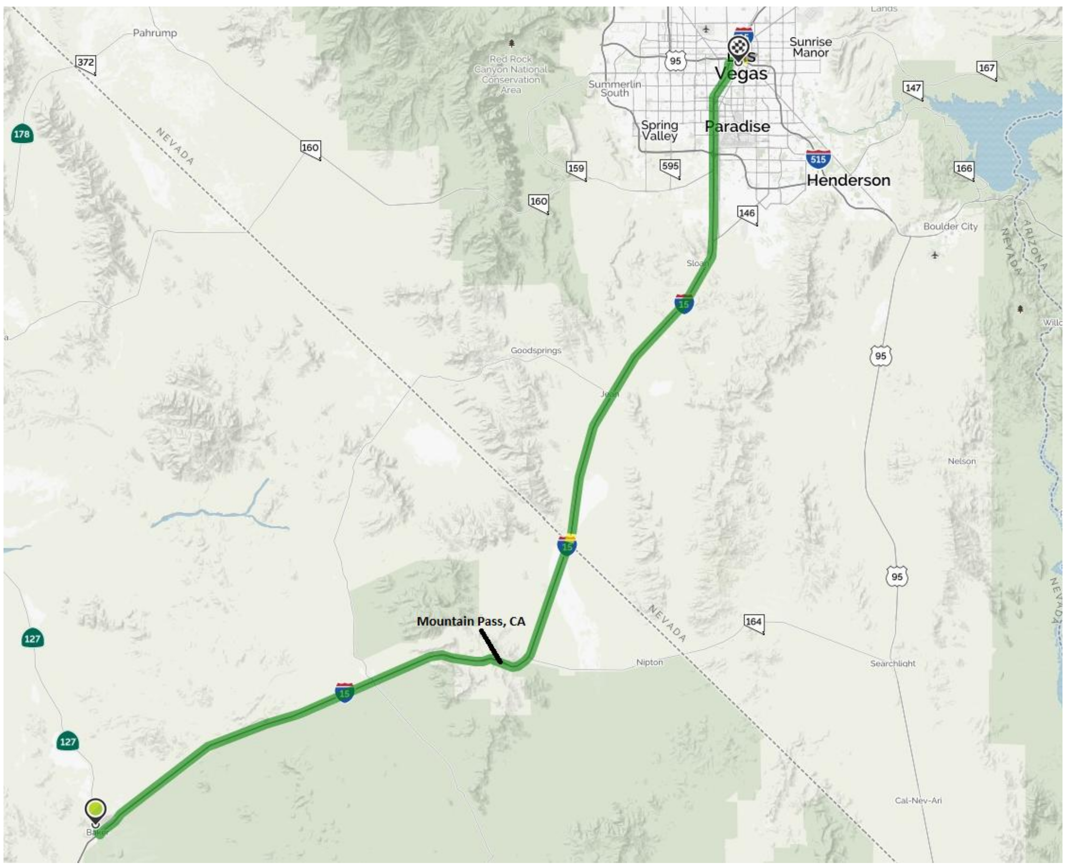

Figure 2-5 (Baker, CA to Las Vegas, NV)

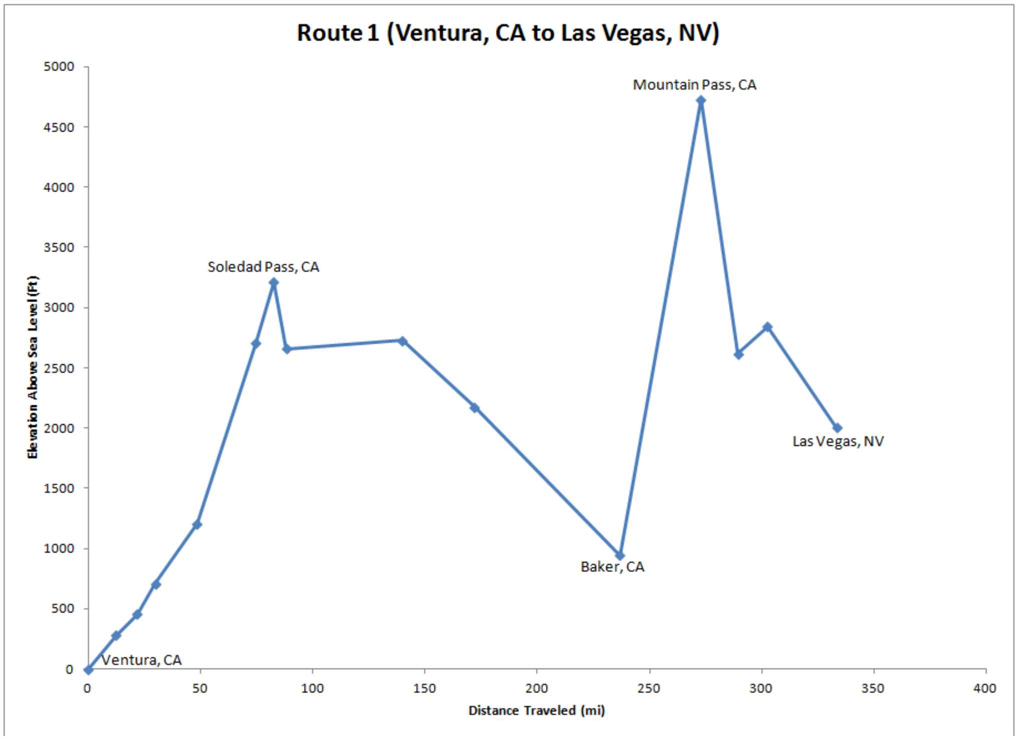

Figure 2-6

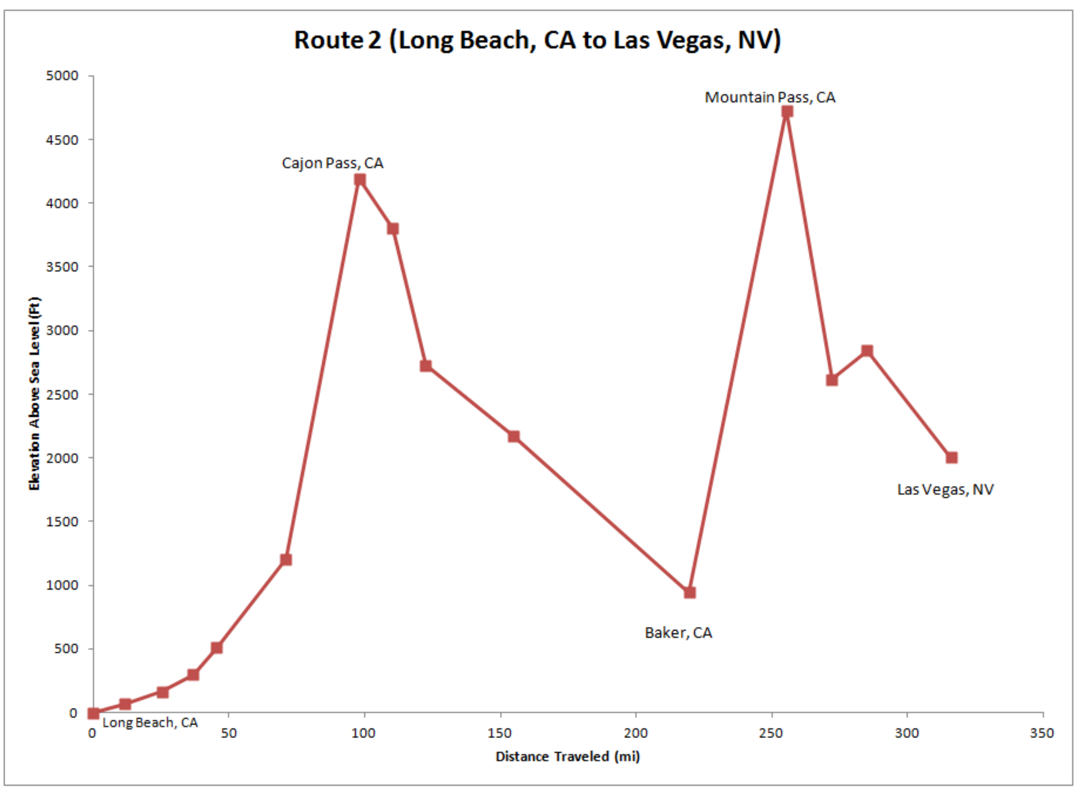

Figure 2-7

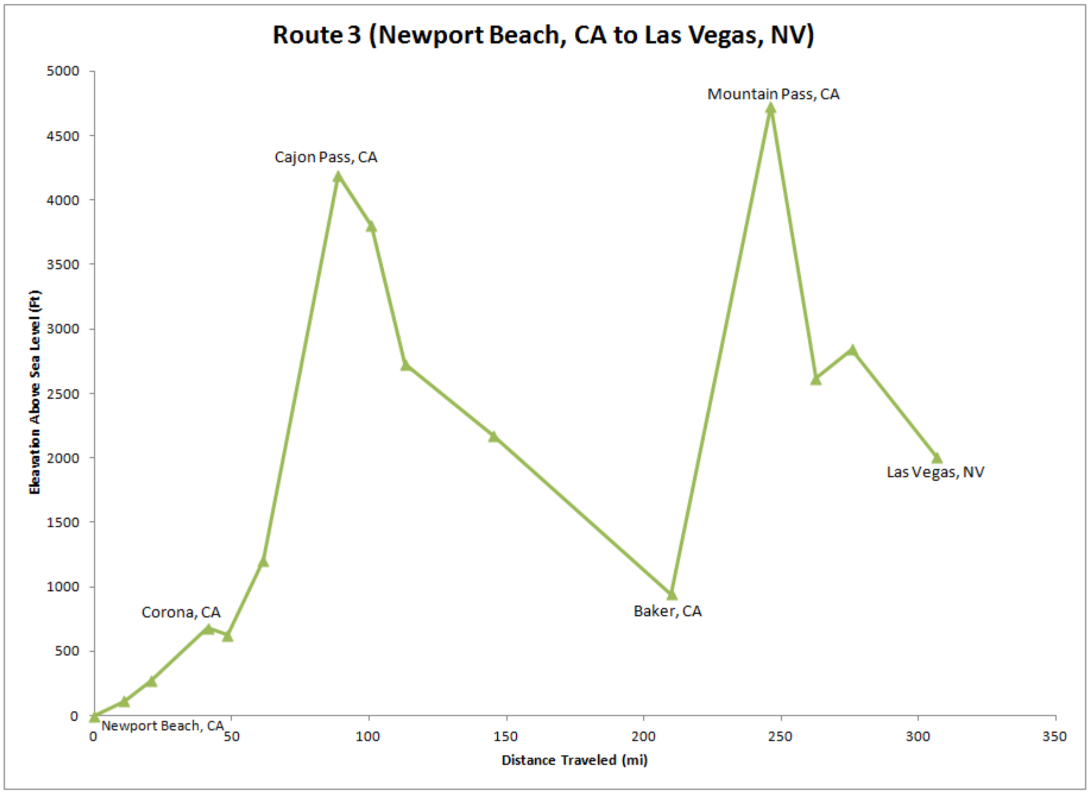

Figure 2-8

The quantitative values are summarized in Table T2-1 and colored for additional clarity.

Table T2-1

Route	Location	Distance (mi)	Change in Height (ft)
1	Ventura, CA	0	0
1	Santa Paula, CA	12.2	279
1	Fillmore, CA	9.5	177
1	Piru, CA	8.2	253
1	Santa Clarita, CA	18.4	498
1	Acton, CA	26.2	1503
1	Soledad Pass, CA	8	499
1	Palmdale, CA	5.6	-552
2	Long Beach, CA	0	0
2	Compton, CA	11.5	69
2	Pico Rivera, CA	13.7	95
2	El Monte, CA	11.5	135
2	Duarte, CA	8.7	213
3	Newport Beach, CA	0	0
3	Santa Ana, CA	10.7	115
3	Placentia, CA	9.9	157
3	Corona, CA	20.7	407
3	East Vale, CA	7	-52
2,3	Rancho Cucamonga, CA	25.4, 13.1	695, 580
2,3	Cajon Pass, CA	27.2	2983
2,3	Oak Hills, CA	12.2	-391
1,2,3	Victorville, CA	51.7, 12.2, 12.2	69, -1073, -1073
1,2,3	Barstow, CA	32.1	-551
1,2,3	Baker, CA	64.9	-1233
1,2,3	Mountain Pass, CA	36.1	3786
1,2,3	Primm, NV	16.5	-2110
1,2,3	Jean, NV	13.1	223
1,2,3	Las Vegas, NV	30.9	-840

Chapter 3- Desalination Plant Concept

Desalination is a process by which seawater is converted into potable water suitable for human consumption. While multiple methods are available to desalinate seawater, this study will focus on three specific methods, Multiple Stage Flash, Multiple Effect Distillation, and Reverse Osmosis. In order to supply enough water to allow supplementing or replacing use of the Colorado River for Southern Nevada, the desalination plant should be able to desalinate (for 100% replacement of river water) approximately 13.5 billion gallons of water per month.

The Multiple Stage Flash (MSF) method, described by Reference (1), Section 2.2, involves pumping heated seawater into chambers of different pressures (stages), which causes a portion of the seawater to flash to steam, illustrated in Figure 3-1. Seawater is pumped into the MSF unit enters at ambient temperature and intake pipe pressure (T_0, P_0). It does not interact with the pressure(s) of each stage, but does increase in temperature due to heat transfer between the seawater and steam generated in each stage. The seawater then travels through a heat exchanger to reach its final temperature (T_1). After leaving the heat exchanger, it enters the first stage at a designated pressure (P_1) where a portion of the heated seawater flashes to steam. The steam condenses to water due to interaction with the seawater intake pipe. The distilled water is transferred out of the chamber, and the remaining brine sent to the next stage, where the process is repeated at a lower pressure and temperature (T_{n+1}, P_{n+1}) until the final chamber at pressure and temperature (T_f, P_f) discharges the brine mixture. MSF is the simplest method for desalinating seawater, however, mineral buildup within each stage overtime does lead to lower efficiency of the flash chamber. Mitigation of mineral buildup can be accomplished by two processes: 1) Chamber temperatures below 212°F, or 2) an increased number of maintenance cycles to descale the chambers, resulting in periodic outages or reduced production.

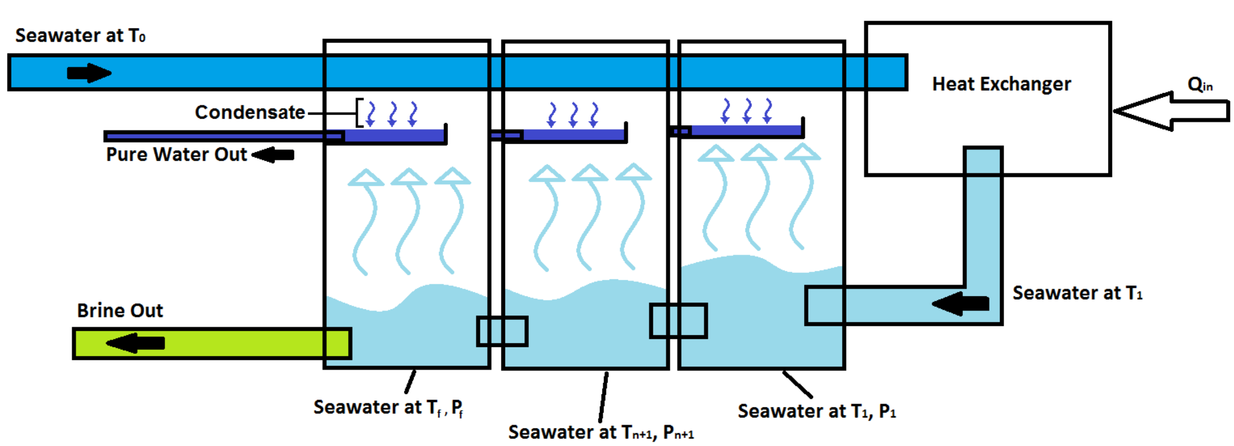

Figure 3-1

The description of Multiple Effect Distillation (MED), per Reference (1), Section 2.2, is a desalination process similar to MSF, but is differentiated by the use of reduced vapor pressure to boil seawater at temperatures below 212°F. As shown in Figure 3-2, the seawater is sprayed into each chamber at a pressure P_n equal to the pressure of the chamber of "n", and is then boiled via a heat exchanger using hot water or steam. The brine that does not boil off is collected and either recycled back into the seawater inlet source or discharged from the system. The distilled water vapor is used as the heat source for the next chamber which is kept at a pressure $P_2 < P_1$. The distilled water vapor from the previous chamber condenses into liquid, and the process repeats with the water vapor that is at pressure P_2, which flows into the next chamber. The MED is slightly less complex than MSF, however, the maintenance cycles (descaling of mineral buildup) are similar to that of MSF.

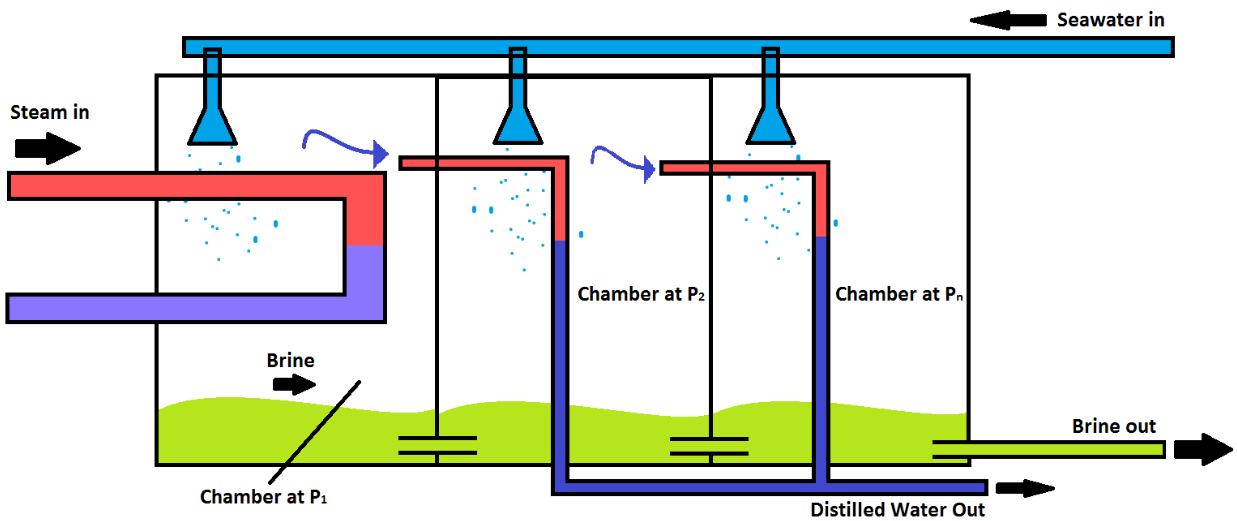

Figure 3-2

Described in Reference (1), Section 2.1, Reverse Osmosis (RO) is a desalination process that uses a filtration system to create potable water from seawater. The process of Osmosis, as described by Webster's dictionary, is "the movement of a solvent (as water) through a semipermeable membrane…into a solution of higher solute concentration that tends to equalize the concentrations of solute [salt] on the two sides of the membrane". Such a process would have equal concentrations of salt in the solvents on each side of the membrane. However, the amount of water, on each side would be different. Reverse Osmosis, shown in Figure 3-3, is the reverse process of osmosis described above, in which water is separated from salt under high pressure. The water that flows across the membrane has reduced salt content, and may go through additional RO membranes to achieve the desired salt concentration. For desalination, Reverse Osmosis takes place when the seawater enters a series of filters (semi-permeable membranes) after being raised to a high pressure, boosted approximately 800 to 1000 psi, which requires a significant amount of energy for the initial pressurization of the feedwater. After passing through the membranes required to obtain the desired salt concentration, the water is then re-mineralized (for taste), and transported to the local water grid. RO does require pre-treatment of the incoming seawater in order to allow the filters to achieve optimal efficiency. As documented in Reference (2), Chapter 2.1, Section *Operation and Maintenance*, maintenance periods to change out filters happen every two to three years, and require outages that depend on how clogged the membranes are. The outages would affect the amount of water produced by the plant.

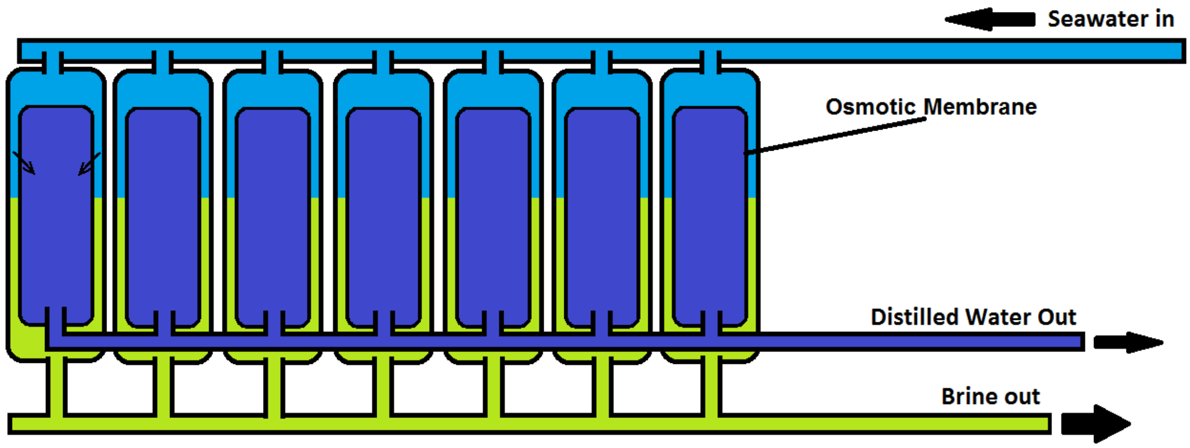

Figure 3-3

Based on information obtained from Reference (2) the highest amount of water usage for the years of 2010 through 2014 has occurred during the late summer early fall. To bound the scope of this analysis, it is beneficial to establish a range of flow rates that can be used to supplement the current water source of Las Vegas, NV. The largest, and smallest amount of water used in single month will be used to determine the maximum, and minimum, flow rate. In August of 2010, the total amount of water billed was 13,543,000,000 gallons of water. In February of 2010, the total amount of water billed was 4,625,000,000 gallons of water. Assuming this same amount of usage for 12 months straight we find the maximum and minimum flow rates to be, respectively:

$$\frac{1.3543x10^{10}gal}{1\,month} = \frac{1.62516x10^{11}\,gal}{1\,year} = \frac{3.125x10^{9}\,gal}{week} = \frac{1.8603x10^{6}\,gal}{hour} =$$

$$310,050\,\frac{gal}{min}$$

and

$$105{,}884\,\frac{gal}{min}$$

Therefore, the Southern Nevada Pipeline would need to desalinate water at approximately these rates. In order to determine a suitable desalination system for the Southern Nevada Pipeline, data on desalination plants currently operating with the three distinct methods previously discussed will be summarized below. The plants described include: 1) Ras Al Khair Power and Desalination Plant (MSF and RO), 2) the Yanbu Power and Desalination Plant (MED), and 3) The Victorian Desalination Plant (RO).

As discussed in Reference (5), the Ras Al Khair complex is a hybrid power and desalination plant located in Saudi Arabia, approximately 75 km northwest of the city of Jubail, and operated by Saline Water Conversion Corporation. The plant, as of 2014, includes a power output of 2,650MW comprising five 600MW combined cycle gas turbine (CCGT) blocks and two 220MW single cycle gas turbines

(SCGT) units. The CCGTs were added during construction of phase two of the plant, with the SCGTs constituting the original power plant. The plant has a capacity to produce 228 million imperial gallons per day of potable water. The plant comprises 8 MSF units, generating 160 million gallons, and 17 RO units that produce the other 68 million gallons of water. From the MSF method, the water produced per desalination unit is 20 million gallons per unit, while each RO unit produces 4 million gallons per unit. Converting to the rate expressed above, an MSF desalination unit can produce 13,889 gallons per minute, per desalination unit. If we scale this desalination method, the Southern Nevada Pipeline would require a minimum of 23 MSF units.

Per the description in Reference (8), the Yanbu Power and Desalination Plant is located approximately 300 km north of the city of Jeddah in Saudi Arabia. Operated by the company MARFIQ, the addition of the MED desalination in phase 2, produces approximately an additional 15 million gallons of potable water for the single unit. The plant, prior to phase 2 could produce 146,160 m^3 per day, or about 38,611,385 million gallons per day. The addition increases the total output of the plant by 38 percent. The MED unit was constructed by Doosan Heavy Industries, per Reference (3), and is currently the world's largest MED distillation unit. The MED unit alone can produce water at a rate of approximately 10,416 gallons per minute. Scaling to the required rate of water for the Southern Nevada Pipeline, the pipeline would require a minimum of 30 MED desalination units.

Discussed in Reference (7), the Victorian Desalination Project is located approximately 3 miles west of the town of Wonthaggi in the Australian State of Victoria. The desalination plant finished construction in 2012, but has since been put into standby mode, due to increased amounts of rainfall in the years following the plant coming online. Reference (4) stated that during operation, the plant could produce up to 150 billion liters of water per year, and was potentially expandable to 200 billion liters per year. The plant operated strictly using the RO desalination method. The complex required a land area of approximately 49 acres, and used 90 MW of electricity to desalinate seawater, per description in Reference (5). This plant, producing 150 billion liters of water per year was producing approximately 75,599 gallons per minute. To meet the required rate of water for the Southern Nevada Pipeline, this plant would need to be scaled by a factor of 4.1, inferring that the electricity to desalinate the necessary rate of water would be nearly 360 MW.

Chapter 4- Pipeline Design Concept

The sources and destination discussed previously have formed the baseline criteria for the design of the water pipeline. The internal pipe pressure, internal shear stress created by the flowing water, and external environmental factors are the base design requisites for the pipeline. Additionally, safety, ease of repair and maintenance, and government regulations should also factor into the design of the pipeline. However, these last three factors are beyond the scope of this report, and will be left as an open item for future design documents. The basis for the mechanical properties of the pipeline design will be determined from the flow rates previously identified in this report, ranging from 310,050 gpm to 105,884 gpm ($70.5x10^3$ m^3/hr to $24x10^3$ m^3/hr).

In order to determine the internal pipe conditions of pressure, the velocity of the water will be determined. Assuming a 1-D, fully developed, volumetric flow approximation from Reference (9), section 3.2, the velocity can be determined as follows:

$$\dot{m} = \rho Q = \rho A V \quad (4.1)$$

Where "Q" is the volumetric flow rate, "$\dot{m}$" is the mass flow rate, and "A" is the area which the flow passes through. Since a pipe size is not defined, Table T4-1 tabulates velocity data for selected pipe sizes at the maximum and minimum flow rates. The pipe shape is assumed to be a cylinder.

Table T4-1

Area (m^2)	Velocity at $3.10x10^5$ gpm (m/s)	Velocity at $1.03x10^5$ gpm (m/s)
0.25	77.244	26.081
0.5	39.122	13.041
0.75	26.081	8.694
1.0	19.561	6.520
2.5	7.824	2.608
5	3.912	1.304
7.5	2.608	0.869
10	1.956	0.652
25	0.782	0.261
50	0.391	0.130

Table T4-1 shows that the maximum and minimum respective flow rate velocities are 77.244 m/s and 26.081 m/s for a pipe area of 0.25 m^2, and 0.391 m/s and 0.130 m/s for a pipe area of 50 m^2. With typical industrial sizes of pipe diameter between 1 m to 2.5 m, this concludes that a circular pipeline is feasible to engineer.

Next, the pressure drop needs to be determined, in order to estimate the required pumping power for each route discussed previously. From Reference (9), Section 3.6, the steady state flow energy equation for an incompressible fluid is:

$$\left(\frac{p}{\gamma}+\frac{V^2}{2g}+z\right)_{in}=\left(\frac{p}{\gamma}+\frac{V^2}{2g}+z\right)_{out}+h_{friction}-h_{pump}+h_{turbine} \quad (4.2)$$

where:

- p/γ is referred to as the pressure head of the control volume
- γ is the specific weight (ρg)
- $V^2/2g$ is referred to as the velocity head of the control volume
- g is the acceleration due to gravity
- z height of the inlet or outlet

- $h_{friction}$ is the friction head
- h_{pump} is the pump head
- $h_{turbine}$ is the turbine head extraction

Furthermore, to analyze each route, a control volume analysis will be used between the locations identified in previously, Table T2-1. It is assumed that turbine(s) will extract energy, and no pump will supply additional energy to the control volume. In this instance, we can simplify equation (4.2) to obtain:

$$\left(\frac{p}{\gamma}+\frac{V^2}{2g}+z\right)_{in}=\left(\frac{p}{\gamma}+\frac{V^2}{2g}+z\right)_{out}+h_{friction} \quad (4.3)$$

As shown in Reference (9), Section 6.3, and assuming a configuration shown in Figure 4-1, the volume in Figure 4-1 is static. It can be assumed that $Q_1 = Q_2$, and therefore $V_1 = V_2$.

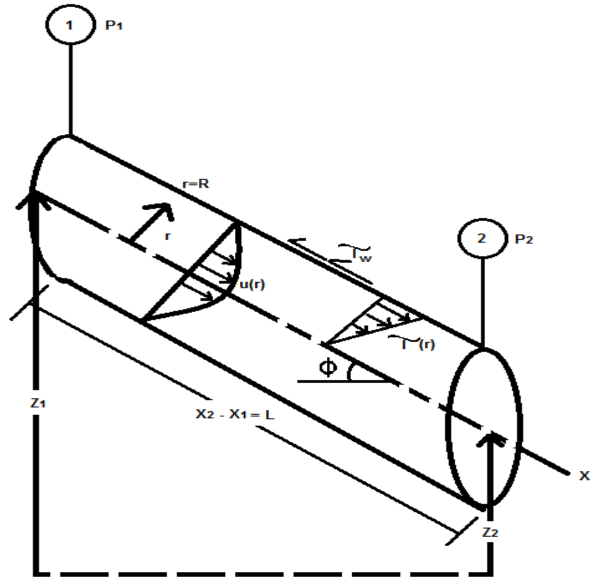

Figure 4-1

Using Figure 4-1, and re-arranging equation (4.3), the pressure drop can be determined as follows:

$$\left[h_{friction} + (z_1 - z_2)\right] \cdot \rho g = (P_1 - P_2) = \Delta P \quad (4.4a)$$

$$\left[h_{friction} + (\Delta Z)\right] \cdot \rho g = (P_1 - P_2) = \Delta P \quad (4.4b)$$

Equation (4.4) agrees with Reference (9), Section 6.3, Equation 6.8, and will allow us to calculate the pressure drop through each route’s pipe control volume. If the values of z_1, z_2, density (ρ), and g are known, the last variable to be determined is the head loss ($h_{friction}$). Reference (9), Section 6.3, correlates head loss in pipe flow to the friction factor shown below:

$$h_{friction} = f\frac{LV^2}{2dg} = f\left[\frac{L}{d}\right]\frac{V^2}{2g} \qquad (4.5)$$

where:

- L is the control volume length
- V is the velocity
- d is the pipe diameter
- g is the acceleration due to gravity
- f is the friction factor

The friction factors are segregated by two conditions based on the value of the Reynold's Number. The values, per Reference (9), Section 6, are as follows:

$$f_{laminar} = \frac{64}{Re_d} \qquad (4.6)$$

$$f_{turbulent} = \left\{-1.8log\left[\frac{6.9}{Re_d} + \left(\frac{\frac{\epsilon}{d}}{3.7}\right)^{1.11}\right]\right\}^{-0.5} \qquad (4.7)$$

Where **ε** is given the value of 0.000046, per Reference (9), Section 6. Reference (9), Section 6.1, defines the value of the Reynold's Number as:

$$Re = \frac{\rho V d}{\mu} = \frac{Vd}{\nu} \qquad (4.8)$$

For internal fluid flow, a Reynold's Number value above 2,300, flow is defined as turbulent. Below this number, the flow is defined as laminar.

Therefore, the process for determining the pressure drop is as follows: 1) Find the Reynold's Number per Equation (4.8), 2) Calculate the friction factor using either Equation (4.6) or (4.7), 3) Determine the head loss with Equation (4.5), then 4) Calculate the pressure drop using Equation (4.4a) or (4.4b), using the change in height and using the properties of density (ρ) and g. Finally, the power required to pump the water will be calculated using the equation per Reference (9), section 11.2 below:

$$P_w = \rho g Q h \rightarrow P_w = Q\Delta P \quad (4.10)$$

"P_w", in Equation (4.10), is the pumping power in watts. The properties of water were obtained from Reference (10). Multiple variables regarding the flow of water were adjusted to obtain reasonable results, including: the surface roughness of the pipe, flow rate, pipe size, and viscosity. The calculated pumping power for the two stated flow rates over each route are shown below in Table T4-2. Additionally:

- The pipe area is 4.961 m^2 (radius of ~1.255 m) for $3.10x10^5$ gpm and $1.06x10^5$ gpm
- The pipe is 304 stainless steel (yield strength of 31,200 psi), cylindrical, and assumed to have a roughness of 0.046 mm ($4.6x10^{-5}$ m)
- The water is kept at a temperature of 20°C, therefore ρ = 1000 kg/m^3

<u>Table T4-2</u>

Route	Power at 310,050 gpm (MW)	Power at 105,884 gpm (MW)
Ventura, CA to Las Vegas, NV	425.06	53.38
Long Beach, CA to Las Vegas, NV	408.98	52.68
Newport Beach, CA to Las Vegas, NV	400.3	52.60

Analyzing the data in Table T4-2, it is feasible to construct a pipeline system that could carry desalinated water from any of the three chosen costal locations to Las Vegas. Calculated amounts of total pumping power (at the maximum flowrate) required for each of the 3 routes, as discussed in chapter 2, are shown in Tables T4-3 through T4-5. The task becomes quite less of a task to pump desalinated water at the minimum rate of 105,884 gpm, based on the data in Table T4-2. A sample calculation is shown below:

$$d = 2.51\,m, \qquad \therefore\ A \approx 4.961\,m^2$$

$$Q = 310{,}050\,gpm \approx 19.56\ {}^{m^3}\!/_{s}, \qquad \therefore\ \vec{v} \approx 3.942\,{}^{m}\!/_{s}$$

$$Re = \frac{\left(1000\,{}^{kg}\!/_{m^3}\right)(3.942\,{}^{m}\!/_{s})(2.51\,m)}{1x10^{-3}s/kg} \approx 9.91x10^6$$

$$f_{turbulent} = \left\{-1.8log\left[\frac{6.9}{9.91x10^6} + \left(\frac{\frac{4.6x10^{-5}}{2.51}}{3.7}\right)^{1.11}\right]\right\}^{-0.5} \approx 0.009$$

$$h_{friction,Route\ 1} = 0.009\frac{(536555.3m)\,(3.942\,{}^{m}\!/_{s})^2}{2(2.51m)\left(9.81\,{}^{m}\!/_{s^2}\right)} \approx 1610\,m$$

$$\left[h_{friction,Route\ 1} + \Delta Z\right]\cdot \rho g =$$

$$= [1610\,m + 610\,m]\cdot\left(1000\,{}^{kg}\!/_{m^3}\right)\left(9.81\,{}^{m}\!/_{s^2}\right)$$

$$= \Delta P \approx 21.73\,MPa$$

$$Power_{Route\ 1} = \Delta P \cdot Q = (21.73\ \ MPa)\left(19.56\ {m^3}/{s}\right) \approx 425.06MW$$

Table T4-3

Route	Location	Distance (m)	+ΔZ (m)	ΔP (MPa)	Total Power (MW)
1	Ventura, CA to Las Vegas, NV	536555.3	610	21.732	425.06

<u>Table T4-4</u>

Route	Location	Distance (m)	+ΔZ (m)	ΔP (MPa)	Total Power (MW)
2	Long Beach, CA to Las Vegas, NV	508552.7	610	20.910	408.98

Table T4-5

Route	Location	Distance (m)	+ΔZ (m)	ΔP (MPa)	Total Power (MW)
3	Newport Beach, CA to Las Vegas, NV	493424.9	610	20.466	400.3

The total power requirement, using the maximum flowrate, will require quite a significant amount of electricity; however, the project is still quite feasible. This is especially true if the pipeline is coupled to an appropriate power source. The proposed power source will be discussed in a later section of this report. For perspective, Reference (11) states that the Edmonston

Pumping Station, a component of the California Aqueduct, uses approximately 60 MW of electricity to pump water approximately 8.5 miles over the Tehachapi Mountain Range in Southern California. Compared to the SNP, the Edmonston Pumping Station route is smaller by a factor of 40. However it is important to note that the volume of water pumped by Edmonston Pumping Station is greater by a factor of 6. This pumping station is the largest single station to lift water to supply the Los Angeles Basin with 1.98×10^6 gpm (450,000 m^3 /hr) of fresh water. Also of note, per Reference (12), the entire California State Water Project, uses a net average of 5.6 billion kWh per year, including recuperating some energy from hydroelectric dams used along the California Aqueduct.

Chapter 5- Desalination Power Source

In order to supply water to Southern Nevada, the project will require three main items: 1) Appropriate desalination technology per information provided in chapter 3, 2) A pipeline system and pumps to transport the water per chapter 4, and 3) A power source for the entire project will be needed. While it is possible to use the current electrical grid resources to power both the desalination plant and pipeline pump system, as discussed in previous chapters 3 and 4, the amount of power required for the Southern Nevada Project may exceed current regional power sources. This in turn would decrease the pipeline flow rate. In order to determine the optimal power source, this chapter will discuss possible energy sources, and determine how each power source is suited to the SNP application. A summary is shown in Table 5-1.

The criteria for the power source exclusively for the SNP, should be based on, but not limited to cost, energy density, pollution, and reliability, to name a few objectives. The technologies that are available to supply power to the project include fossil fuel based power plants, renewable power plants, and nuclear power plants.

For the three previously discussed desalination processes (MSF, MED, and RO), the energy requirements, from Reference (17) for each are shown in the Table 5-1 below:

Table T5-1

Process	Specific Thermal Energy Required ($kW_{th}h/m^3$)	Specific Electrical Energy Required (kW_eh/m^3)
MSF	100	3
MED	50	2 - 3
RO	0	3 - 4.5

To make an informed choice of the best technology to use for a desalination system, a brief description of each type of power source will be described.

Fossil fuel power plants generate electrical power from coal, petroleum, or natural gas. Coal power plants, per Reference (13), Section 2.4.4, generate electricity at a power density of 24.5 MJ/kg. Typical coal power plants, such as West Burton 'B' located in England, are sized for 900 MW_e per generation unit, and have a space requirement of 67 ha, or about 670,000 m^2 (about 166 acres). As shown in

Reference (13), Section 2.3.3, coal power plants emit significant amounts of pollution, as shown below:

CO_2	CH_4	N_2O	SO_2	NOx	Particulates
880 g/kWh	2.9 g/kWh	0.06 g/kWh	1.1 g/kWh	2.2 g/kWh	0.16 g/kWh

In contrast, petroleum power plants, as discussed in Section 3.2.6 of Reference (14), generate electricity from fuel oils with a power density of 41 MJ/kg, and sized for 530 MW_e per generator unit. A typical heavy fuel oil power plant, such as the Lauffen plant , 35 km north of Stuttgart, Germany, requires a space of 19,000 m^2 (about 4.7 acres). As shown in Table 3.12 of Reference (14), pollution emitted by oil power plants is as follows:

CO_2	CH_4	N_2O	SO_2	NOx	Particulates
608 kg/kWh	22.7 g/kWh	15.2 g/kWh	798 g/kWh	798 g/kWh	N/A

Rounding out the last of the fossil fuel energy sources is natural gas. Natural gas, when used for electrical power generation, produces 47.2 MJ/kg for the heat of combustion, per Reference (16). A Gas Turbine Combined Cycle unit can have a thermal efficiency of approximately 60% in modern units, which incorporates a heat recovery system. When designed in a combined Gas Turbine and Steam Cycle generation unit, such as the Killingholme 'A' power plant in England, Reference (15), Section 2.2.8, the entire plant is designed to generate 652 MW_e and occupy an area of 13 ha, or about 130,000 m^2 (about 32.1 acres). Per Section 2.3 of Reference (15) and assuming a cycle efficiency of approximately 47%, the pollution emitted by the power plant would be as follows:

CO_2	CH_4	N_2O	SO_2	NOx	Particulates
393 g/kWh	N/A	0.013 g/kWh	Negligable	0.71 g/kWh	N/A

It should be noted that desalination with fossil fuel power plants is used for removing waste heat from the thermal power cycle of the power plant, and is quite prevalent in the Middle East,. As previously discussed, the fossil fuel plants that utilize the desalination methods of MSF and MED are used in conjunction with fossil fuel power plants.

Renewable power plants include generating from wind, hydroelectricity, solar, and geothermal. Using renewable energy sources to desalinate seawater can utilize either thermal energy or electrical power. Brief descriptions of these renewable energy sources are discussed as follows.

Using wind to generate power (mechanical or otherwise), has been used for centuries. As stated in Reference (18), Section 3, wind power plants are composed of multiple wind turbines, each rated at 300 kW. The largest wind farm in the U.K., located 3 km south of the village of Llandinam, consists of 103 wind turbines, occupying over 300 ha (741.3 acres), and has a maximum generating capacity of 30.9 MW_e. In order for the wind farm to generate any electrical power, the wind speed needs to be at least 5 m/s. This creates a drawback to utilizing wind power as a base load power source, since the power output is related to the current wind conditions at the wind farm.

Hydroelectric power uses water, typically from man-made reservoirs, to generate electrical power. As discussed in Reference (19), Section 2.2, the Sauda Hydroelectric Project utilizes the Storlev River located in the Sauda Fjord (southwestern Norway). The four original hydroelectric power stations of the project have an electrical power generation capacity of 674 MW_e. It operates from a reservoir with an area of 375.4 sq km (about 145 sq mi) containing about 28.1 million m^3 of water is required.

Solar power uses energy from sunlight to generate power directly (via photovoltaic cell) or indirectly (via thermal heating). Using photovoltaic (PV) cells, light particles (photons) interact with the solar cell, and cause electrons to flow, generating direct current electricity, per Reference (20). PV solar cells energy density is related to the amount of solar irradiance impacting the PV cells. Using the most conservative data points from Reference (20), electrical power generated by PV solar cells is about 16 W/m^2, assuming 16% efficiency and direct light beam incident on the solar cell.

Solar thermal energy can be used to generate power by focusing sunlight to a point on a heat transfer fluid, as discussed in Reference (21). With the assumption of 1 kW of direct solar radiation, perpendicular to the Earth's surface, Figure 13 shows overall thermal power cycle efficiencies of two different solar thermal energy systems; the parabolic trough and the concentrated solar tower. The efficiencies of these systems are approximately 20% and

25%, respectively, and are still theoretical, based on full direct incident sunlight on the system.

Nuclear power plants generate power from the fission of Uranium, Plutonium, or a mix of both. The fission reaction releases energy as heat, which can be used in thermal power cycles to generate electricity, similar to a conventional fossil fuel power plant, but using no combustion. The International Atomic Energy Agency (IAEA) published two research reports related to seawater desalination with nuclear reactor technology, References (23) and (24). As reported in Section 1.5, Table 8, of Reference (23), many different nuclear reactor technologies and countries have used nuclear reactors to desalinate sea water. Section 3.1 of Reference (24) discusses coupling nuclear power reactors to desalination technologies previously discussed in this study. For example, Madras Atomic Power Station (MAPS) in Kalpakkam, India, couples a MSF and RO system to a Pressurized Heavy Water Reactor, utilizing the waste heat from the reactor for the MSF desalination method, and the electricity for the RO desalination method. The energy density of nuclear fission is as follows, assuming a burn-up rate of $50x10^3$ MWD/1000 kg:

$$\frac{50{,}000\,MWD}{1000\,kg} = \frac{50{,}000\ x\ 10^6 MJ\ x\ 1\ Day}{1s\ \cdot 1000\ kg} = \frac{50{,}000\ x10^6 MJ\ x86{,}400s}{1000\ kg \cdot s}$$

,which is approximately 4.32×10^{12} MJ/kg. This allows which allows for nuclear power plants to require an area of, per Reference (26), 42 acres for 600 MW_e of electrical power.

In summary, coal, oil, and natural gas, offer both the generation of electricity, while also allowing the benefit of co-generation of desalination, utilizing the waste heat generated during the thermal power cycle. However, fossil fuel power plants have the following disadvantages: 1) Each use significant amounts of land area relative to the other energy technologies, 2) The amount of energy generated has significant amounts of pollution coupled with them, 3) They require a constant stream of each type of resource to run continuously, which makes all three subject to short-term market price volatility.

Renewable energy methods to generate electricity have the advantage of generating insignificant amounts of pollution. However, all renewable energy methods are at significant disadvantages with respect to the following: 1) Wind and solar technologies cannot run continuously, 2) All renewable sources require specific sites that allow for maximum performance, 3) All sources require significant amounts of land area to generate acceptable amounts of electrical power.

Nuclear energy sources have significant advantages over the alternative power generation methods discussed. Nuclear reactors have been coupled to desalination systems successfully for many years. They have power densities that no other contemporary source of power can compete with, and run continuously for years before requiring the reactor to be refueled. Nuclear power plants, especially small modular reactors (SMRs), require very little land area (for the entire site), and generate insignificant amounts of pollution. Nuclear power plants do have disadvantages, however: 1) Nuclear waste must be stored on-site until final disposal, 2) Operations personnel need high levels of technical training, 3) They require significant construction costs, however, SMRs are attempting to reduce these costs.

To determine the best power source for the SNP desalination project, a summary analysis for the decision is shown in tables below. The capacity factor data is from Reference (30), Table 5.2, for the year 2009:

Objective Criteria		
Objective	Want/Must	Weight (1 – 10)
Low Cost	Want	5
Small Size	Want	8
High Capacity Factor*	Must	GO/NO-GO
Ease of Scalability	Want	5
Low Pollution	Want	9

*Denotes Average Capacity Factor ≥40%

Power Source	Coal	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	9	45
Small Size	6	48
High Capacity Factor	N/A	GO
Ease of Scalability	4	20
Low Pollution	1	9
TOTAL		122

Power Source	Oil	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	6	30
Small Size	7	54
High Capacity Factor	N/A	NO-GO
Ease of Scalability	4	20
Low Pollution	3	27
TOTAL		

Power Source	Natural Gas	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	7	35
Small Size	8	64
High Capacity Factor	N/A	GO
Ease of Scalability	5	25
Low Pollution	5	45
TOTAL		169

Power Source	Hydroelectric	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	8	40
Small Size	2	16
High Capacity Factor	N/A	GO
Ease of Scalability	1	5
Low Pollution	8	72
TOTAL		133

Power Source	Wind	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	6	30
Small Size	1	8
High Capacity Factor	N/A	NO-GO
Ease of Scalability	7	35
Low Pollution	7	63
TOTAL		

Power Source	Solar (PV)	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	5	25
Small Size	2	16
High Capacity Factor	N/A	NO-GO
Ease of Scalability	7	35
Low Pollution	8	72
TOTAL		136

Power Source	Solar (Thermal)	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	6	30
Small Size	2	16
High Capacity Factor	N/A	NO-GO
Ease of Scalability	4	20
Low Pollution	8	72
TOTAL		138

Power Source	Geothermal	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	6	30
Small Size	5	40
High Capacity Factor	N/A	NO-GO
Ease of Scalability	3	15
Low Pollution	8	72
TOTAL		157

Power Source	Nuclear	
Objective	Score	Weighted Score (Score x Weight)
Low Cost	7	35
Small Size	8	64
High Capacity Factor	N/A	GO
Ease of Scalability	9	45
Low Pollution	9	45
TOTAL		189

From the tables above, the best decision for the desalination power source is nuclear power, specifically small modular reactors. The next best decision would be natural gas, however, the hydrocarbon economy is quite a volatile market and such a power source would require a steady stream of fuel. All of the renewable energy sources are not suitable for this specific application, given the reasons stated earlier.

Chapter 6- Recommendation for the Southern Nevada Project

The designated route for the project should be Route number 3, because of the power required. Route 1 needs the most power, Route 2 needs slightly more. The disadvantages of using Route 3 include metropolitan areas that would need to be traversed along travel route, since the design would need to be elevated off the ground. The pipeline would need to be monitored for integrity based on location, which could become a complex operation in both the urban and rural locations of the pipeline.

The desalination type should use a MED system coupled to the chosen power source for the SNP. While both the MED and MSF systems utilize waste heat from a power plant to achieve desalination, MED is more effective method to utilize the waste heat from the SNP power source. While the MSF system is a simpler method to desalinate sea water, the MED becomes more effective and when other components are added, such as Vapor Compressors, increasing the complexity, maintenance, and electrical energy of each MED unit. The only viable alternative to MED would be RO. While RO has become more cost effective over time, for the SNP, RO would require significant amounts of equipment, maintenance, power, and a plant size beyond any currently operating RO desalination plant. Any desalination method used would require a customized system given the SNP project's objective.

The pipeline itself needs to be durable, simple to construct, and cost effective, both for initial capital cost and over time. The criteria associated with this type of analysis could lead to numerous iterations, and is beyond the scope of this study. However, in order to examine the feasibility of this project, a specific design for the pipeline was chosen, with one additional alteration for relative magnitude. A conservative initial design that was analyzed was stainless steel, with a diameter of 2.3m (7.55 ft), along each route from the southern California coastline to Las Vegas. The range of assumed flow rates was equal to the amount of water that Las Vegas uses every minute (310,050 gpm max and 105,884 gpm min), which is enough to replace the city's total use of the Colorado River. The diameter of 2.3m would allow the pipe to be manufactured off-site and transported to the construction site. To reduce cost further, the stainless steel pipe could be manufactured as thin walled section, inserted into a larger carbon steel pipe. To protect the carbon steel pipe from environmental effects, a coating painted on the external surface should be applied. The flow rate would require, in the worst case, 425 MW of power. For comparison, the power required for the flow rates in a carbon steel tube with a stainless steel insert for each route are shown in Figure 6-1.

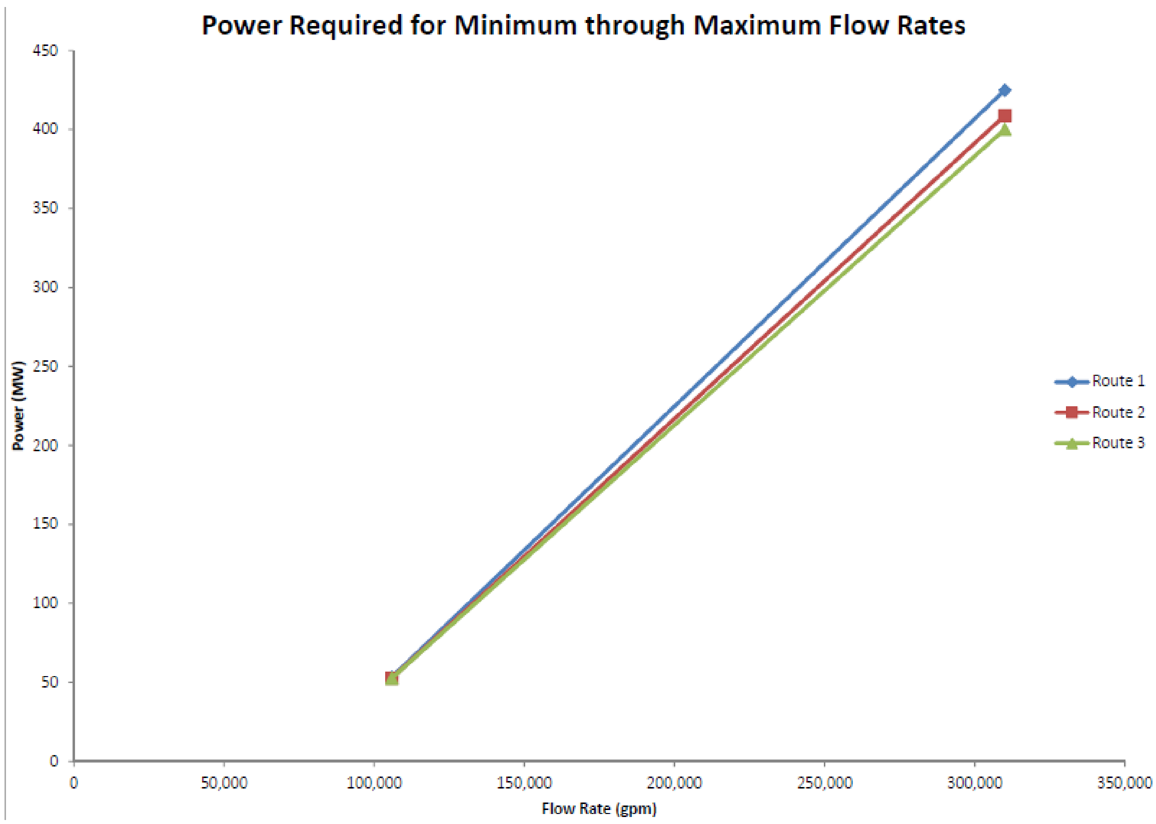

Figure 6-1

Since each route, as analyzed in Chapter 2, contains two main elevation changes, there should be at least 2 pumping stations to pump the water along the pipeline route. The first pumping station can be located by the desalination facility. The second pumping station should be located near Baker, CA, prior to the ascent at Mountain Pass, CA. If needed, an additional pumping station should be located prior to Las Vegas.

In order to determine the appropriate dimensions for wall thickness of the carbon steel pipe with a stainless steel insert, the use of Barlow's Formula, Reference (31) will be used:

$$P = \frac{2 \cdot S_Y \cdot T}{D_{out}}$$

where:

P = Pressure (psi)

S_Y = Material Yield Strength (psi)

T = thickness (inches)

D_{out} = Outer Diameter (inches)

Re-arranging to determine a thickness:

$$T = \frac{D_{out} \cdot P}{2 \cdot S_Y}$$

Obtaining material properties from References (32) and (33):

304 Stainless Steel Yield Strength (psi)	A500 Carbon Steel Yield Strength (psi)
31,200	50,000

As shown below in Figure 6-2, the thicknesses for various pipes, of stainless and carbon steel are displayed, at specified pressures. For the maximum pressure of 21 MPa, assuming the pipeline is a single pressurized pipe, the pipe thickness should be approximately 4.2 inches, for carbon steel.

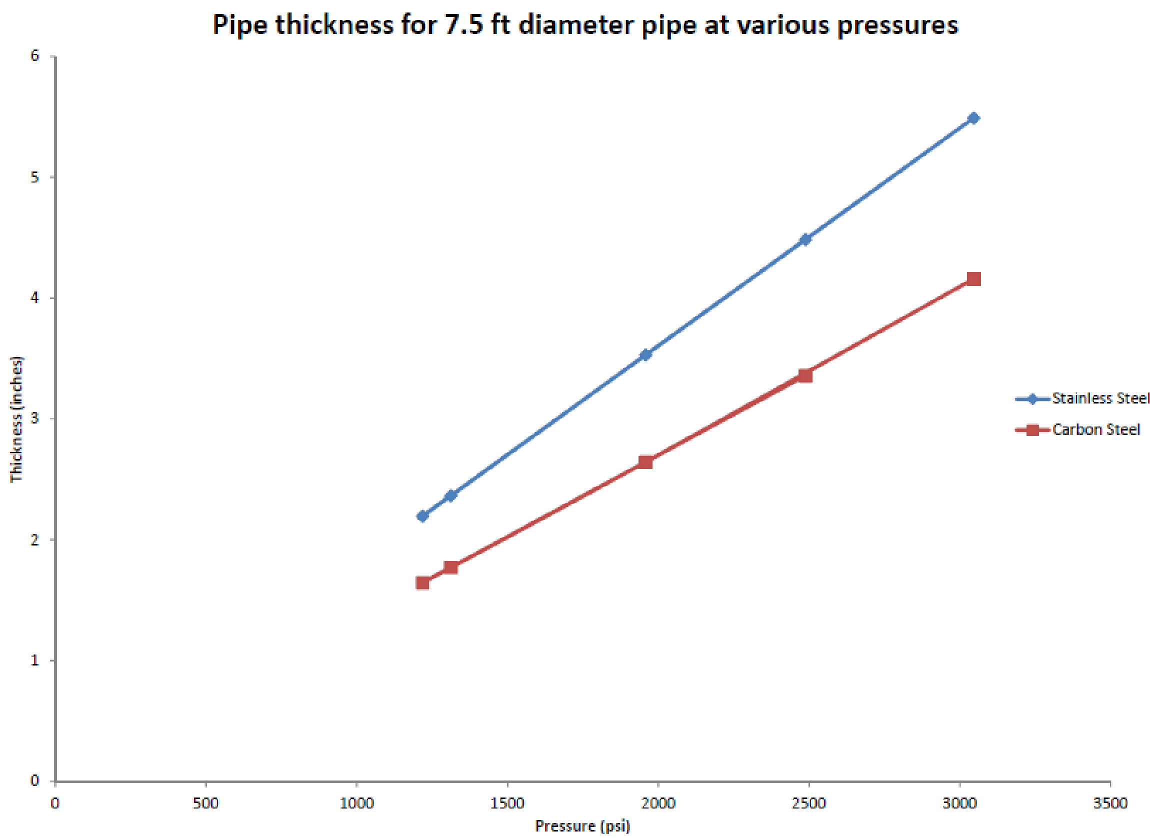

Figure 6-2

The power source, as discussed previously, should be a nuclear power source. As revealed by Reference (27), Pacific Gas and Electric has decided to not renew the operating license for the Diablo Canyon Nuclear Plant Units 1 and 2. The operating licenses are set to expire in 2024 and 2025, respectively. However, this nuclear power station could be utilized for the SNP project. As determined earlier in this study the amount of power required for pumping the water is approximately 400 MW_e. If the power station was coupled to a RO desalination station, assuming 4.5 kWh/m^3;

$$\frac{4.5\ kW_e \cdot h}{m} \cdot \frac{1173\ m^3}{min} \cdot \frac{60\ min}{h} = 316.7\ MW_e, \therefore$$

$$400\ MW_e + 317\ MW_e = 717\ MW_e$$

one reactor (Unit 1 or 2) could easily fit the power generating requirements for the entire system. Assuming that no present nuclear power plant is utilized, a small modular nuclear reactor design that is low-maintenance, compact, and cheaper to operate should be used instead. To illustrate a SMR power concept, the information contained in Reference (26) will be used. The NuScale nuclear reactor is designed to produce 160 MW of thermal energy and approximately 48 MW of electricity per reactor. Per Reference (28), twelve units are expected to compose the entire nuclear plant, with a total electrical output of 540 MW of electricity produced, a capacity factor of >92%, and needing to refuel each reactor module every two years. Of all current SMR designs, the NuScale nuclear system, as documented in Reference (29), is the nearest to actual operation, with a full prototype planned to be online by 2024. Therefore, for the SNP, this will be the assumed power source and configuration.

The design of the MED desalination plant for the SNP should be similar to the MSF plant coupled to the PHWR as discussed in Reference (24). This will simplify the SNP desalination plant design process by using a design that is similar to an existing nuclear desalination plant. The desalination section of this plant operates with approximately 20,600 kg/hr of steam, Reference (24), figure 2.19, from the low pressure steam turbine of the power plant. The steam heats the incoming seawater from 113^{O}C at the heat exchanger inlet up to 121^{O}C at the outlet. Seawater enters the desalination plant at a temperature of 31^{O}C and a mass flow rate of 1450 m^3/hr. The distilled water leaves the plant at a temperature of 40^{O}C and a mass flow rate of 187.5m^3/hr or about 709 gpm. If the plant was scaled up by a factor of 18, the flow rate of approximately 12,402 gpm can be achieved.

The final system design recommendation should be a MED desalination plant that can output an amount of potable water between 12,000 to 19,000 gpm. The desalination plant should be coupled to the waste heat generated by a SMR nuclear power station, utilizing the design of the NuScale power reactor complex. Coupling of desalination plants (specifically MED) could be accomplished using the waste heat from the nuclear plant, if the MED stages were lower to the right pressures in sequence. The water generated from the desalination plant should be sent from the area near Newport Beach, CA, and pumped by a carbon steel pipe with a stainless steel insert to Las Vegas, Nevada following the 3rd route discussed in this report. This report is an initial scoping study for the maximum flow rate required to replace all of Las Vegas's current water usage of the Colorado River. This report concludes that such an engineering project is feasible, and provides a top level study of a single proposed system. It should be noted that additional in-depth studies should be undertaken to optimize each system component, in order to choose the most efficient system. Such analysis of each system component is beyond the scope of this study.

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