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Sustainable Water Treatment Systems: A Direct Potable Proposal

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Murray State University Honors College

HONORS THESIS

Certificate of Approval

Sustainable Water Treatment Systems

Kayla Alsup

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Approved to fulfill the
requirements of HON 437

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Civil and Sustainability Engineering/
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Sustainable Water Treatment Systems:
A Direct Potable Proposal

Submitted in partial fulfillment
of the requirements
for the Murray State University Honors Diploma

Kayla Alsup

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ABSTRACT

SUSTAINABLE WATER TREATMENT SYSTEMS: A DIRECT POTABLE PROPOSAL

A common need among all people is water—we cannot survive without it. And yet, all around the world, achieving a high quality of drinking water is a constant struggle. This water crisis is brought on by many different factors. Some are natural, such as droughts and flooding, but as the effects of climate change continue to reveal themselves, some areas are becoming drier, while other areas are experiencing less predictable and harsher weather patterns.

Our current approach towards water is not sustainable, and we are starting to see that in both under-developed and developed countries alike. Indiscriminate use of water leading to groundwater depletion, low quality water treatment facilities, the growing demand for freshwater, and the overall undervaluing of water as a resource all lead to its lack of preservation and overall waste. To compensate for this growing need, implementing tactics that will enhance the optimal usage of our water resources is important.

Introducing direct potable reuse (DPR) systems, in which the effluent from a wastewater treatment plant and undergoes the water treatment process and is reused an alternative to discharging the effluent back into the environment. Wastewater can be directly reused to help curb shortages and reduce the amount of groundwater needed. The location experiencing a water shortage that will be identified and analyzed is Carlsbad, New Mexico. A theoretical DPR system was designed to find approximate dimensions. The necessary community outreach will be discussed, as will future benefits to demonstrate to the city of Carlsbad, the state of New Mexico, and surrounding communities that this technology is a feasible solution to the ever-present water scarcity crisis.

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Chapter 1: Introduction

I. The Necessity of Water Reuse: The Global Water Scarcity

Water scarcity is a problem that developing and developed nations alike face on a regular basis. Imagining that people within developed nations such as the United States are lacking a resource they will die without is difficult, and yet the Southwestern states face this reality. There are many reasons for this worldwide scarcity. Economic stress, natural disasters such as droughts, depletion of freshwater, and climate change and all play a significant role, while the undervaluing of water as a resource in developed nations amplifies an already strained situation. Developing nations tend to struggle more than developed nations when it comes to economic issues; an increasing population growth is a symptom of the economic development of a nation, and high poverty levels often can be correlated to this increase. “In the developing world, an estimated 1 billion people lack access to safe affordable drinking water, 2.7 billion lack access to sanitation, and many millions die each year from preventable waterborne diseases.” (Grant, et al., 2012, p. 681) The technology is available, it just isn’t feasible to implement in low-income areas due to start-up costs.

Developed and developing nations struggling alongside one another is proof of the complexity and unpredictability of this issue. The underpricing of water is a serious issue because it leads to excess water demand and shortfalls for water utilities. “Underfunded utilities tend not to maintain infrastructure or repair leaks [or] adequately treat wastewater (spoiling scarce water resources).” (Grant, et al., 2012, p. 685) The Colorado River is currently shared by seven states, including Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming. To compensate for this strain, the Colorado River Compact was created in 1922. The main complaint about the Compact is that it does not appropriate water to the states individually, as there is no agreement on equitable distribution. “Changes in local ecologies and/or water shortages could also result in diversion of water for one community that negatively impacts adjacent human populations and economically vital ecosystems.” (Fuller & Harhay, 2010, p. 2) The actions of the community action affect everyone downstream.

To remedy our water scarcity situation, it is important to take a step back and consider alternative, more sustainable methods to better use the water we extract. In a time when the depletion of non-renewable resources such as natural gas, oil, and coal, are in constant conversation, we need to stop considering water as disposable and start seeing it as the renewable resource it is. The three primary uses of water include agriculture, industrial, and municipal, with agriculture having the largest demand. Water reuse can be implemented at each of the three levels, being reused to do things like irrigate crops, and being recycled into drinking water. Water savings can be incorporated in the daily lives of individuals at home as well by limiting water use at home. Substituting reuse water for fresh water regularly can save both resource and money. Across the world, our water supply is viewed as a linear entity: collection, treatment to water standards, use, treatment of wastewater, ultimately leading to disposal. Through this process, we generate wastewater that we need to get rid of. Even after wastewater treatment, the effluent that we put back is not the same quality at which it was when we took it, and nature is left to complete the filtration process and reap the consequences. Eventually, the water is used again in a different location, and the process begins again, further depleting freshwater sources.

If we were to change our perspective and see this ‘wastewater’ as a potential for drinking water instead of something to dispose of, “communities [could] enjoy the same goods and services, generate less wastewater, and leave more freshwater in streams, rivers, lakes, and coastal estuaries to support biodiversity.” (Grant, et al., 2012, p. 681) Producing less wastewater means less resources need to go into its disposal, conserving other resources such as fossil fuels that would be used in the process. When the freshwater remains in place, it preserves pre-developed likeness of the ecosystem and subsequently it’s health.

Several economic advantages come from water reuse in general. In agriculture, water reuse can provide a constant water source for crops during a drought. There is also economic incentive to water reuse by saving money on fertilizers when reclaimed water nutrients are used on crops in lieu of fertilizer. Municipal and industrial benefits include decreases in capital cost of diversion structures, drought storage, transfer systems and water treatment, decrease in operation and maintenance costs, and in reduction in freshwater diversions, leaving a better river flow and quality for those downstream. (Anderson, 2003, p. 8)

One of the most significant environmental benefits involves better downstream water quality. The environment is designed to have its own natural barrier of treatment for water throughout its journey, filtered through different sediments and vegetation. Wastewater effluent has certain discharge standards, but they are sufficient to provide water safe for consumption from contaminants entering waterways that the environment may not be equipped to neutralize. Better downstream water quality benefits not only the ecosystem and the organisms that are a part of it but provides benefits to individuals as well. A healthy water quality means there are less containments to worry about, resulting in overall lower water treatment costs and better public health. Spending less on treating the water can free up funds to improve the recreational quality of the water, drawing in tourists and economic opportunity.

II. Wastewater Reclamation Methods

Potable drinking water, sewage, and treatment facilities are designed and usually operated entirely separate from one another. “A huge loss of life-supporting resources is the result of failed organic wastewater recovery.” (Jhansi & Mishra, 2013, p. 2) Rather than designing our systems based on intake and output, it would be beneficial to model them on nature’s water cycle, where the resultant of the wastewater plant would have multiple uses ranging from irrigation to potable water reuse. Not only would the citizens of the community get the most out of the money they invest into their city’s water treatment, but also, the city would save money in regard to developing new water sources, water transfers, treatment, and distribution systems.

Using domestic wastewater for irrigation is nothing new. “Domestic wastewater was used for irrigation by prehistoric civilizations (e.g., Mesopotamian, Indus valley, and Minoan) since the Bronze Age (ca. 3200–1100 BC),” (Angelakis & Snyder, 2015). In 1650, wastewater was still being used for increased crop production in Scotland. Sewage farms, which are basically large fields in which wastewater is disposed in high quantities, were common in cities in the U.S. and Europe with rapid population growth. The 1900’s saw a significant decrease in these practices, as significant drawbacks started to arise with large area requirements, field operation problems, and the inability to achieve the higher hygiene criteria requirements required. (Angelakis & Snyder, 2015, p. 4888)

In recent years, significant advances in the water treatment field have provided several options when it comes to treatment type. Many elements go into selecting the appropriate reclamation technology. The National Research Council (U.S.) (2012) provides the following central factors: “the type of water reuse application, reclaimed water quality objectives, the wastewater characteristics of the source water, compatibility with existing conditions, process flexibility, operating and maintenance requirements, energy and chemical requirements, personnel and staffing requirements, residual disposal options, and environmental constraints. Decisions on treatment design are also influenced by water rights, economics, institutional issues, and public confidence.” This provides engineers with numerous design options.

Figure 1 shows a general outline of the wastewater treatment process. Treatment plants are typically comprised of preliminary treatment, followed by primary and secondary treatment, and occasionally tertiary treatment as well. Finally, the effluent is disinfected and discharged.

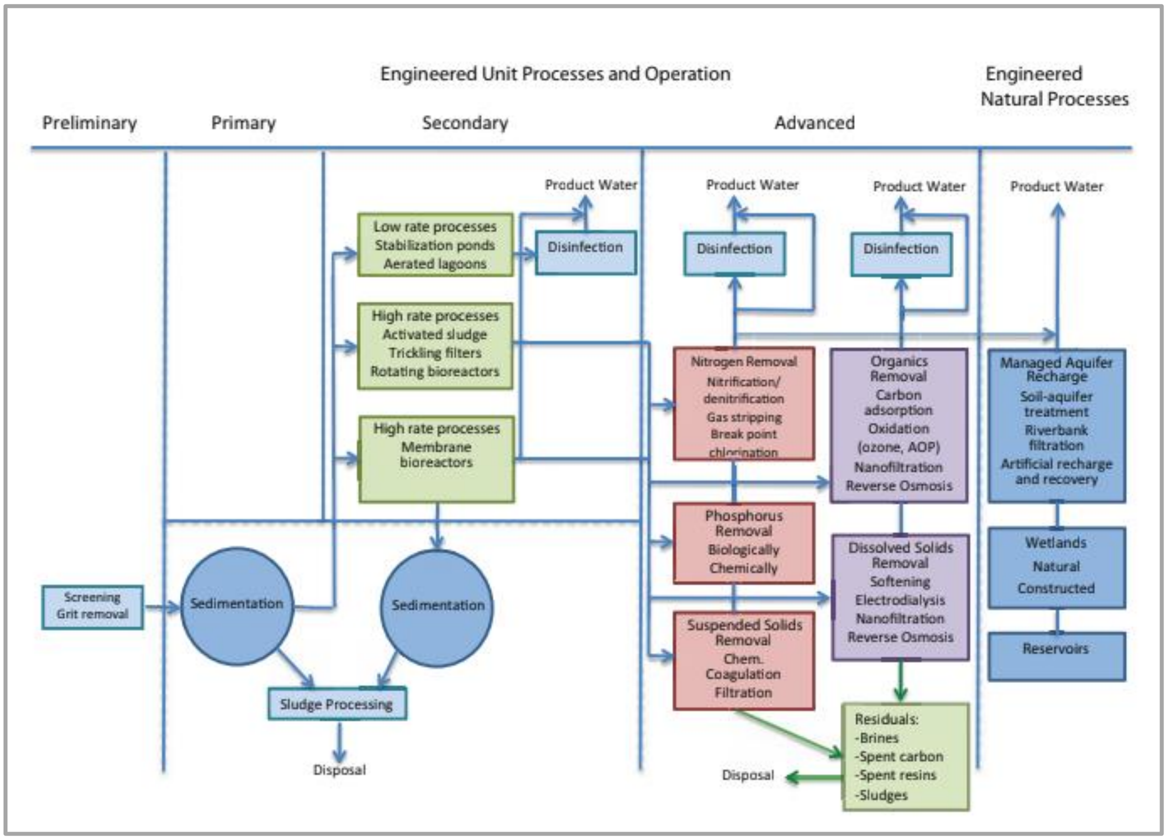

Figure 1. A diagram of the wastewater treatment process, demonstrating the different methods and potential reuse options by providing product water instead of leading only to disposal. This table includes preliminary, primary, secondary, and advanced operations, as well as and engineered natural processes.(National Research Council (U.S.), 2012)

Preliminary steps include measuring the flow coming into the plant, screening out large solid materials, and grit removal to protect equipment against unnecessary wear. Primary treatment targets settleable matter and scum that floats to the surface.

Secondary treatment processes are employed to remove total suspended solids, dissolved organic matter (measured as biochemical oxygen demand), and, with increasing frequency, nutrients. Secondary treatment processes usually consist of a biological process such as aerated activated sludge basins or fixed-media filters with recycle flow (e.g., trickling filters; rotating biocontactors), followed by final solids separation via settling or membrane filtration. Ordinarily, disinfection is the final step. (National Research Council (U.S.), 2012, p. 67). Disinfection is performed by either ultraviolet (UV) light or chlorine. Figure 2 on the next page shows the relative effectiveness of various disinfection methods. CT (concentration x time) is the product of disinfectant concentration and reaction time.

UV and chlorine cover a different range of organisms, therefore a combination of the two is sometimes employed for optimal treatment levels.

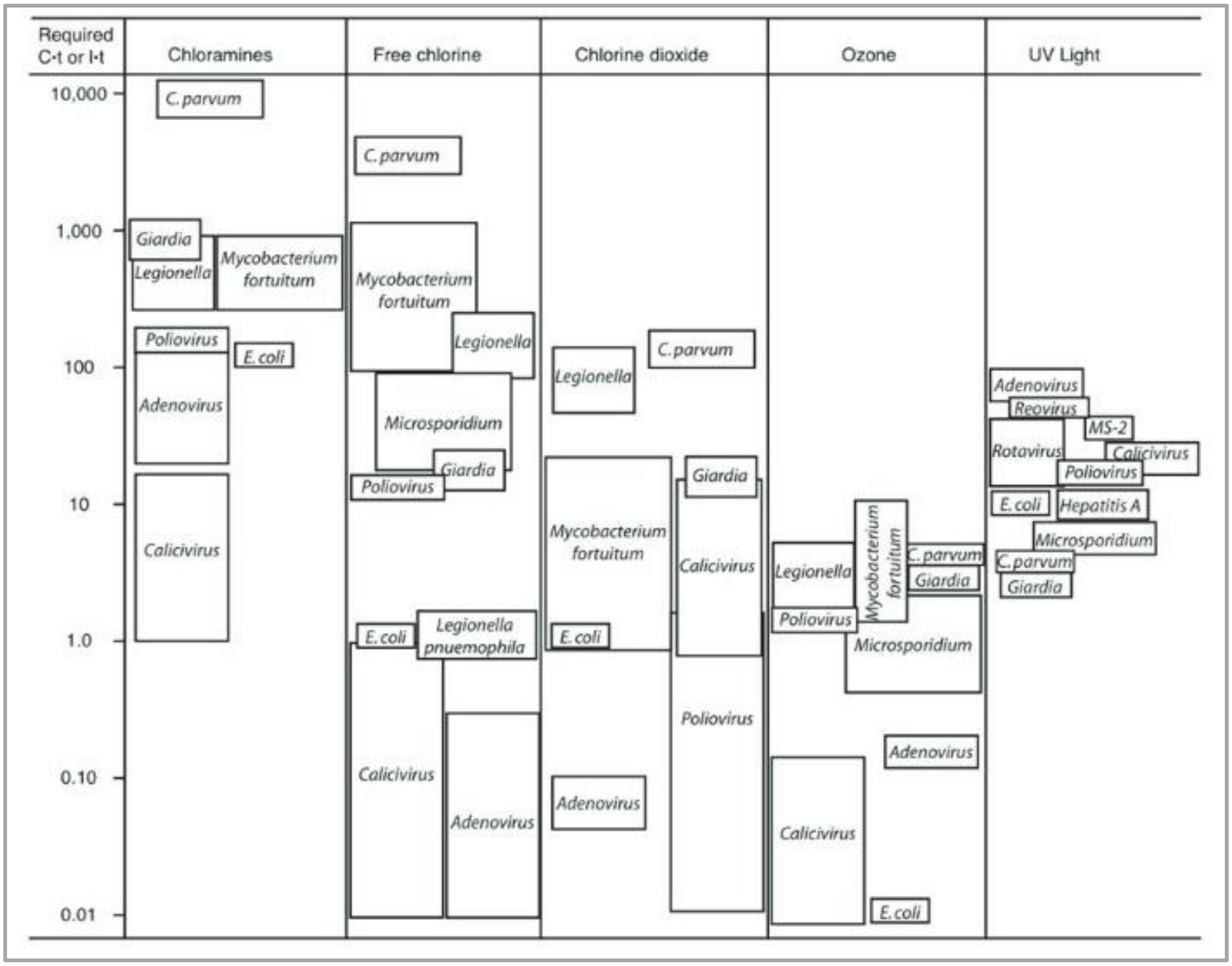

Figure 2. Disinfection methods: the relative effectiveness of various disinfection methods expressed in (C*t), including chloramines, free chlorine, chlorine dioxide, ozone, and UV Light. C*t values range from 0.01 to 10,000. (National Research Council (U.S.), 2012) Chlorine and UV Light are the most frequently used.

Advances over the past 20 years in membrane bioreactor (MBR) technologies have resulted in an alternative to conventional activated sludge processes. An MBR system does not require primary treatment and secondary sedimentation. When an MBR is used, the preliminary step is no more than a screen. Cloudcroft, NM utilizes this technology, and is explained further in Chapter 2, and is the inspiration for the reuse system proposed in Chapter 3.

Chapter 2: Literature Review

I. Indirect and Direct Potable Reuse

The design of either the indirect potable reuse (IPR) or direct potable reuse (DPR) facility begins with the wastewater treatment plant—now referred to as the water resources reclamation plant (WRRP). It normally consists of primary treatment, secondary treatment (activated sludge nitrification/denitrification), granular media filtration, and sequential chlorination disinfection.

When designing a successful IPR or DPR, four primary qualities need to be considered: reliability, redundancy, robustness and resilience. First and foremost, the treatment must be reliable. There should never be a question as to what quality the water will be—reclaimed potable water must have the same or better quality than the traditional water treatment system in place. The water should be tested often and regularly, and the public should be informed of any findings. The testing and treatment measures should also be redundant. They should go beyond treatment requirements to prove a consistent reliability.

The treatment should have a high level of robustness, equipped with a diversity of barriers to address anything that may come its way. Finally, the system must be resilient to potential failure. Staff need to be trained and well equipped to deal with emergencies. Measures should be in place to activate automatically in a crisis. (Davis, 2019)

II. Primary Examples of Potable Water Reuse

i. Indirect potable reuse (IPR)

The two most common IPR processes include surface water augmentation and groundwater augmentation. In both situations, the water goes through the entire wastewater treatment process and the effluent is then used to recharge drinking water sources. When effluent is discharged into local rivers and bodies of water, it has time to experience further treatment in the environment before it reaches the location in which it will eventually be extracted for the water treatment process.

a) Surface Water Augmentation

Abilene, Texas, a city of over 120,000 people, began implementing IPR through surface water augmentation due to an increasing water scarcity. Excessive droughts caused the Lake Fort Phantom Hill reservoir to be depleted to 30% capacity, motivating the city to find new ways to supplement its water. Ultimately, the city upgraded the WRRP to divert almost 12 million gallons per day (MGD) to the reservoir to increase its supply. A diagram of the treatment implemented is seen in Figure 3, showing the final destination of the effluent is the Lake Fort Phantom Hill reservoir.

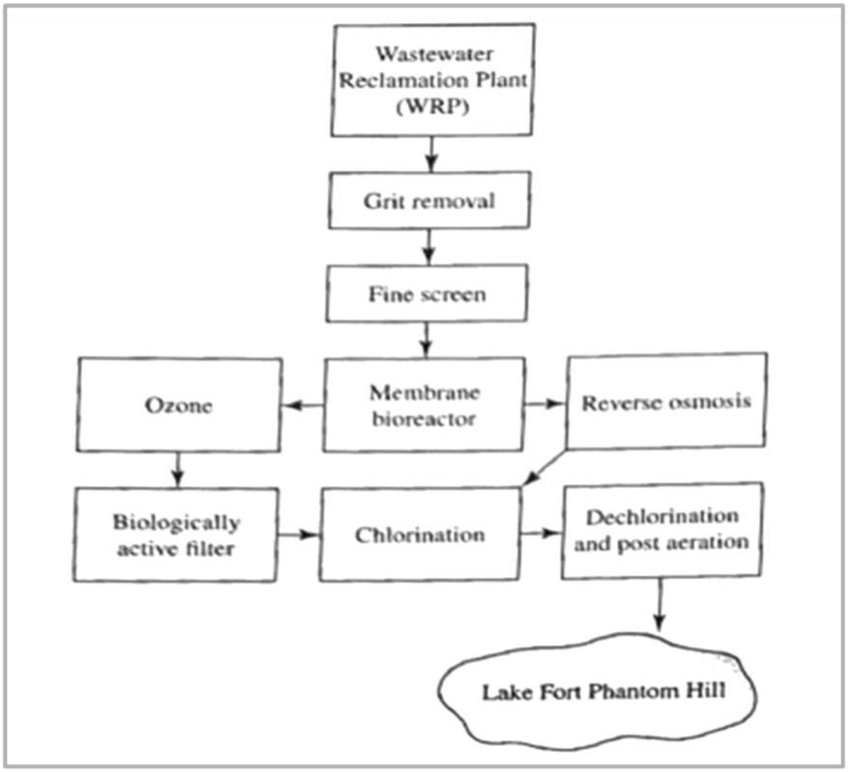

Figure 3. Abilene, TX, process flow for Indirect Potable Reuse. (Davis, 2019 process flow diagram. (Davis, 2019) The wastewater is treated to effluent standards, and then injected into Lake Fort Phantom Hill reservoir to be retained there.

b) Groundwater Augmentation

Driven by the desire to increase available drinking water to the people of Long Beach, CA, the Leo J. Vander Lans Water Treatment Facility (LVLWTF) was expanded from a design capacity of 3 MGD to 8 MGD. Effluent from the Long Beach Water Reclamation Plant and the Los Coyotes Water Reclamation Plant are fed into this new facility, and the final treated product is used to recharge the drinking water aquifer. The IPR process is shown in Figure 4.

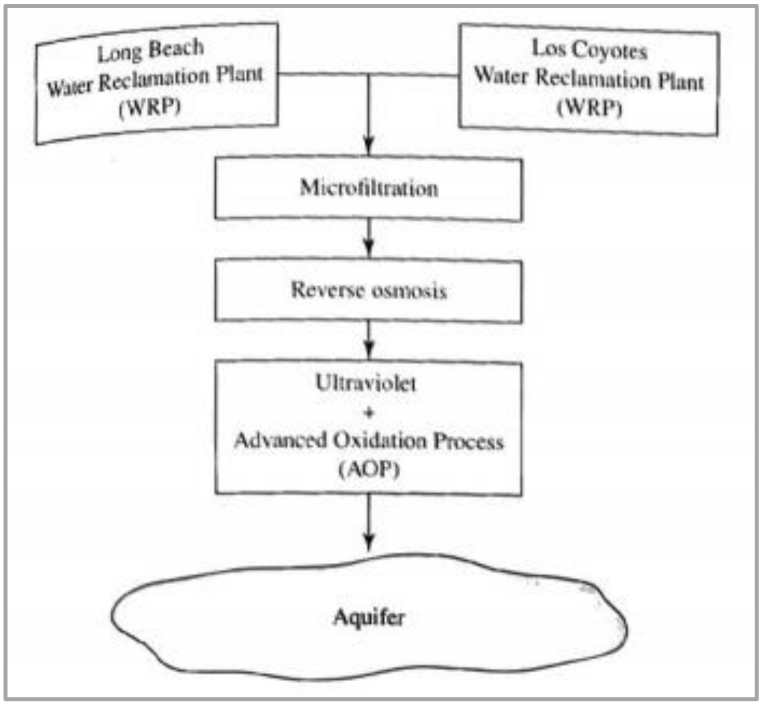

Figure 4. Leo J. Vander Lans Water Treatment Facility, CA process flow diagram for Indirect Potable Reuse with groundwater. (Davis, 2019) The wastewater comes from Long Beach WRP and Los Coyotes WRP, and is treated to effluent standards, and then mixed the aquifer for further treatment.

The first step of treatment used to target pathogen reduction, not shown in the figure, is the chlorine disinfection that takes place at the end of the WRRP process. Once the water has been injected into the aquifer, it is retained there until it is drawn into a production well. This provides dilution and further natural treatment so water can be drawn and is treated for potable use. According to Davis (2019), the estimated retention in this system is 4.3 years.

ii. Direct potable reuse (DPR)

a) Namibia: the "Original" Potable Reuse System

In modern terms of water reuse, Windhoek, Namibia's Goreangab reclamation plant is the start of it all. Located in between the Namib Desert and the Kalahari Desert, the city has already exhausted its original groundwater and was forced examine other options for sources of water. Current conditions were barely supporting a small number of people, and the growth driven in by tourism caused a further strain to this area. In 1969, they began directing their wastewater effluent into the conventional water treatment plant. “This was the start of the first … water recycling plant for direct potable use.” (Escobar & Schäfer, 2009)

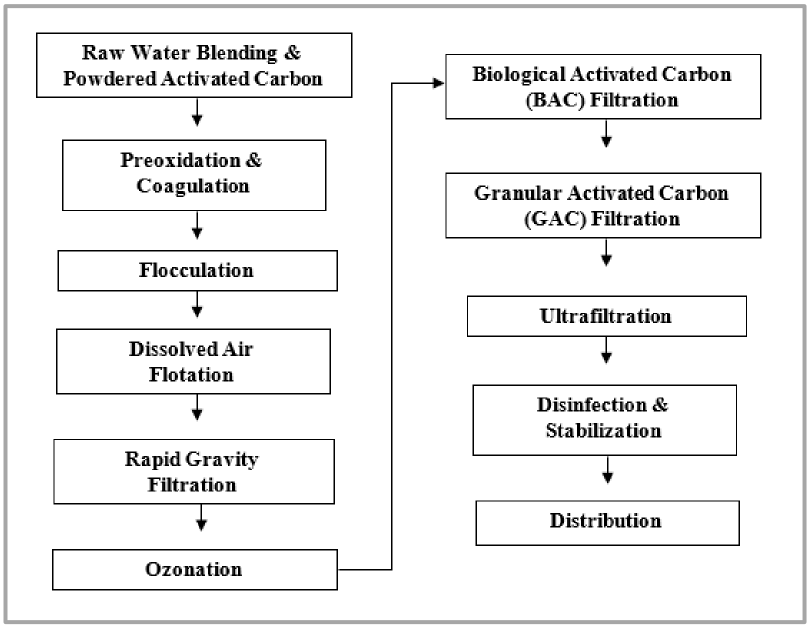

Figure 5. Namibia Direct Potable Reuse process flow diagram. (Veolia, 2021) This treatment plant is the first of its type and is still the only of its kind in South Africa.

With an original capacity of 4,300 cubic meters per day (m^3/day), and upgrades made to increase that to 7,500 m^3/day, the plant was eventually redesigned and expanded in 2002 to its current capacity of 21,000 m^3/day. The city relies on the plant to supplement its water supply in times of need. Current design allows for the reclaimed water to compose a maximum of 35% of the final drinking water. (Escobar & Schäfer, 2009) This was the beginning of DPR, and to date, is still the only DPR system in Africa.

The website for the plant states that industrial and other potentially toxic wastewater is diverted from the main domestic wastewater stream. The wastewater is still treated as it would be regularly but is then further treated to produce safe potable water. They employ a multi-barrier approach to treatment sequence to ensure reliability, redundancy, robustness, and resilience. The plant reports "no negative health effects have been detected as a result of the use of reclaimed water since 1968." (Veolia, 2021) The treatment process is shown in Figure 5.

b) Cloudcroft, NM

Cloudcroft, NM, has a population of about 750 regularly, with closer to 2,000 during peak times such as the weekends and holidays due to tourism. As a result of annual droughts and the constant flux of demand, the community decided to implement a DPR system to be used when water supplies are running low on supply. The treatment process is seen in Figure 6.

Not only is the wastewater treated, but it is then blended with the well water the community uses for water treatment, at no more than a 1:1 ratio. This water is then further treated to drinking water quality standards using UF, UV disinfection and GAC.

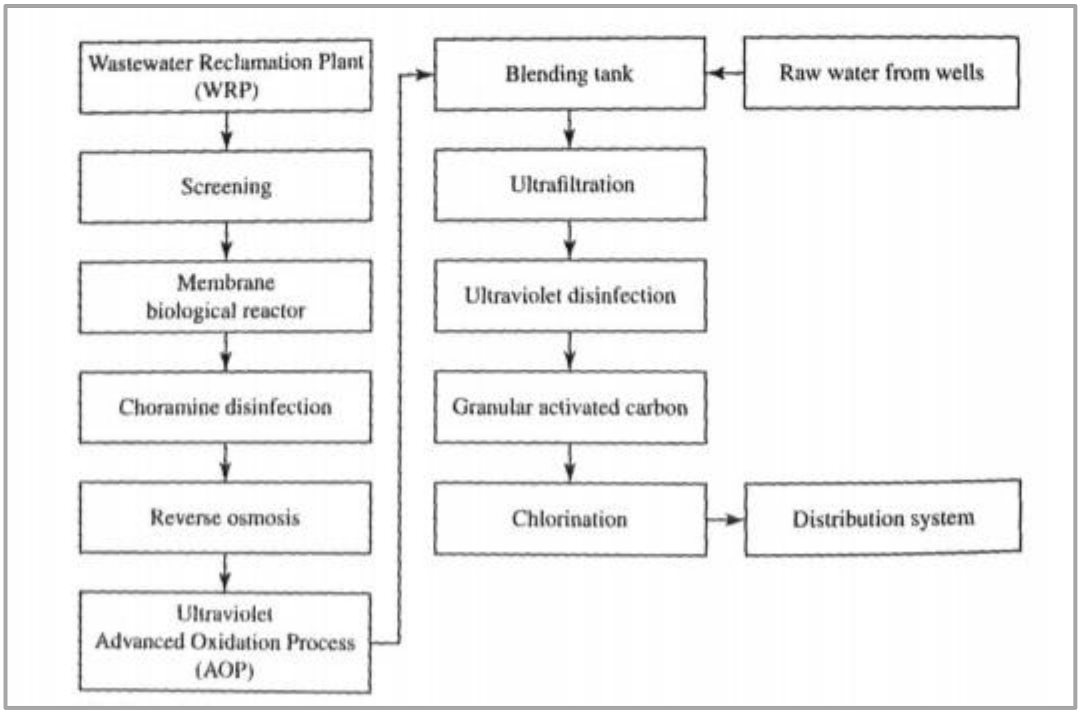

Figure 6. Cloudcroft, NM DPR process flow diagram. (Davis, 2019) The wastewater is treated to effluent standards, and then mixed with raw water from nearby wells. Further treatment takes place to achieve drinking water quality standards.

This city was the inspiration for selecting the location of Carlsbad, NM. It is suggested that the public in a state that has already begun implementing some form of water reuse would be more comfortable with a DPR system, in comparison to one where potable reuse has yet to be introduced.

c) El Paso, TX

The city of El Paso started practicing indirect potable reuse 30 years ago and has implemented conservation measures that have reduced daily consumption to about 130 gpcd (gallons per capita per day), a significant decrease from their consumption rate of 225 gpcd in 1970. (Davis, 2019, p. 1251) Even with these measures in place, severe drought has pushed the community to find a more sustainable, long-term solution.

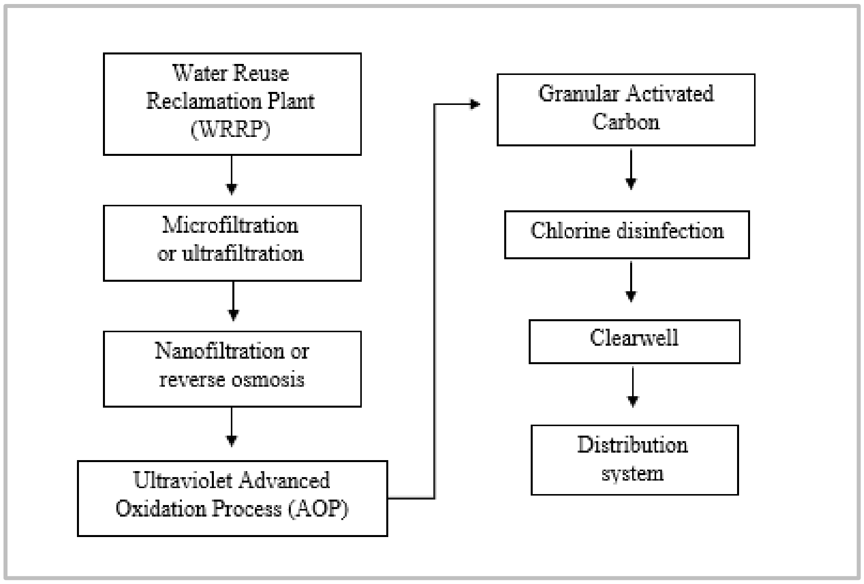

Figure 7. The Advanced Water Purification Facility, DPR, in El Paso, TX. As the first of its kind in the United states, it served as another primary inspiration for the proposed water treatment plan in Chapter 3. (Davis, 2019)

After conducting a feasibility study and finding it was possible, taking their reuse to the next level with DPR was the natural next step. The project is estimated to cost a total of $100 million. El Paso's facilities are located on their treatment campus, and their current facilities include a surface water treatment plant and a WRRP. The Advanced Water Purification Facility will be located on the same campus, treating up to 10 million gallons per day (MGD) of secondary effluent from the Roberto R. Bustamante Wastewater Treatment Plant to produce high-quality purified water. The treated water will be introduced directly into the potable water distribution system at the adjacent Jonathan W. Rogers Water Treatment Plant." (Carollo, 2021) The proposed DPR system is shown in Figure 7.

The main difference between the El Paso DPR system and the DPR system used in Cloudcroft, NM, is the blending. Cloudcroft chose to blend their potable reuse water with the existing surface water supply, 50/50 prior to final treatment. El Paso is injecting reuse water directly into the distribution system.

The construction of the El Paso DPR treatment facility is groundbreaking for the United States. As IPR has begun to gain acceptance, there is still some uncertainty when it comes to DPR. History has taught communities that reusing their wastewater can cause serious health risks and concerns. Less than 200 years ago, this practice was not feasible due to the inability to achieve the higher hygiene criteria, but this is no longer a concern. The successful use of a DPR system in El Paso could help prove the potential of this technology, setting a good example for the states in the Southwest that struggle regularly with water shortages due to low rainfall and extended drought periods.

III. Challenges to Water Reclamation: Public Perception

Obstacles in water reclamation include uncertainty regarding the maintenance costs of infrastructure, the durability of the system, upfront costs for piping, storage, land, and quantifying unpriced benefits. While the technology might be available, the public is not always willing to be engaged in water reclamation, purely based on the fact that it comes from wastewater. “Public support for wastewater reuse, for example, is higher for uses such as landscape irrigation or car washing that minimize human contact.” (Grant, et al., 2012, p. 685) People are afraid that the water isn’t safe enough for consumption. How can the public be sure that everything is being done to protect them from contaminants and pathogens in the water that could cause sickness or harm?

The first impression of the concept of water reclamation on the public could make or break the project. “To increase the likelihood of public acceptance, decision-makers should first demonstrate why changes are required to avert water shortages and that these water-saving schemes are safe." (Grant, et al., 2012, p. 685) The seriousness of water scarcity must be stressed; the people need to understand why they should change from the water treatment system they know is safe, and are comfortable with, to something with which they are unfamiliar They need to understand why they will see a benefit from this on a personal level, and they need proof that this alternative is safe.

Changing our regulations on water reuse to focus on the health of the individual could help. "Australian water reuse regulations, for example, emphasize protecting human health, which may foster a more favorable regulatory environment than in the United States, where water laws emphasize environmental health." (Grant, et al., 2012, p. 685) This is a reminder, and makes it clear, that the health of the community is the top priority.

A high level of community outreach and interaction from the beginning is needed. Including the community on water reuse helps establish its foundation. "There is a strong sense of ownership by members of the community in their projects. This pride in the new development…Once the project is implemented, local participation on tributes to the community's confidence in the new technology and allows them to take on other challenges such as accessing financial aid for other infrastructure projects." (Jhansi & Mishra, 2013, pp. 10-11) If we are able to educate and empower the community along the way, they may work alongside the project instead of fighting back.

While people are willing to do whatever it takes in a time of crisis, that feeling does not always carry over when the crisis ends. To implement a successful, permanent, sustainable water system, it may be necessary to offer incentives for compliance to the community.

Ultimately, the way we communicate this data is critical. "Scientists have an opportunity to help move the field forward through development of more effective communication of complex data and by making sure that reused water quality is compared to that of existing urban water resources." (Angelakis & Snyder, 2015, p. 4893) We need to make sure we are initiating a positive conversation and educating individuals of the benefits.

IV. The Proposed Research: Implementing Wastewater Reuse

i. Direct Potable Reuse

The concept of IPR has started to become more acceptable as it is slowly implemented across the world to compensate for water shortages due to a magnitude of differing reasons. As technology and science advance, the public has begun to recognize the benefits they are able to reap by taking advantage of this sustainable technology. Unfortunately, DPR has not had the same sense of successful implementation. While the technology is available, the public has not been as receptive to consuming water they know has recently come from a WRRP and have a general concern regarding the presence of harmful pathogens. A community that struggles with water scarcity and is familiar with the concept of recycling would likely be easier to convince than one with no prior knowledge on the benefits.

The way we approach water reclamation now and how receptive people are will determine its future success. Cloudcroft, NM, has implemented a DPR process that blends the treated water with well water so that it composes no more than 50% of the total flow, helping to dilute any possible contaminants. El Paso, Texas is currently in the process of creating their own DPR, using entirely treated effluent and therefore relying entirely on its treatment processes to keep the water up to standards, and a feat that has not yet been taken on by another treatment facility. Such a DPR system has the potential to benefit local communities, and when introduced to a receptive community, could be a testimony of the feasibility and safety of water reuse.

ii. Selecting the Location

The struggle over the water from the Colorado River demonstrates the severity of the consequences that come with a drought. “This has led to exploitation of local ecosystems and a changing of the habitat to a degree where these adjacent states in particular will face more extreme and sustained droughts in the coming years, leading to thorny political and legal conflicts over distribution.” (Fuller & Harhay, 2010, p. 2) This means that New Mexico, Texas, and the other southwestern states could really benefit from a more sustainable water source. As their water levels continue to decrease, this makes them all viable candidates for DPR reuse systems. “With the Southwestern United States’ growing populations dependent on limited natural water sources, the region’s water situation and thus equitable distribution is increasingly challenged by demographic trends, such as heavy migration and attendant city growth to states like New Mexico and Arizona.” (Fuller & Harhay, 2010, p. 2) New Mexico’s citizens, already having the DPR system that mixes dilutes reused water before treatment with freshwater, may be more willing to take that water reuse a step further to the DPR that treats their wastewater without additional dilution.

The city of Carlsbad, NM, represented by the red star in Figure 8, lies a little under 100 miles to the southeast of Cloudcroft, represented by the yellow triangle.

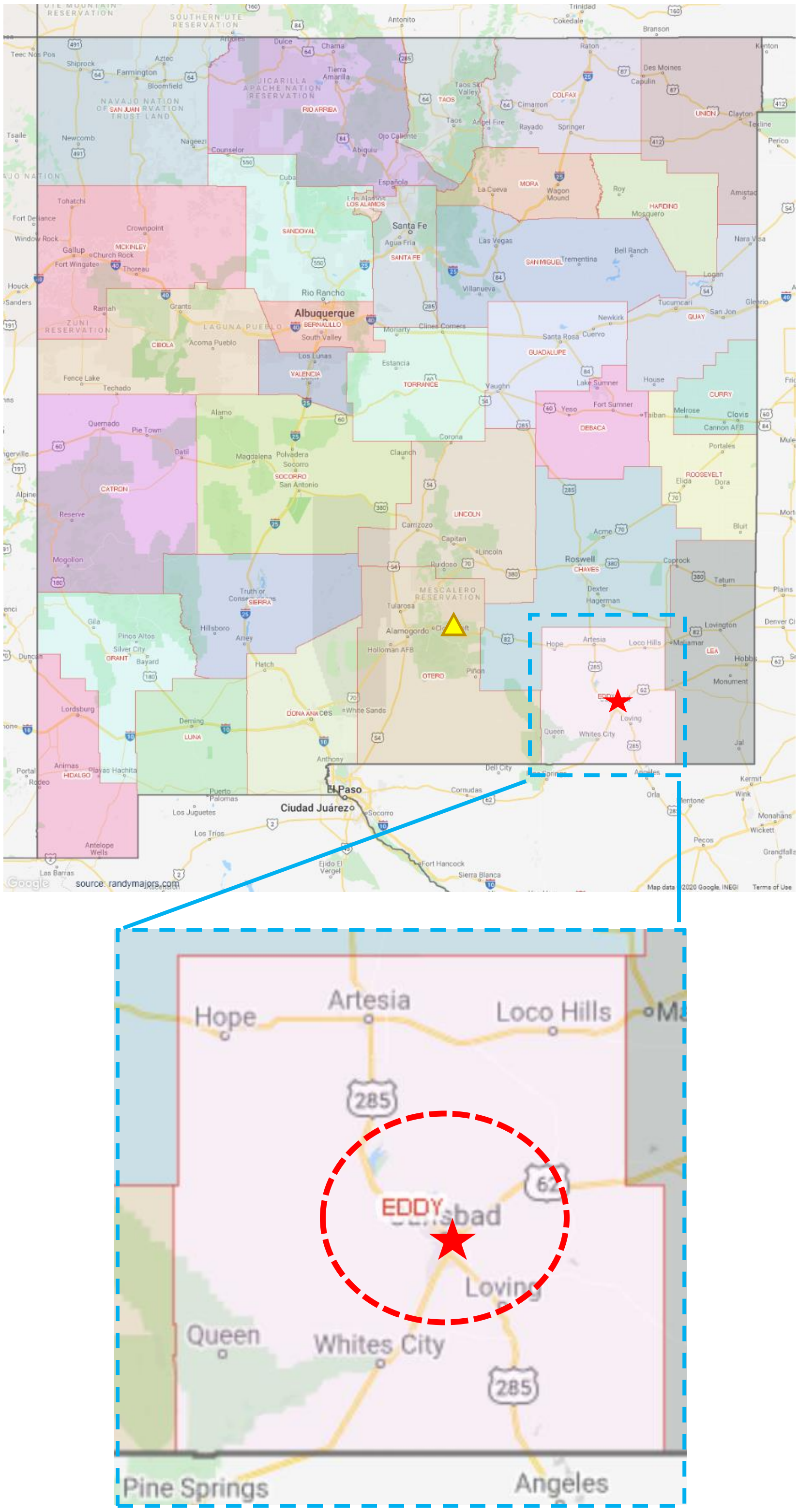

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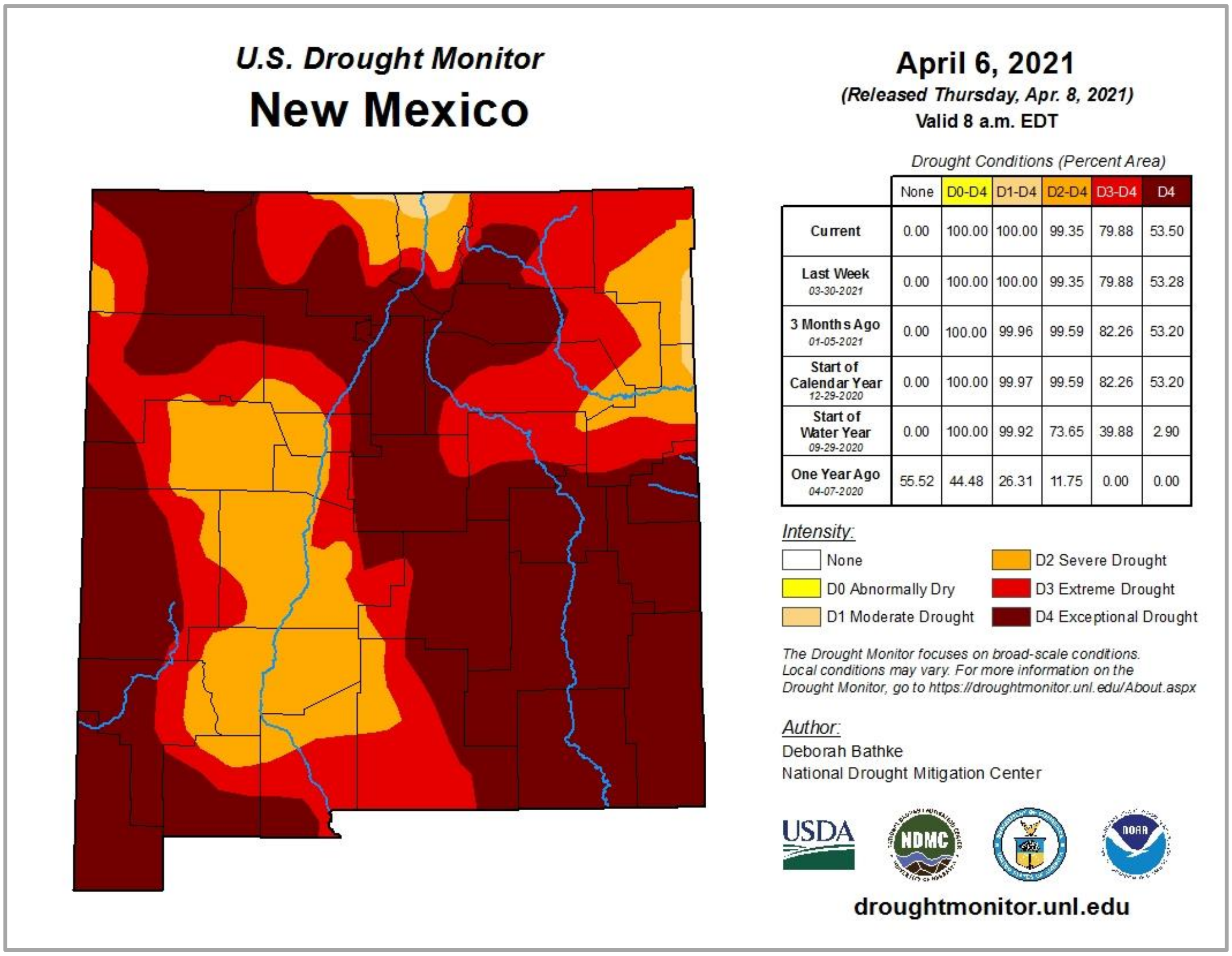
Figure 8. The city of Cloudcroft, NM (yellow triangle), and city of Carlsbad in Eddy County, NM (red star) (US Census Bureau & Office of National Statistics, 2021).



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	100.00	99.35	79.88	53.50
Last Week 03-30-2021	0.00	100.00	100.00	99.35	79.88	53.28
3 Months Ago 01-05-2021	0.00	100.00	99.96	99.59	82.26	53.20
Start of Calendar Year 12-29-2020	0.00	100.00	99.97	99.59	82.26	53.20
Start of Water Year 09-29-2020	0.00	100.00	99.92	73.65	39.88	2.90
One Year Ago 04-07-2020	55.52	44.48	26.31	11.75	0.00	0.00

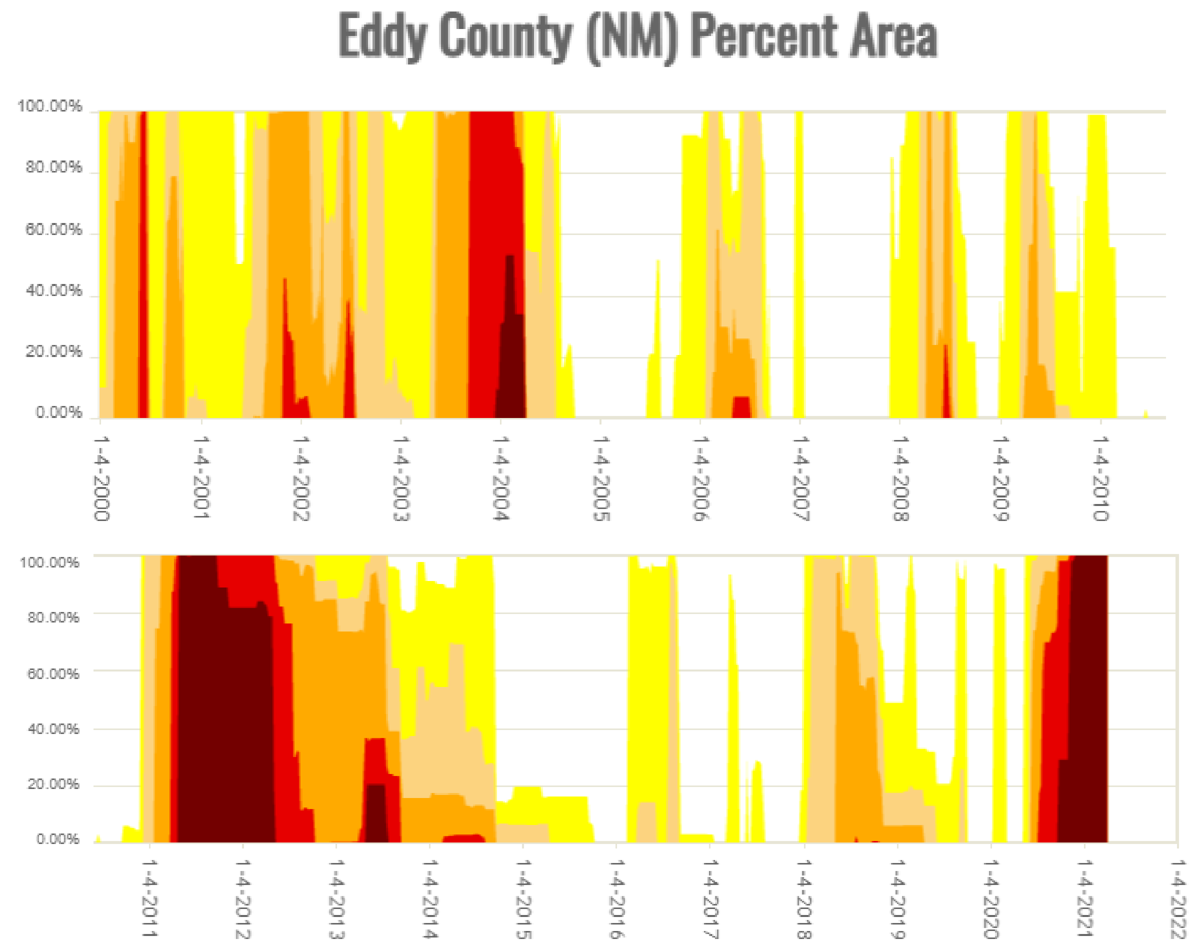
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. For more information on the Drought Monitor, go to https://droughtmonitor.unl.edu/About.aspx

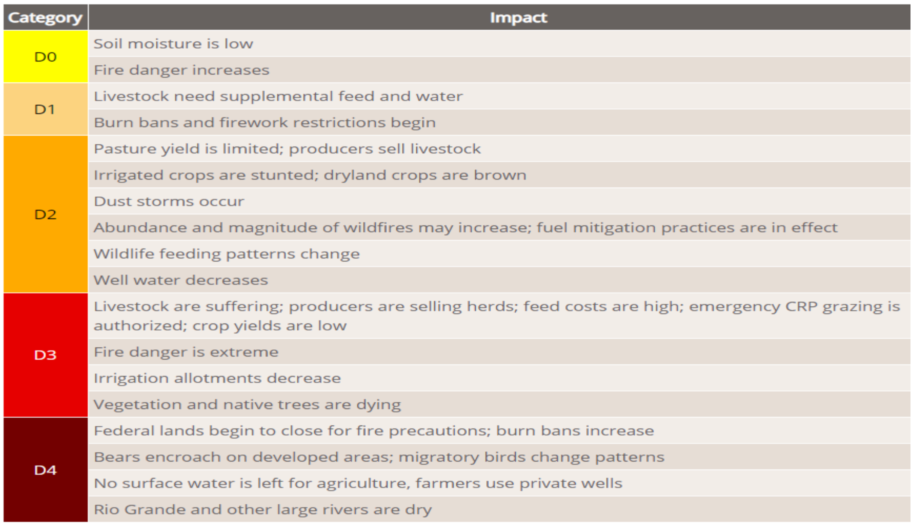
Author:
Deborah Bathke
National Drought Mitigation Center

droughtmonitor.unl.edu

Figure 9. U.S. Drought Monitor: New Mexico. (US Census Bureau & Office of National Statistics) Droughts can be seen across the state, but especially in the Southeastern states, including Eddy County. This shows the severity of the drought across New Mexico, and demonstrates similar struggles to that of their neighboring Southwestern states.

Figure *10* shows the drought history of Eddy County, where Carlsbad is located, starting in January of 2000 to present, as of April 6th, 2021 (US Census Bureau & Office of National Statistics, 2021). About every 10 years, the state experience a significant drought and the data suggests that one is currently taking place.





Category	Impact
D0	Soil moisture is low
	Fire danger increases
D1	Livestock need supplemental feed and water
	Burn bans and firework restrictions begin
D2	Pasture yield is limited; producers sell livestock
	Irrigated crops are stunted; dryland crops are brown
	Dust storms occur
	Abundance and magnitude of wildfires may increase; fuel mitigation practices are in effect
	Wildlife feeding patterns change
	Well water decreases
D3	Livestock are suffering; producers are selling herds; feed costs are high; emergency CRP grazing is authorized; crop yields are low
	Fire danger is extreme
	Irrigation allotments decrease
	Vegetation and native trees are dying
D4	Federal lands begin to close for fire precautions; burn bans increase
	Bears encroach on developed areas; migratory birds change patterns
	No surface water is left for agriculture, farmers use private wells
	Rio Grande and other large rivers are dry

Figure 10. Eddy County, where the city of Carlsbad is located, has a regular, extreme drought about every 10 years, on average. (The National Drought Mitigation Center, 2021) The Impact table demonstrates the meaning of each color and category.

This state struggles not only with a regular drought period, but with rising temperatures as well.

Figure *11* shows the trend of rising summer temperatures in New Mexico, with recent spikes to be seen in 2010. These increasing temperatures will only further deplete the already strained water resource system in Carlsbad, making it the perfect candidate for a DPR system.

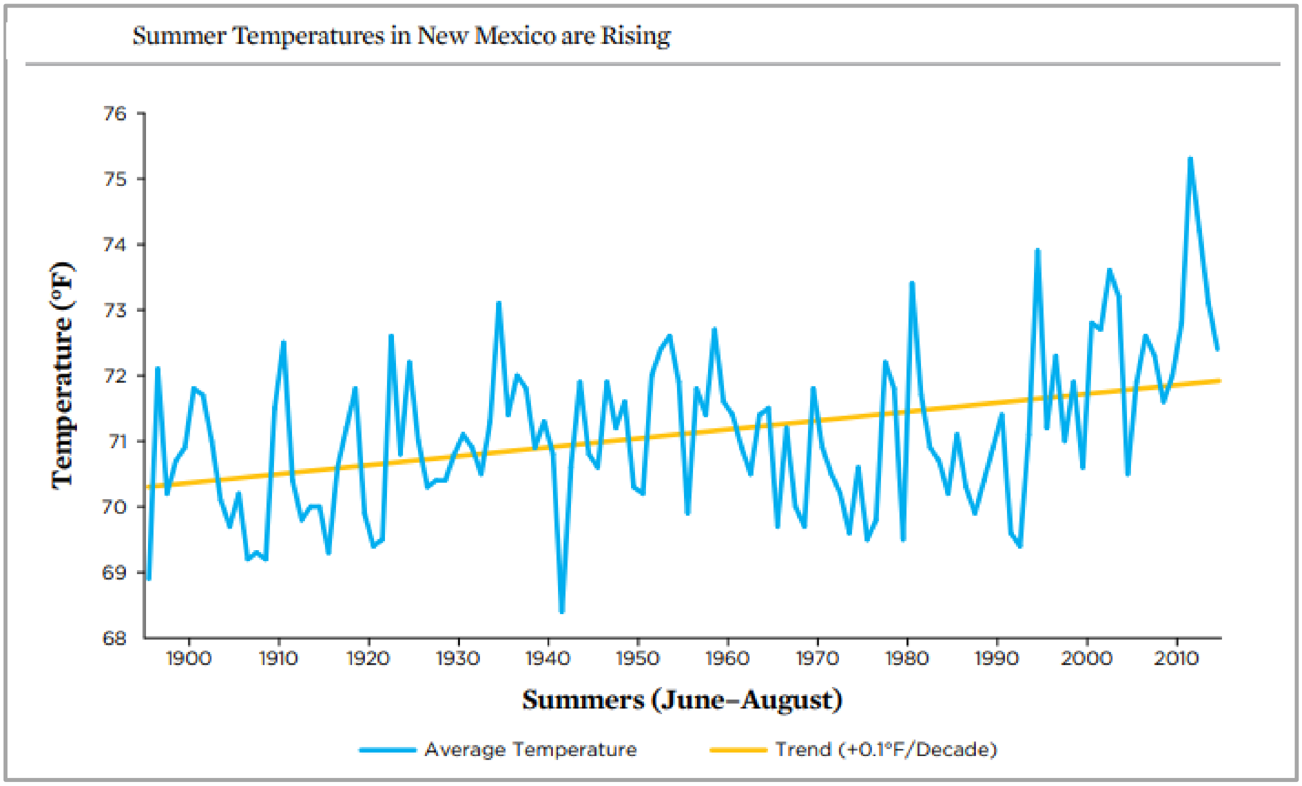


Figure 11. The summer temperatures in New Mexico vary, but have shown a consistent warming trend, through the months of June through August, and have a trend of 0.1 degree Farenheit increase, per decade. (Confronting Climate Change in New Mexico, 2016)

People tend to be more likely to consider an alternative when they are running out of options. The trends seen in population growth, regular droughts, and increasing temperatures are all contributors to the growing desperation for water in the state. Suggesting a DPR system to the community during a time of drought would be a good time to remind people of how desperate the situation is and get them on board, with time to build the system and have it ready to go during the next serious drought. Based on past trends of droughts, there is likely to be one in 2030 as there tends to be one every 10 years. If planned efficiently, the system could be ready for that drought.

Chapter 3: Water Reclamation Application: A Case Study in Carlsbad, NM

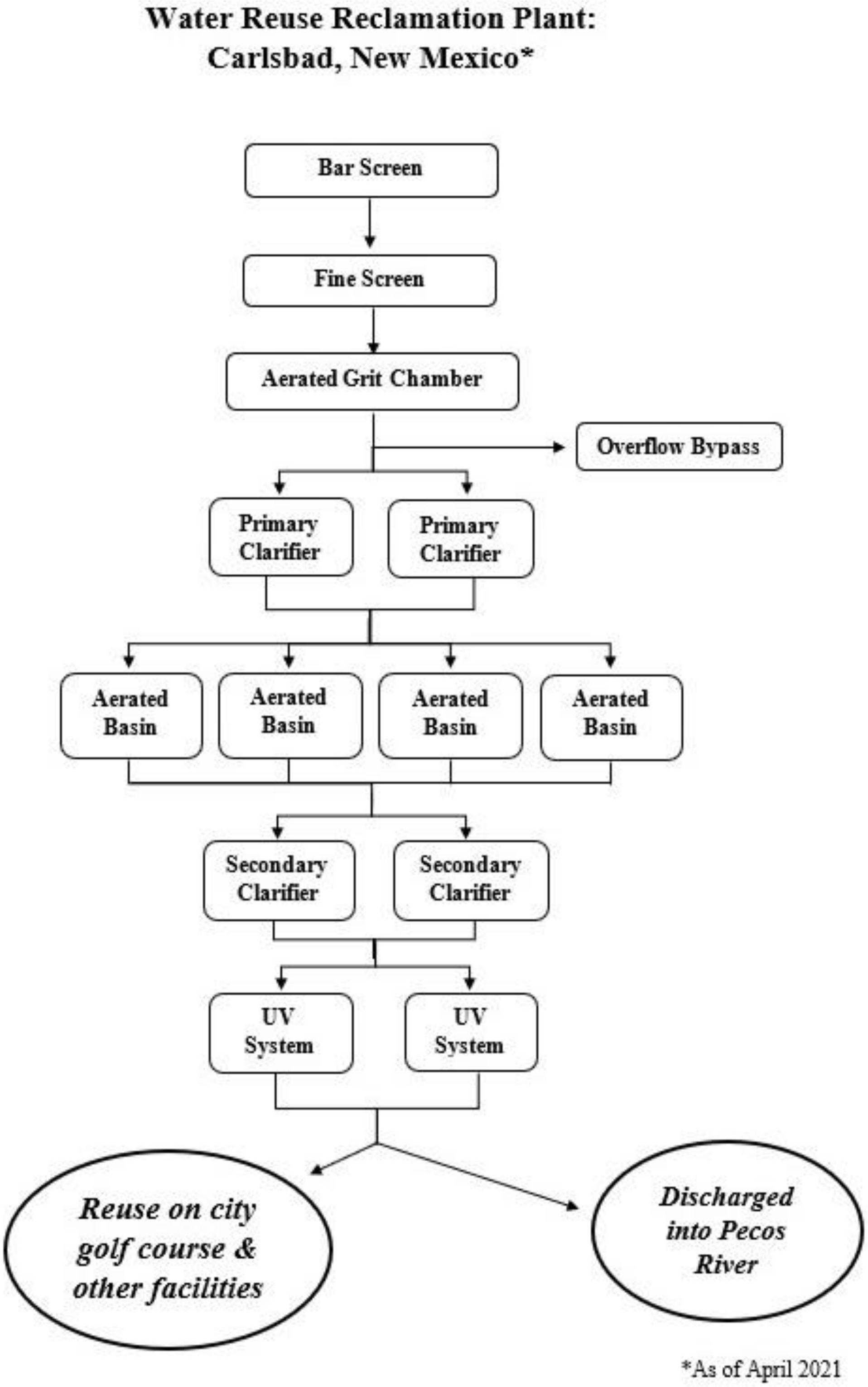
I. Current treatment in place

The city of Carlsbad currently uses the Carlsbad Wastewater Treatment Plant (hereafter referred to as the Carlsbad Water Resource Reclamation Plant (CWRRP)) for their wastewater treatment is seen in Figure 12.

Influent entering the plant first goes through a bar screen to separate out any large debris and then a fine screen to separate any remaining debris. From there the wastewater goes through an aerated grit chamber to further remove heavier particles. Primary clarifiers then remove more solids and prepare the water for biological treatment in the aerated basins. The aerated basins have anoxic and aerobic zones for nitrogen removal. Secondary clarifiers remove any leftover solids from the biological process. The water is then disinfected with UV and discharged into the Pecos River or reused on the city golf course and other facilities, an example of direct non potable use.

Sludge from the primary clarifiers is pumped to primary sludge digesters for anaerobic treatment. Activated sludge from the secondary clarifier is sent back to the aeration basins. When waste is necessary the sludge is dewatered through a belt thickener and sent to a landfill.

The current plant processes about 2.5 MGD of sewage but has the capacity to handle as much as 6 MGD. (Carlsbad, 2021) Based on census data from the past 20 years, a future population equation was utilized, proving that the CWRRP will be able to serve the community and its growing population for at least the next 20 years.



Water Reuse Reclamation Plant:
Carlsbad, New Mexico*

*As of April 2021

Figure 12. Current Water Reuse Reclamation Plant in Carlsbad, NM. At present, the treated effluent is used for reuse on some city properties. Ultimately, the rest of the water is discharged into the Pecos River.

i. Double Eagle Water System

The Carlsbad Municipal Water System is owned and operated by the city of Carlsbad. The city has two sources of municipal water: the Sheep Draw Well Field primarily, along with the Double Eagle Water System (DEWS). "Information from the Eddy County 40-year water plan indicates the Sheeps Draw Well Field is susceptible to drought and would result in water shortages for the City of Carlsbad." (United States Department of the Interior BLM, 2011) Concern for the lack of available water in the area and the expected depletion of the Sheep Draw Well Field pushed the city to expand their utilization of the DEWS.

The Double Eagle Water System is a water distribution system that draws from wells, originally designed for commercial and industry use, and therefore was equipped with pipes 12 inches in diameter or less and a roundabout route in the area it was established. Entirely reconstructed and finished towards the end of 2020, the new system delivers water to the people of Carlsbad in 24" diameter pipes on a direct route. The Double Eagle system is to work side-by-side with the Sheep Draw Water System to meet the city's needs. According to Onsurez (2018), this doubles the capacity for water delivery in Carlsbad from its current 3 MGD to 6 MGD, with the project totaling around $40 million.

The City of Carlsbad (2014) also states that it has plans to eventually involve the Tatum water system as well, which is north of the Double Eagle System. The Tatum system is believed to have the capacity to produce significantly more water than the Double Eagle system, and the hope is that it is development will secure Carlsbad's water production ability into the distant future and allow for planned growth.

While no specific plans have been published in regard to the Tatum system project, it demonstrates the city of Carlsbad's growing need for accessible potable water. The Double Eagle

Water System project cost the city $40 million, and it still is not a sustainable enough source to satisfy all of the future needs for Carlsbad. A sustainable DPR system would prevent the city from needing to expand their facilities farther outside of city lines, saving money on infrastructure and building costs. The CWRRP is located within city limits, providing an opportunity to minimize the distance the water would need to travel and reducing the need to lay further piping on land the city would need permits for.

ii. Reuse strategies practiced

The current WRRP produces compost from wasted sludge. Using special equipment, the sludge is dried out, stockpiled, and prepared to compost, meeting the top class of pathogen reduction requirements. The composted sludge is used on city properties and given away to the public. (Surface Water Quality Bureau, 2016, p. 6) The compost has been tested and proven to meet the strictest USEPA limits for heavy metals content. This allows for unrestricted use of the compost for any horticultural purpose. (Carlsbad, 2021)

This would suggest that the community of Carlsbad already understands that implementing a standard of reuse for their wastewater and its byproduct has the potential for benefit. Figure 12 shows that a portion of the effluent from the CWRRP is saved to be reused on facilities like the city golf course, while the rest is discharged into the Pecos River. If there are individuals willing to take advantage of composted sludge from their local WWTP on a regular basis and are comfortable with their wastewater effluent being used to irrigate sports and recreational areas, it is likely to think their opposition to DPR would be lower than that of a community without prior experience recycling wastewater.

II. Changes proposed

i. Technical Implementation Information

While the majority of the current WRRP will remain the same with a few additions, the staff will need to be larger. “The staff should include more instrument technicians, computer programmers, and mechanics than a typical water/wastewater treatment plant.” (Davis, 2019, p. 1244). Additional staff will be necessary to run this plant.

One of the challenges of wastewater reuse is the diversity of options. Plant design should reflect the needs of the community in which it will serve; there is no cookie-cutter solution for wastewater reuse. Each location comes with a different community, culture, climate, economy, and so on.

The Environmental Working Group (EWG) performed an evaluation on the city of Carlsbad’s tap water and found the following contaminants to be within legal limits, but not within safe limits. The level of those contaminants in comparison to EWG’s Health Guideline Limits is seen in Table 1.

<table>
<tr><th colspan="2"><i>Carlsbad Municipal Water System</i></th></tr>
<tr><th colspan="2">Concentration of Contaminants Identified in Tap Water from 2012-17</th></tr>
<tr><th>Contaminant Detected</th><th>Above EWG’s Health Guideline Limits</th></tr>
<tr><td>Arsenic</td><td>931x</td></tr>
<tr><td>Bromodichloromethane</td><td>7x</td></tr>
<tr><td>Bromoform</td><td>3.7x</td></tr>
<tr><td>Chromium (hexavalent)</td><td>19x</td></tr>
<tr><td>Dibromo acetic acid</td><td>8.3x</td></tr>
<tr><td>Dibromochloromethane</td><td>12x</td></tr>
<tr><td>Halo acetic acids (HAA5)</td><td>3.7x</td></tr>
<tr><td>Nitrate and nitrite</td><td>13x</td></tr>
<tr><td>Radium, combined (-226 & -228)</td><td>2x</td></tr>
<tr><td>Total trihalomethanes (TTHMs)</td><td>23x</td></tr>
</table>

Table 1. The EWG Tap Water Database Concentration of Contaminants in Carlsbad, NM. (EWG's Tap Water Database, 2019) Though all contaminants are in the legal limit, the table above demonstrates that these containments are not within recommended drinking standards, by EWG’s standards.

The EWG Tap Water Database (2019) shows that all contaminants can be reduced using reverse osmosis. Converting the WRRP in Carlsbad, NM into a DPR system would be feasible without the need to modify the system until after the secondary clarifier. Putting a Reverse Osmosis (RO) system in between the secondary clarifier and the UV treatment removes salts and organic chemicals, providing a barrier for microorganisms. After the last step of the current process, which is UV, the system would progress onto the same treatment practices as that of their drinking water: filtration and chlorination. This design will add those two processes to the end of the current WRRP, as the current water treatment plant in Carlsbad is not equipped to handle the additional flow of the WRRP.

An ultrafiltration system will need to be added as well. “Membrane filters, such as and ultrafiltration (UF), exhibit pore sizes in the range from 0.08 to 2 mm for MF and 0.005 to 0.2 mm for UF, [in comparison to 10 to 30 m or larger for surface filtration.]” . (National Research Council (U.S.), 2012, pp. 72-73) The current WRRP does not use Chlorination, so that process will need to be added, for residual disinfection. This final barrier to microorganisms lasts until the water reaches homes and businesses.

Figure 13 shows the proposed DPR system for Carlsbad. The following processes will need to be added: multimedia filtration, ultrafiltration, reverse osmosis, activated carbon, and chlorination. All calculations are shown in Appendix A.

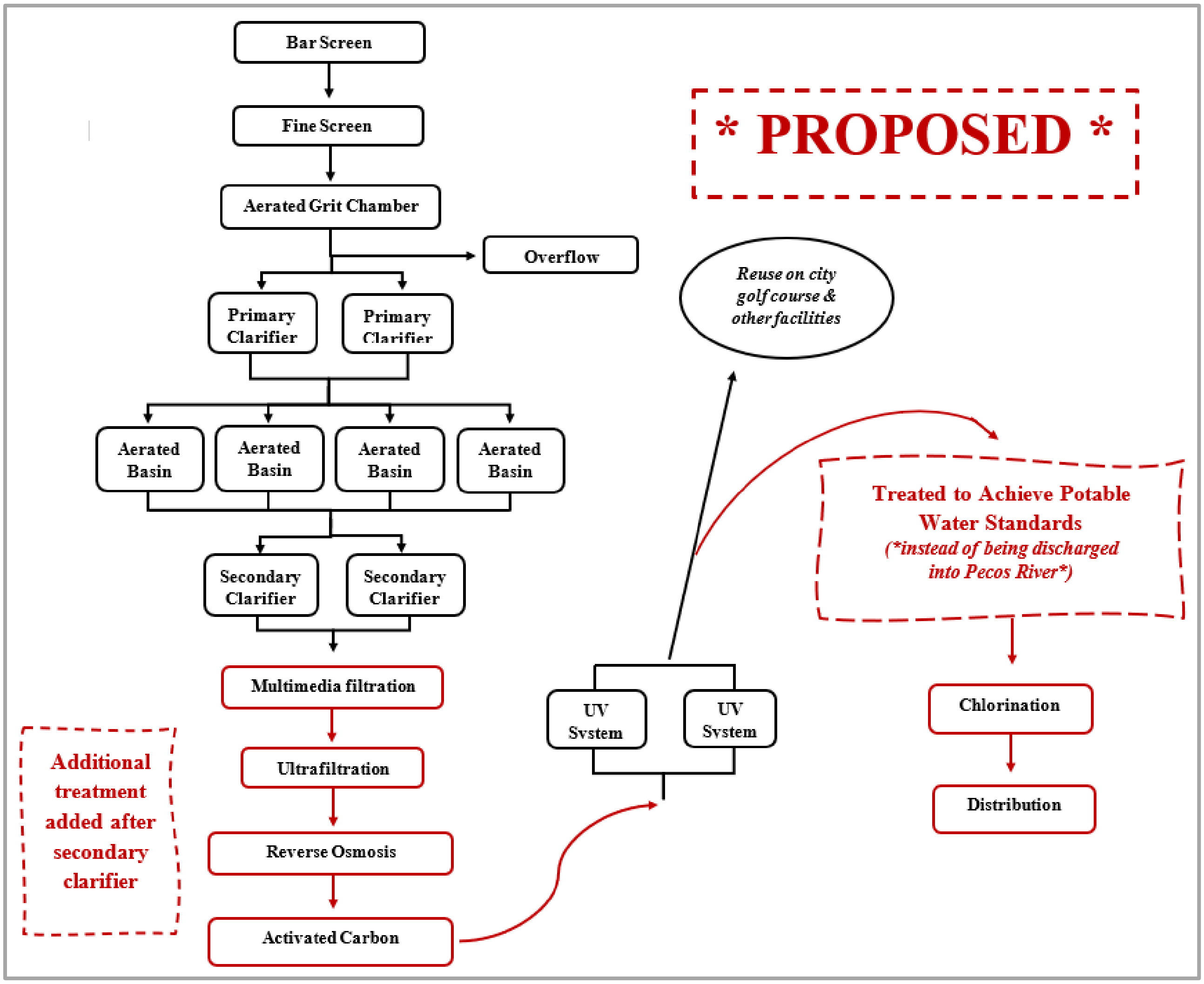
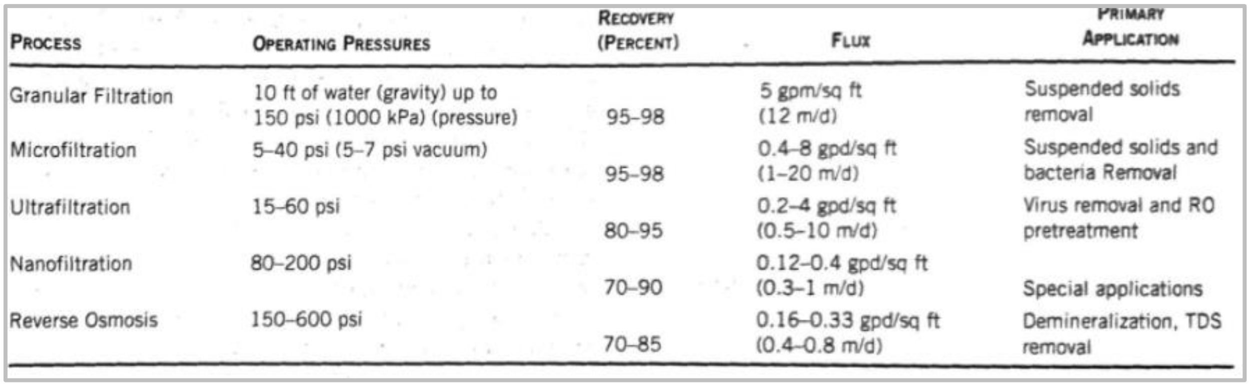


Figure 13. The proposed Direct Potable Reuse facility for Carlsbad, NM. By adding a few advanced processes onto the current WRRP, such as ultrafiltration, reverse osmosis, and chlorination, the wastewater is able to be treated to potable standards.

Table 2 summarizes the criteria used to the designs of the multi-media filters, ultrafiltration, reverse osmosis systems.



PROCESS	OPERATING PRESSURES	RECOVERY (PERCENT)	FLUX	PRIMARY APPLICATION
Granular Filtration	10 ft of water (gravity) up to 150 psi (1000 kPa) (pressure)	95–98	5 gpm/sq ft (12 m/d)	Suspended solids removal
Microfiltration	5–40 psi (5–7 psi vacuum)	95–98	0.4–8 gpd/sq ft (1–20 m/d)	Suspended solids and bacteria Removal
Ultrafiltration	15–60 psi	80–95	0.2–4 gpd/sq ft (0.5–10 m/d)	Virus removal and RO pretreatment
Nanofiltration	80–200 psi	70–90	0.12–0.4 gpd/sq ft (0.3–1 m/d)	Special applications
Reverse Osmosis	150–600 psi	70–85	0.16–0.33 gpd/sq ft (0.4–0.8 m/d)	Demineralization, TDS removal

Table 2. Various design criteria and applications for filtration. (Davis 2019) For this project, the specifications for granular filtration, ultrafiltration, and reverse osmosis were used in the calculations for designing the plant.

a) Multimedia Filtration

For multi-media filtration, five 12’ x 24’ filters will be used. Figure 14 shows an example of the typical cross section layers for a filter. Three of the filters are necessary based on the surface area required, but there will be two additional filtration units to allow for continuous operation when backwashing is taking place.

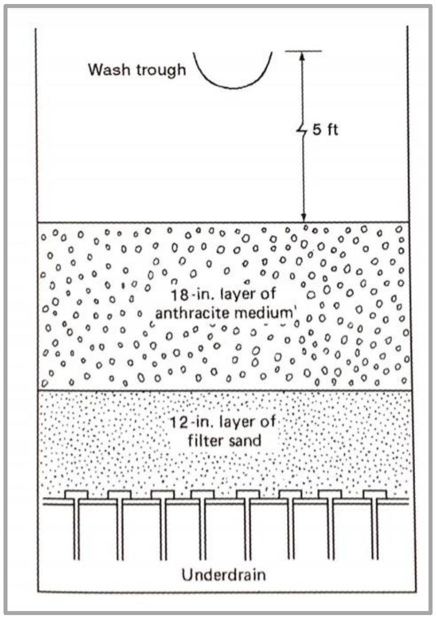


Figure 14. Example of cross-sections in a multi-media filter that will be used in the Carlsbad DPR facility, prior to ultrafiltration and reverse osmosis. (Hammer & Hammer, 1996)

b) Ultrafiltration (UF)

This unit is necessary before reverse osmosis to catch any last contaminants that might cause clogging our fouling in the RO unit. The UF unit will operate based on a membrane area of 50 m^2 per module. The total membrane area required comes to about 102,000 ft^2 and will require a total of about 200 filtrations cylinders, also known as modules.

c) Reverse Osmosis (RO)

Figure 15 gives a simplified version of the reverse osmosis process. With saline water on one side, and fresh water on the other, the water is pushed at high rates of pressure through a semipermeable membrane, leaving the salt and unwanted contaminants behind.

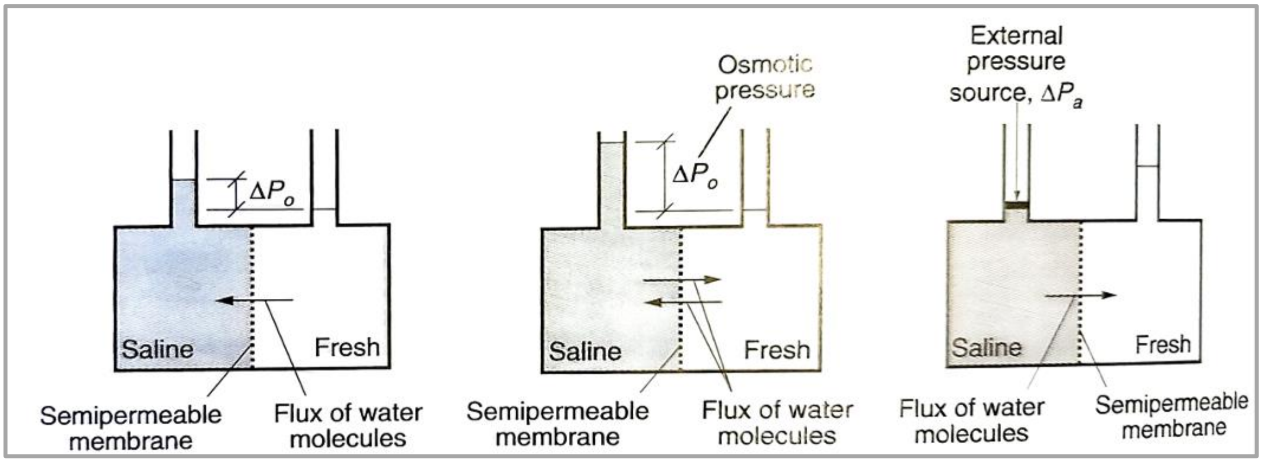


Figure 15. A simplification of the three steps of the reverse osmosis process that will be used in the Carlsbad DPR facility. (Davis 2019) Through the use of osmotic pressure, freshwater is separated for further treatment.

An example of a reverse osmosis membrane is shown in *Figure 16*, showing the way the membrane is wrapped around in layers. The RO system here will require around 8,600,000 ft^2 of this membrane. Based on other RO units, this would require about 16,000 cylinders to house the membrane.

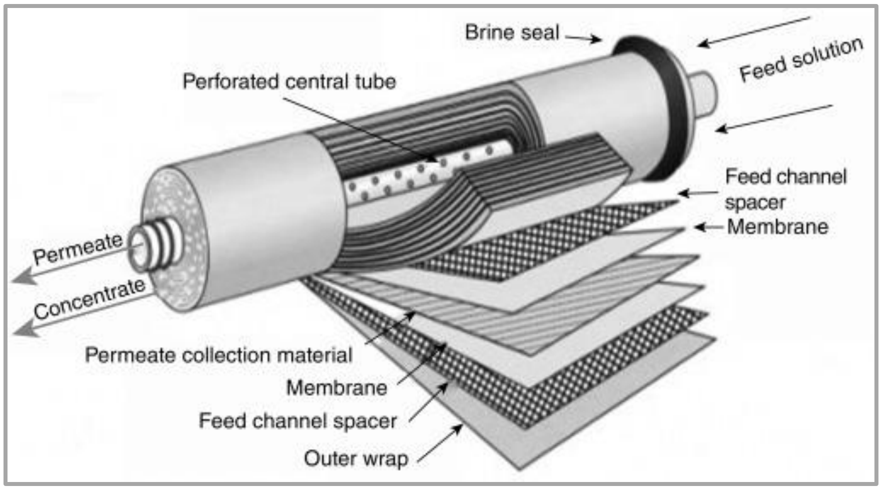


Figure 16. A reverse osmosis membrane cross section, similar to the one that would be used for the DPR facility. (Maynard & Whapham, 2020) While the total area required for the membrane is over 8,000,000 ft^2, it can be seen in the figure that the membrane is wrapped several times around each cylinder.

d) Activated Carbon

In a typical system, many types of activated carbon are available. To determine the appropriate retention bedtime and flux, the break-through lab test should be run. In this case, however general estimates were used. While many sizes of cylinders exist, typical cylinders that can be shipped in and don’t need to be put together on site are 8’ to 10’ in diameter. In this case, for ease of transportation purposes, a 10’ diameter and 12’ height was chosen. Therefore, a total of 16 carbon cylinders will be needed for treatment.

e) Chlorination

For chlorination, a typical treatment dosage in order to achieve a residual of 1 mg/L residual is 10 mg/L of chlorine. A jar test would be needed to confirm the actual doasage. All calculations were based on a pH of 7.5 and a temperature of 10 degrees Celsius. The chlorination will require a clearwell with a volume of about 75,000 m^3 and will require 12,010 pounds of chlorine every 30 days.

ii. Social Implementation Information

The most difficult part of DPR is public perception; people aren't always easily convinced that reusing wastewater is safe. Therefore, getting the support of the local community is critical. Implementing water reuse on the small scale of the community keeps the concept of water conservation on the minds of the people and keeps it as a priority.

By encouraging the community to practice water conservation habits on an individual basis, even with little things like high-efficiency showerheads and toilets, or setting up and irrigation schedule instead of watering the lawn every night, it can keep them engaged and conscious of their water use. "An analysis of 96 owner-occupied single-family homes in California, Washington, and Florida included that the installation of high-efficiency showerheads, toilets, and clothes washers reduced household use of municipal water by 10.9, 13.3, and 14.5%, respectively." (Grant, et al., 2012, p. 684) Regular reports from officials regarding the drinking water quality of the DPR facility should be made available for community members to access, helping to prove the benefits and safety of this sustainable technology.

Chapter 4: Conclusion

Water must be identified as a renewable resource to be recycled, rather than the linear "extract, use, dispose" system we employ now. Socioeconomic factors are essential in potable reuse success. Past reuse systems are proof that the backing of the community will either make or break the success of its implementation. Public perception remains the biggest roadblock in implementing DPR, but as more communities implement the technology and can testify to its safety and feasibility, hopefully others will start to catch on to its benefits

DPR and IPR are not limited by technical science, but rather by social science. While it is true that wastewater reuse was discontinued in many countries during the 1800s due to health risks, treatment technology has continued to improve since then and is at a level in which it can be successfully implemented if all factors are considered and accounted for appropriately. Facilities that do not currently practice potable water reuse can update their facilities, sometimes by simply adding on to the current system rather than needing to redesign the entire facility, especially if the facility has been updated recently.

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Appendix

Calculations for the Carlsbad Water Reuse Reclamation Plant

general info

City carlsbad

STATE New Mexico

POPULATION 31,000 people

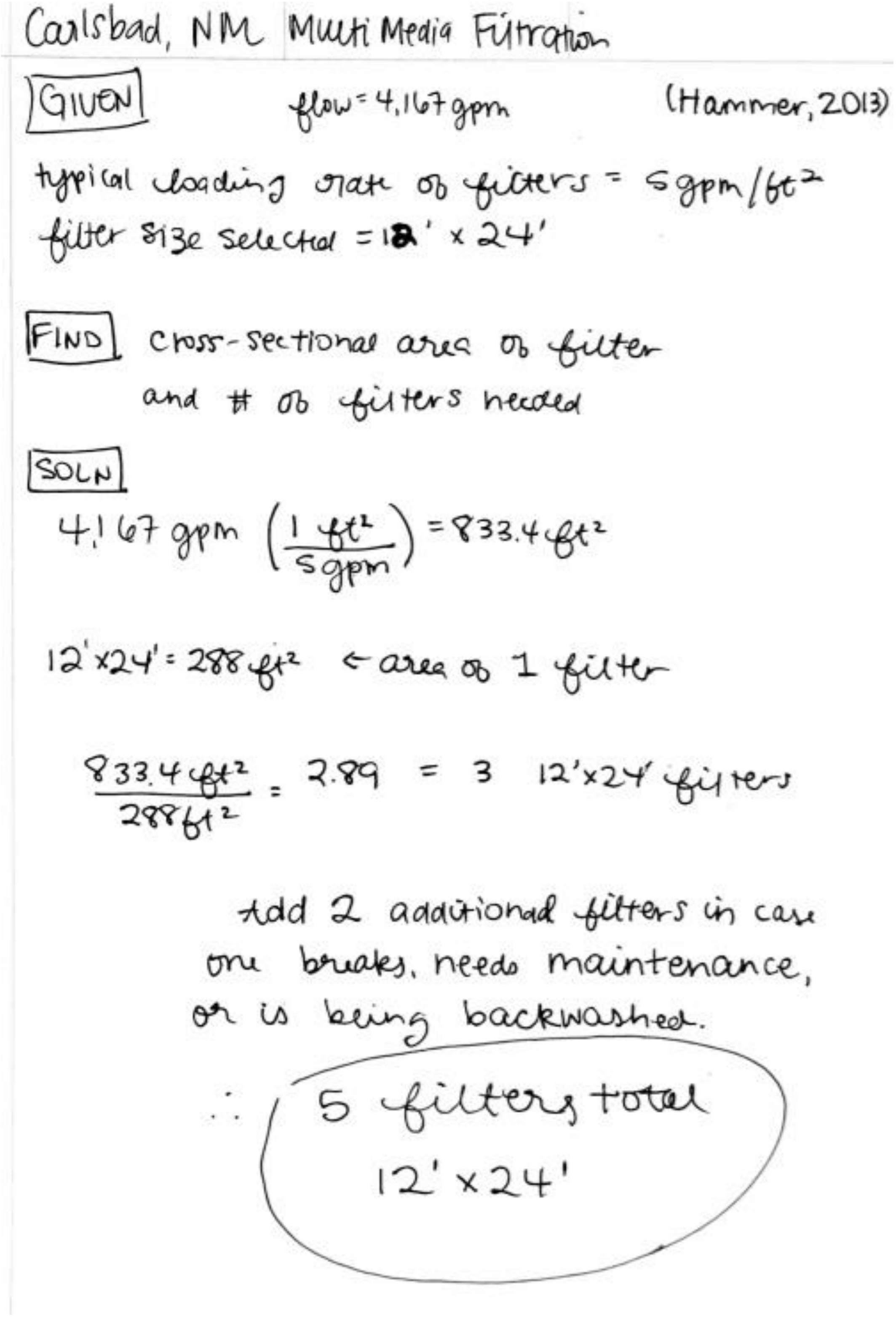
FLOW 6 MGD $\left(6{,}000{,}000 \frac{\text{gallon}}{\text{day}}\right)$

$= 557 \frac{ft^3}{min}$

$= 4{,}167 \frac{\text{gallon}}{\text{min}}$ or 4 167 gpm

$= 9.28 \frac{ft^3}{sec}$ or 9.28 cfs

Multimedia Filtration:



Carlsbad, NM Multi Media Filtration

$\boxed{\text{GIVEN}}$ flow = 4,167 gpm (Hammer, 2013)

typical loading rate of filters = 5 gpm/ft²

filter size selected = 12' x 24'

$\boxed{\text{FIND}}$ cross-sectional area of filter and # of filters needed

$\boxed{\text{SOLN}}$

$$4{,}167\ \text{gpm}\left(\frac{1\ \text{ft}^2}{5\ \text{gpm}}\right) = 833.4\ \text{ft}^2$$

$12' \times 24' = 288\ \text{ft}^2$ ← area of 1 filter

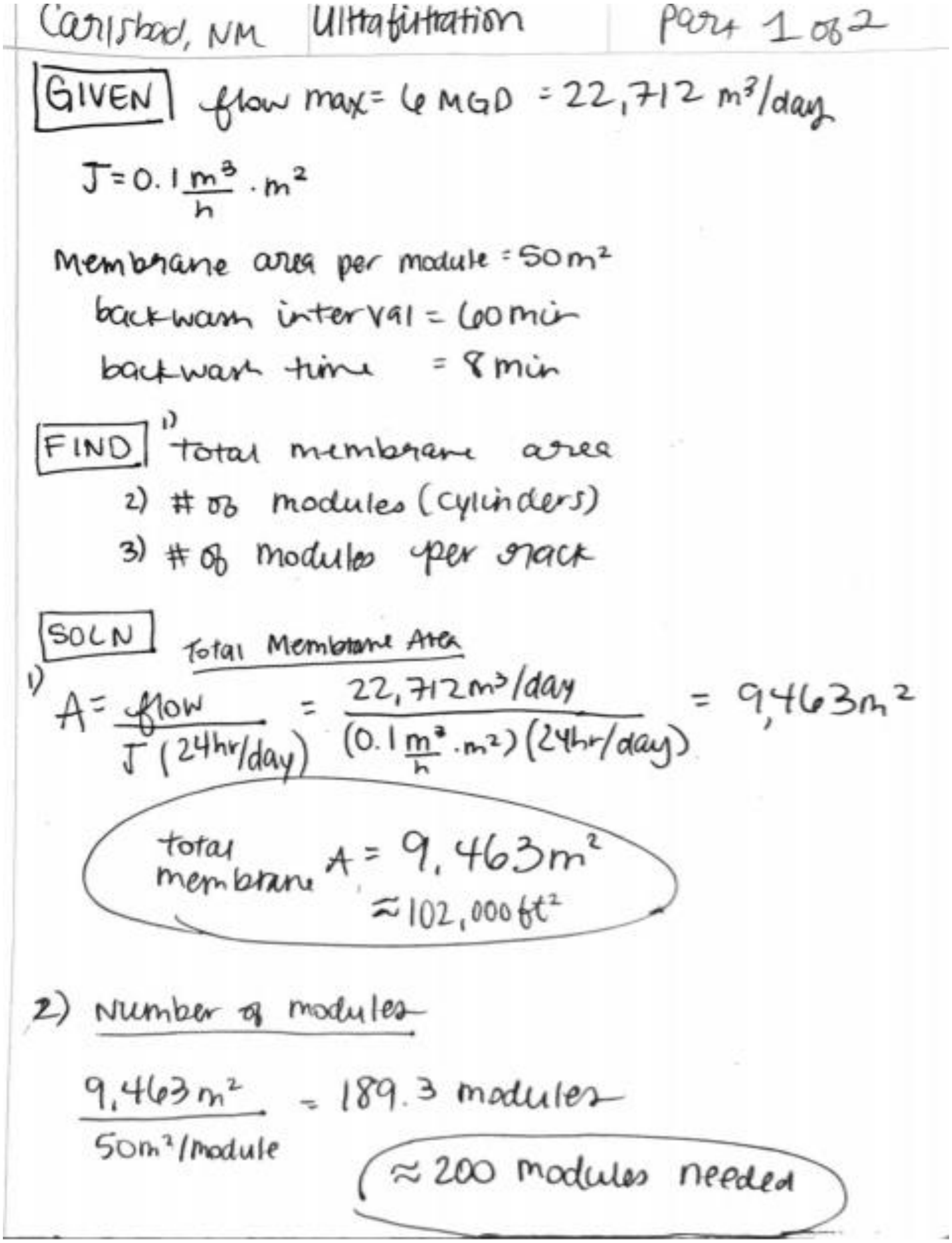
$$\frac{833.4\ \text{ft}^2}{288\ \text{ft}^2} = 2.89 = 3\ \ 12' \times 24'\ \text{filters}$$

Add 2 additional filters in case one breaks, needs maintenance, or is being backwashed.

∴ 5 filters total

12' x 24'

Ultrafiltration:



Carlsbad, NM | Ultrafiltration | part 1 of 2

GIVEN flow max = 6 MGD = 22,712 m^3/day

$J = 0.1 \frac{m^3}{h} \cdot m^2$

Membrane area per module = 50 m^2

backwash interval = 60 min

backwash time = 8 min

FIND 1) total membrane area

2) # of modules (cylinders)

3) # of modules per rack

SOLN Total Membrane Area

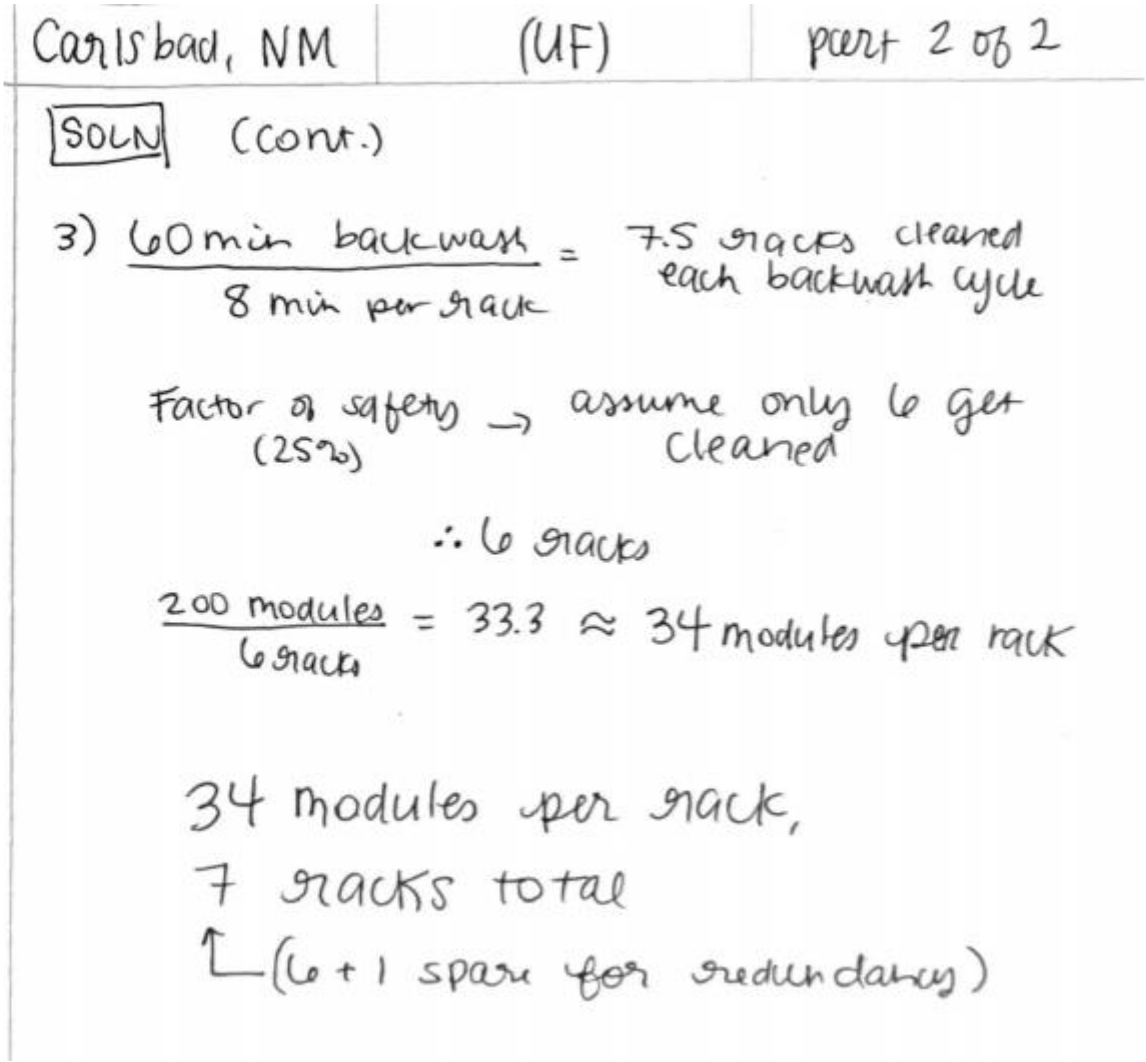
1) $A = \frac{flow}{J\,(24hr/day)} = \frac{22,712 m^3/day}{(0.1 \frac{m^3}{h} \cdot m^2)(24hr/day)} = 9,463 m^2$

$\boxed{\text{total membrane } A = 9,463 m^2 \approx 102,000 ft^2}$

2) Number of modules

$\frac{9,463 m^2}{50 m^2/module} = 189.3$ modules

$\boxed{\approx 200 \text{ modules needed}}$



Carlsbad, NM	(UF)	part 2 of 2

$\boxed{\text{SOLN}}$ (cont.)

3) $\dfrac{60 \text{ min backwash}}{8 \text{ min per rack}} =$ 7.5 racks cleaned each backwash cycle

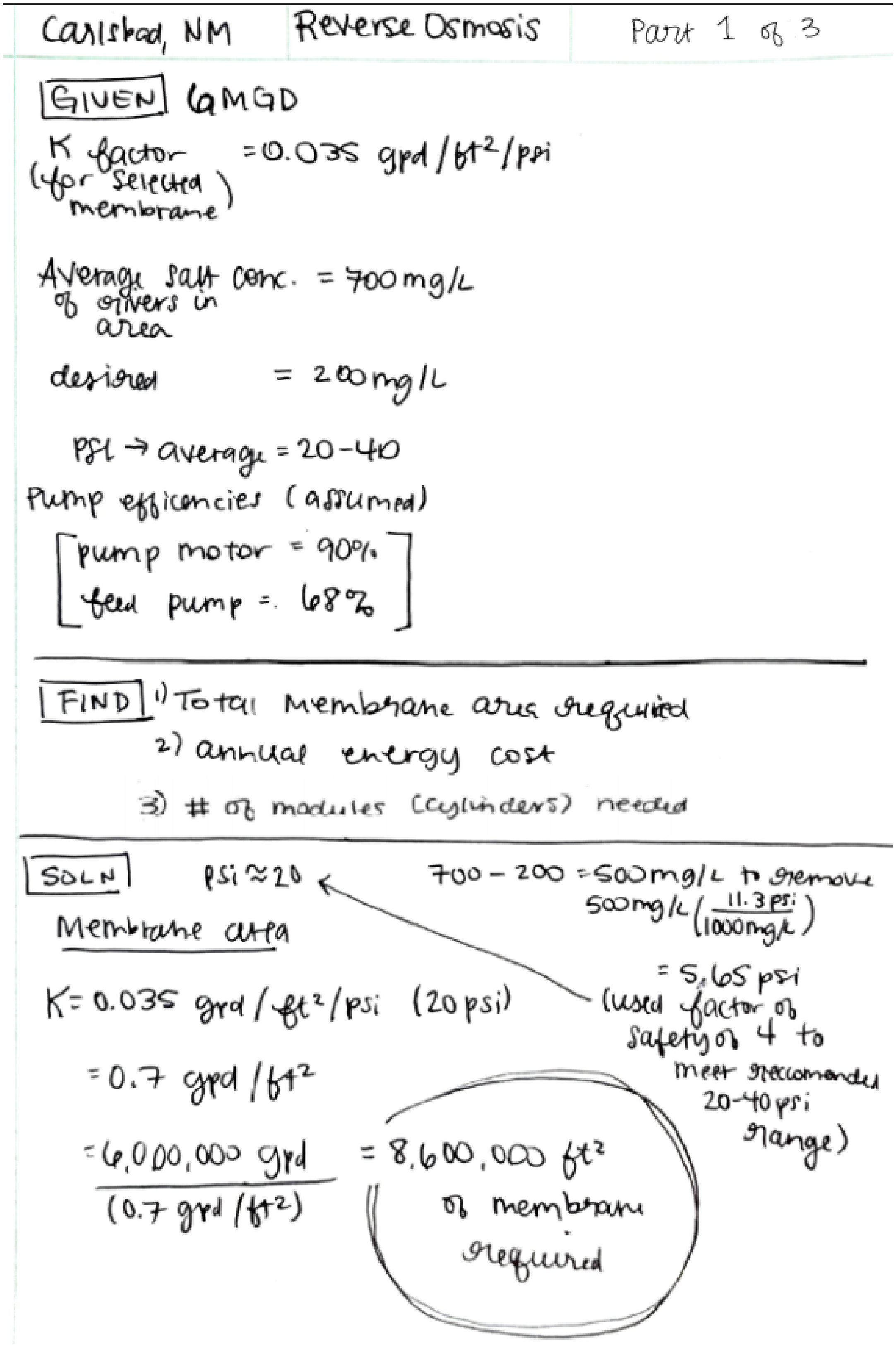
Factor of safety (25%) → assume only 6 get cleaned

∴ 6 racks

$\dfrac{200 \text{ modules}}{6 \text{ racks}} = 33.3 \approx 34$ modules per rack

34 modules per rack,
7 racks total
↳(6 + 1 spare for redundancy)

Reverse Osmosis (RO):



Carlsbad, NM | Reverse Osmosis | Part 1 of 3

GIVEN 6MGD

K factor (for selected membrane) = 0.035 gpd/ft^2/psi

Average salt conc. of rivers in area = 700 mg/L

desired = 200 mg/L

psi → average = 20-40

Pump efficiencies (assumed)

$$\begin{bmatrix} \text{pump motor} = 90\% \\ \text{feed pump} = 68\% \end{bmatrix}$$

FIND 1) Total membrane area required

2) annual energy cost

3) # of modules (cylinders) needed

SOLN psi ≈ 20

700 − 200 = 500 mg/L to remove

$500\,\text{mg/L}\left(\frac{11.3\,\text{psi}}{1000\,\text{mg/L}}\right)$

= 5.65 psi

(used factor of safety of 4 to meet reccomended 20-40 psi range)

Membrane area

K = 0.035 gpd/ft^2/psi (20 psi)

= 0.7 gpd/ft^2

$$= \frac{6{,}000{,}000\ \text{gpd}}{(0.7\ \text{gpd/ft}^2)} = 8{,}600{,}000\ \text{ft}^2$$

of membrane required

$\boxed{\text{SOLN}}$ (cont)

2) Annual energy

$$BHp = \frac{gpm \times ft^{*2}}{{}^{*1}3960 \times \text{efficency of feed pump}}$$

*1 [Conversion factor for gpm to Hp]

BHp = brake horsepower

MHp = mechanical horse power

$$MHp = \frac{BHp}{\text{efficency of motor} \rightarrow 0.9}$$

*2 [ft = feet of water in tank
= 2.31 (psi)
= 20 (2
= 46.

∴

$$BHp = \frac{4{,}167\,gpm\,(46.2\,ft)}{3960\,(.68)}$$

$$\boxed{BHp = 71.5\ Hp}$$

$$MHp = \frac{71.5\ Hp}{.9} = 79.5$$

$$\boxed{MHp = 79.5\ Hp}$$

$$\text{Kwh used yearly} = (MHp)\,(hr/yr)\left(0.745\,\frac{Kwh}{Hph}\right)$$

$$= 79.5\,Hp\,(8760\,hr/yr)\left(0.745\,\frac{Kwh}{Hph}\right)$$

$$\boxed{= 51{,}883.29\ kwh/yr}$$

Carlsbad, NM	Reverse Osmosis

part 3 of 3

3) <u>\# of modules</u>

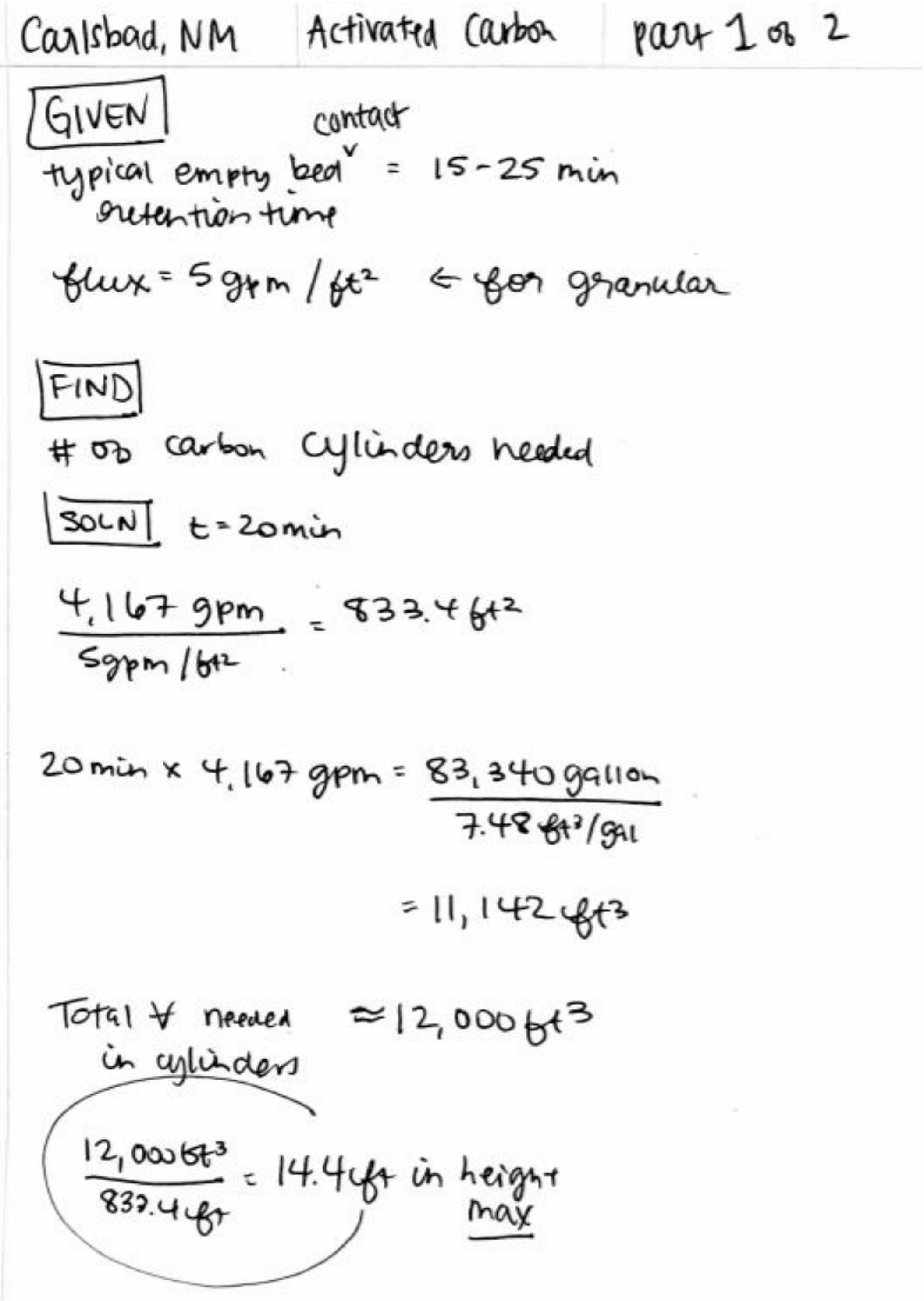
$50 m^2$/module

$8,600,000\ ft^2 = 798,966.1\ m^2$

$$\frac{798,966.1\ m^2}{50\ m^2} = 15,979.3 \text{ modules}$$

≈ 16,000 modules needed

Activated Carbon:



Carlsbad, NM | Activated Carbon | part 1 of 2

GIVEN

typical empty bed contact retention time = 15 - 25 min

flux = 5 gpm / ft² ← for granular

FIND

\# of carbon cylinders needed

SOLN t = 20 min

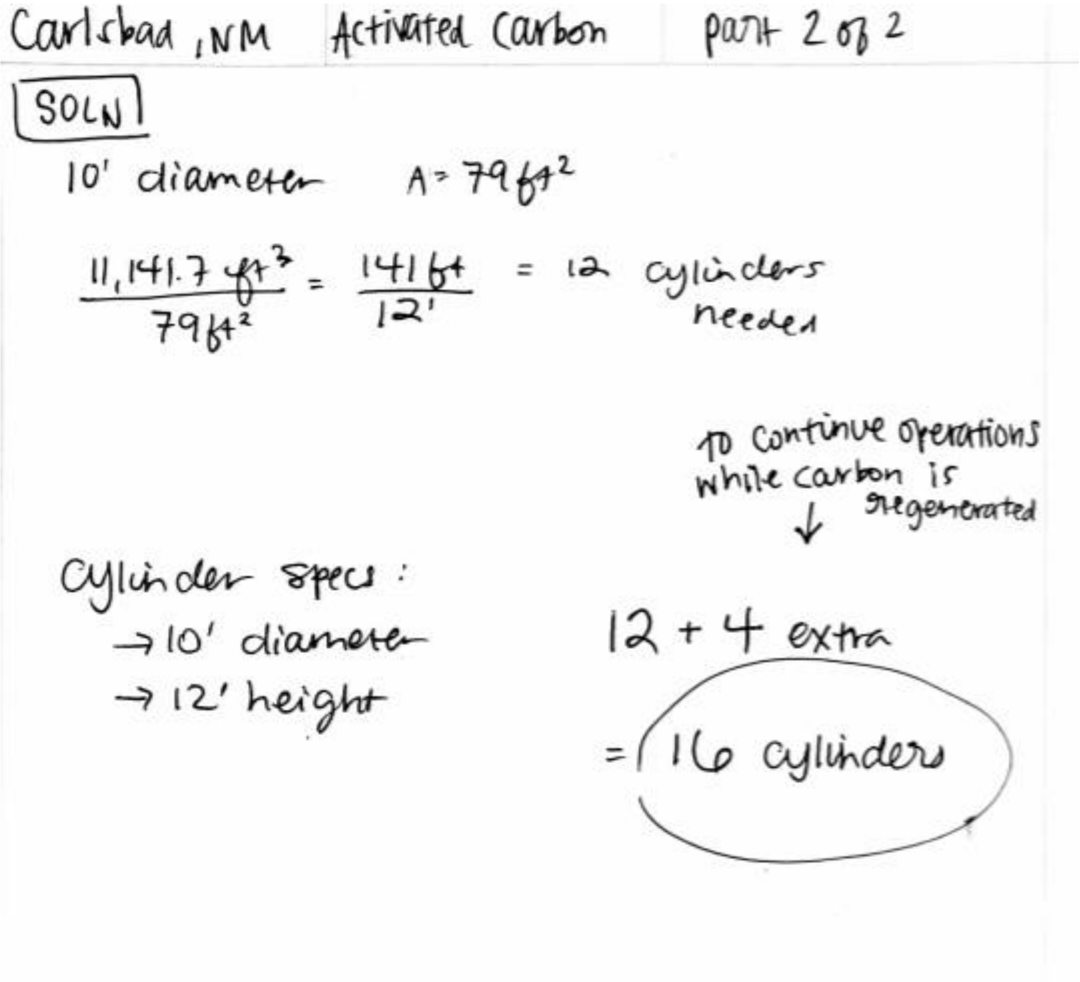
$$\frac{4,167 \text{ gpm}}{5 \text{ gpm}/\text{ft}^2} = 833.4 \text{ ft}^2$$

$$20 \text{ min} \times 4,167 \text{ gpm} = \frac{83,340 \text{ gallon}}{7.48 \text{ ft}^3/\text{gal}}$$

$$= 11,142 \text{ ft}^3$$

Total ∀ needed in cylinders ≈ 12,000 ft³

$$\frac{12,000 \text{ ft}^3}{833.4 \text{ ft}} = 14.4 \text{ ft in height } \underline{\text{max}}$$



Carlsbad, NM | Activated Carbon | part 2 of 2

SOLN

10' diameter $A = 79\ ft^2$

$$\frac{11,141.7\ ft^3}{79\ ft^2} = \frac{141\ ft}{12'} = 12 \text{ cylinders needed}$$

to continue operations while carbon is regenerated ↓

Cylinder specs:

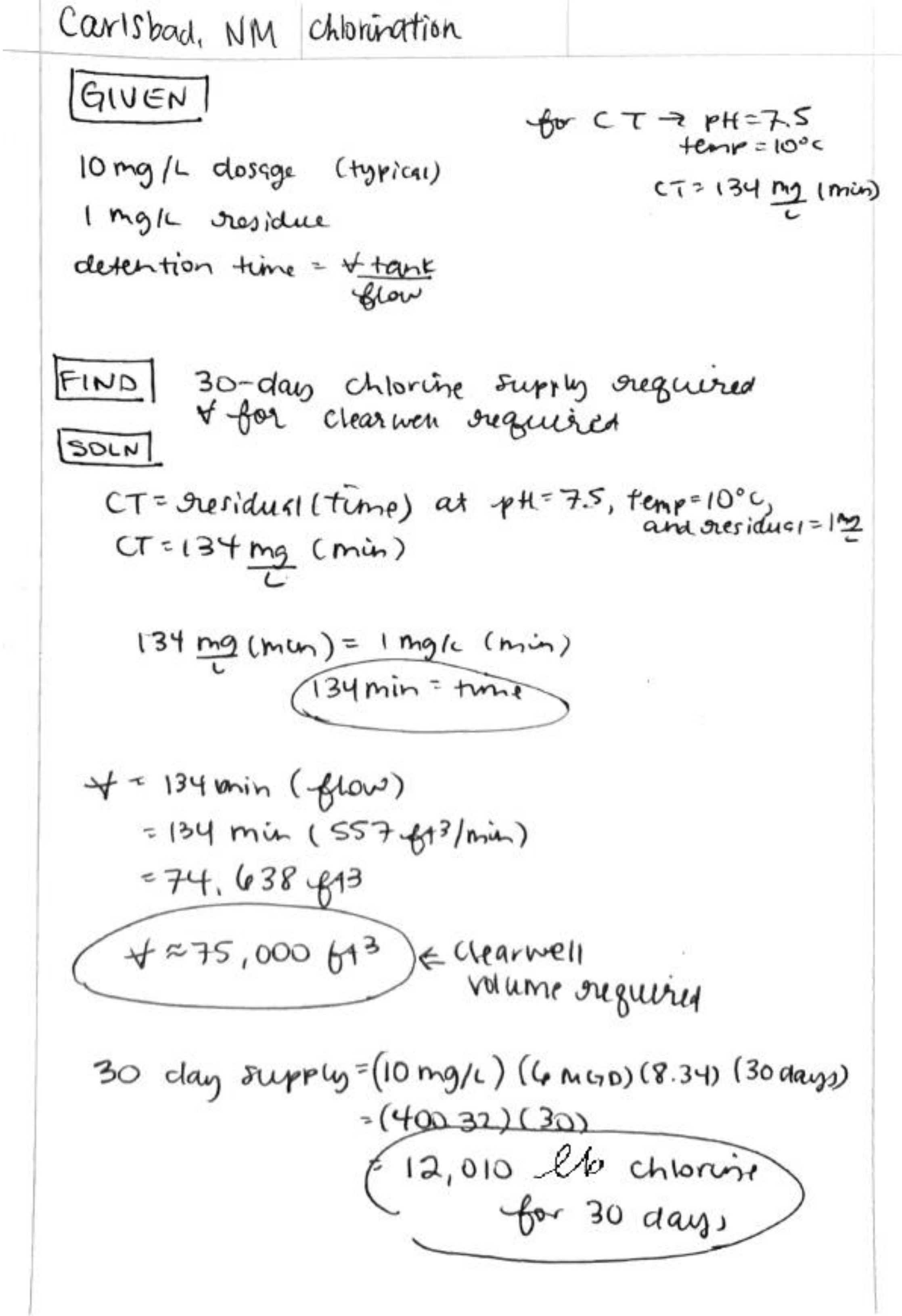
→ 10' diameter

→ 12' height

12 + 4 extra

= 16 cylinders

Chlorine:



Carlsbad, NM | chlorination

GIVEN

for CT → pH = 7.5
temp = 10°C

CT = 134 $\frac{mg}{L}$ (min)

10 mg/L dosage (typical)

1 mg/L residue

detention time = $\frac{\forall \text{ tank}}{\text{flow}}$

FIND 30-day chlorine supply required
$\forall$ for clearwell required

SOLN

CT = residual (time) at pH = 7.5, temp = 10°C, and residual = 1 $\frac{mg}{L}$

CT = 134 $\frac{mg}{L}$ (min)

134 $\frac{mg}{L}$ (min) = 1 mg/L (min)

134 min = time

$\forall$ = 134 min (flow)
= 134 min (557 ft³/min)
= 74,638 ft³

$\forall \approx$ 75,000 ft³ ← Clearwell volume required

30 day supply = (10 mg/L) (6 MGD) (8.34) (30 days)
= (400.32) (30)
= 12,010 lb chlorine for 30 days