GRAND CANYON RAILWAY BOILER WASTEWATER MANAGEMENT

Final Design Report

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Abstract

The goal of the Grand Canyon Railway project is to determine an effective wastewater management plan for a wastewater source from two biodiesel-fired steam locomotives at the Grand Canyon Railway. The wastewater to be treated is produced from a process called “Boiler Blowdown” in which water in the boiler is heated and pressurized to blow out the built-up sediment at the bottom of the boiler. The resulting wastewater has a high pH and high concentration of total dissolved solids. These parameters will be treated to meet minimum requirements for discharge into Williams Wastewater Treatment Plant. This report looks to provide treatment alternatives, costs and design recommendations to effectively treat and manage the wastewater produced.

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List of Abbreviations

ADEQ	Arizona Department of Environmental Quality
BOD	Biochemical Oxygen Demand
CFR	Code of Federal Regulation
EPA	Environmental Protection Agency
GCR	Grand Canyon Railway
GCRP	Grand Canyon Railway Boiler Wastewater Pretreatment and Storage Project
GIS	Geographic Information Systems
NAU	Northern Arizona University
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WWTP	Wastewater Treatment Plant
WWWTP	Williams Wastewater Treatment Plant

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1. Project Introduction

1.1. Project Understanding

The Grand Canyon Railway Boiler Wastewater Management Project (GCRP) has been tasked with designing a treatment system for the boiler wastewater produced from two biodiesel-fired steam locomotives. The process of running the trains produces boiler wastewater contaminated with a total dissolved solids (TDS) concentration of 1500mg/L and a pH of 11.2. At the end of each season, to prevent freeze damage to the piping system, the Grand Canyon Railway (GCR) performs a "blowdown" process in which the boiler is filled, heated, pressurized and evacuated to remove any remaining solids from the boiler. The boiler wastewater had previously been discharged to the local wastewater treatment plant (WWTP) however, due to new influent standards implemented by the United States Environmental Protection Agency (EPA), the wastewater requires treatment in order to adhere to these newly implemented standards. Currently, GCR is transferring the boiler wastewater to an industrial wastewater treatment plant in Phoenix, a process that is costly and cumbersome. The GCRP will present the client with several different pretreatment alternatives that are both effective and more fiscally responsible than the current disposal methods.

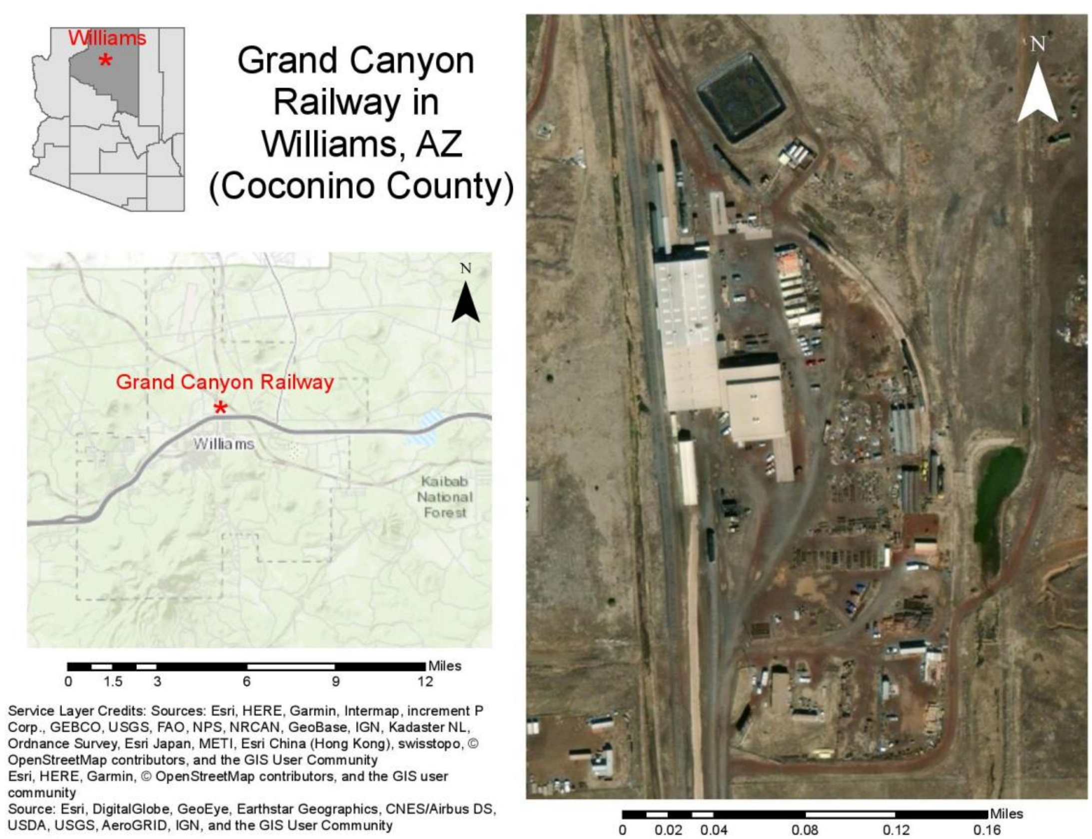

Figure 1. Site map of the Grand Canyon Railway Station (ArcMap).

As shown in Figure 1, above, the site of the Grand Canyon Railway Station is in Williams, Coconino County, Arizona approximately 35 miles west of Flagstaff, Arizona. The station itself is positioned less than a quarter of a mile east of the local Williams Wastewater Treatment Plant (WWWTP).

1.2. Project Background

Figure 2, below, displays the entire boiler water cycle, from source to sink. Source water is either rainwater collected in the on-site reservoir or tap water, depending on the availability of each source. Source water is then sent through a sand filter and softener to remove hardness ions, preventing precipitation of the calcium and magnesium out of solution and thus scaling on the heat transfer pipes within the boiler. Treated source water is then sent to the tender, the storage tank on the train, to supply water to the boiler. The locomotives leave the Grand Canyon Railway station in Williams, AZ with the boiler and tender tank filled with treated water to complete the trip to and from the Grand Canyon. The replacement of the water in the boiler from the tender occurs throughout the trip to and from the Grand Canyon to maintain boiler temperature and pressure. This process causes constant deposition of solids that precipitate out as the water is turned to steam. This cycle is completed every month from early spring to late fall and requires about 12,000 gallons to get to and from the Grand Canyon. Since this process occurs throughout the season, the dissolved solids concentration increases until the end of the season when the boiler is blown down with 4000 gallons of water. This blowdown process occurs for both steam engines and thus 8,000 total gallons of wastewater is produced with an approximate TDS concentration of 1500 mg/L and a pH of 11.8. In addition to the 8000 gallons of wastewater produced, 7000 gallons of tender water is added for treatment. The blowdown wastewater is stored in a holding tanker until it is eventually transported to and treated at a Phoenix WWTP at a cost of approximately $15,000 each year. GCR would like to send boiler wastewater to the Williams WWTP however influent water the plant must have less than 350 mg TDS/L and a pH less than 9 and greater than 5.5. Instead of the boiler wastewater entering the holding tanker, the wastewater will be sent to the chosen on-site pretreatment. From there the wastewater will be sent to Williams WWTP through a grinder pump located onsite.

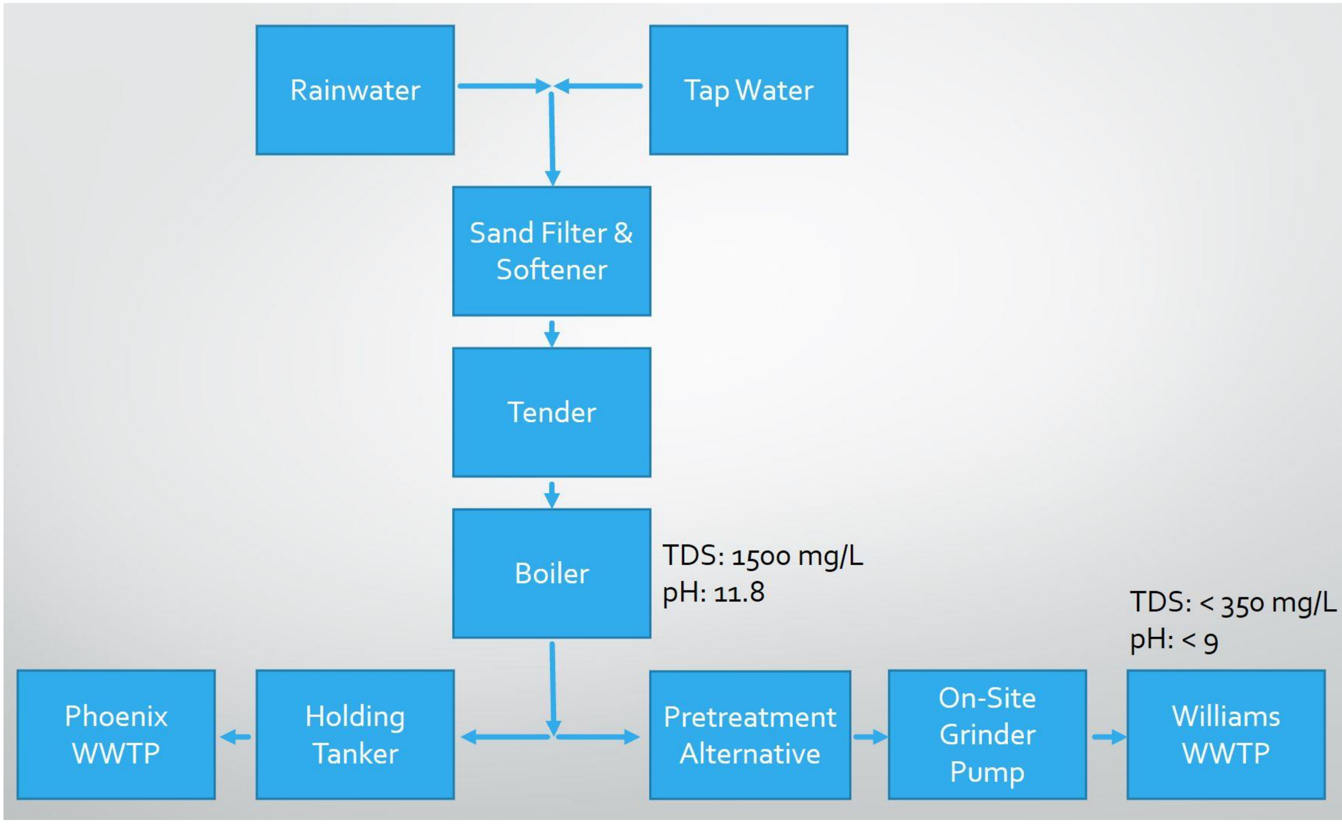

Figure 2. Boiler water source to sink schematic (Microsoft PowerPoint).

Prior to operating the boilers, there are several chemicals that are added to the influent boiler water to prevent scaling, corrosion, and ionic transformations. The chemicals being added to the boiler are produced by ChemTreat. However, due to trademark concerns, exact concentration, ratios, and volumes of each compound added cannot be determined. These chemicals include the following outlined in Table 1, below.

Table 1: ChemTreat chemicals added to influent boiler water.

ChemTreat Product	Main Compound	Use
SS16 (ChemTreat, Safety Data Sheet SS16, 2018)	Citric Acid	Cleans resin from the softener and assists in the softening of influent water.
BL197 (ChemTreat, Safety Data Sheet BL197, 2018)	Polyalkylene Glycol Monobutyl Ether	Anti-foaming agent added to boiler water to increase efficiency.

BL1240 (ChemTreat, Safety Data Sheet BL1240, 2018)	Erythorbic Acid	An oxygen scavenger that creates an oxygen free environment and prevents corrosion.
BL1775 (ChemTreat, Safety Data Sheet BL 1775, 2018)	Nitrate/Phosphate Compound	Prevents caustic embrittlement of the piping and tank.
BL8100 (ChemTreat, Safety Data Sheet BL8100, 2018)	Filming Amine	A filming amine that creates a monomolecular film that protects the tank from corrosion.

1.3. Constraints and Limitations

This project is limited by several factors that could impact the effectiveness of the pretreatment option and wastewater storage alternatives. The exact chemical make-up of each compound added to the influent boiler water are unknown with respect to their volumes, ratios, concentrations, and frequency. This will remain unknown because the manufacturer has established this as their trademark recipe for boiler maintenance. Additionally, the members of the GCRP team are unauthorized to retrieve a sample of the boiler wastewater due to constraints of occupational safety and health regulations. Because of this, collection methods of the sample may not consistent with proper sampling and storage methods outlined in the proposal.

Influent wastewater must meet be treated to certain standards per the WWWTP. The current state of GCR's wastewater does meet the standards of the WWWTP and therefore must be pre-treated to allow disposal.

Table 2: Influent wastewater standards set by the Williams WWTP

Parameter	Boiler Wastewater	Williams WWTP Influent Requirements
pH	11.8	5.5 < pH < 9
TDS (mg/L)	1500	< 350

The influent standards provided give a constraint of how the wastewater can be treated. The treated water must be treated to a level between the constraints. These constraints effect how the wastewater can be treated and therefore what methods are used during pre-treatment.

1.4. Major Objectives and Unique Deliverables

1.4.1. Cost and Lifecyle Analysis of Pretreatment Alternatives

The major objective of the project is to generate cost and life cycle analyses of the chosen pretreatment alternatives. It will be presented to the client for them to make an informed decision on how they would like to handle the boiler wastewater. This is a client and CENE 486 deliverable.

1.4.2. Project Status Presentations

Each project member will generate and present a 6 to 8-minute presentation and answer questions for 5 to 7 minutes. The presentation will update CENE 486 students and professors on the progress of the project. This is a CENE 486 deliverable.

1.4.3. Reflection

Each project member will complete a personal reflection of their own experience with the project. Each reflection will include information on the "Triple Bottom Line" and how it relates to the project, project management skills developed during the project, as well as teamwork during the project. This is a CENE 486 deliverable.

1.4.4. Meeting Memo Binder

A meeting memo binder is maintained to organize and archive meeting minutes from team meetings, grading instructor meetings, technical advisor meetings, as well as client meetings. This is a CENE 486 deliverable.

1.4.5. Progress Reports

Four progress reports will be generated: a 30% report, a 60% report, a 90% report, and a final report. Progress reports ensure that the team in on schedule to complete the project within the allotted time frame. This is a client and CENE 486 deliverable.

1.4.6. Website

A publicly-accessible website will also be produced that explains the project. It will contain team, client, and project information as well as a document repository of all deliverables. This is a CENE 486 deliverable.

2. Field Work

2.1. Site Investigation

Initial site investigation of the Grand Canyon Railway led to the determination that the chemical additions outlined in Table 1. These chemicals change the chemistry of the water as it passes through the softener and as it interacts with the boiler. This change in water chemistry impacts the treatment process of the water and the potential solutions to the water quality issue presented. Additionally, the site visit allowed for a visual evaluation of the rainwater catchment basin and its capacity in case the team was to utilize the basin for storage. Finally, the site visit allowed for the team to conclude that a small-scale treatment and storage system is required to utilize the space efficiently. Below are pictures of the site, including the softener column, rainwater reservoir, and grinder pump location, respectively.

Figure 3-5: Grand Canyon Railway's current softener column, rainwater reservoir, and grinder pump location.

2.2. Sampling

Sampling of the boiler water and rainwater was completed using ASTM 3370-10. However, due to restraints by the occupational safety and health act (OSHA) the team was unable to sample from the boiler water. Employees at GCR obtained the sample at the instruction of the team to maintain QA/QC of the sample to be tested for the parameters outlined in section 3.

3. Testing/Analysis Performed

3.1. NAU Environmental Engineering Lab Testing

Table 3: Lab procedures used to test boiler wastewater.

Type of Test	Test Method Used	Water Samples Tested
pH Measurement	ASTM D1293	Boiler wastewater, post-softener, tap water, and rainwater
Total Dissolved Solids (TDS) Concentration	ASTM D5907	Boiler wastewater, post-softener, tap water, and rainwater
Total Suspended Solids (TSS) Concentration	ASTM D5907	Boiler wastewater, post-softener, tap water, and rainwater
Total Iron Concentration	HACH 8008	Boiler wastewater, post-softener, tap water, and rainwater

3.1.1.Results

The boiler wastewater was sampled and tested for pH, TDS, TSS, and total iron at four different stages: source rainwater, source tap water, post-softener source water, and post-use boiler wastewater. Table 3 below, displays the results of the lab analysis. The raw data set is available in appendix A2.

Table 4. TDS, TSS, pH, and Iron Test Results.

Sample Type	Total Iron	TDS	TSS	pH
	mg Fe/L	mg/L	mg/L	
Boiler Wastewater	0.40	2196.90 +/- 26.59	23.40 +/- 8.63	11.70 +/- 0.06
Post-Softener	3.17	397.25 +/- 13.08	16.00 +/- 1.98	6.99 +/- 0.25
Rainwater	5.58	3.00 +/- 1.56	24.60 +/- 3.68	6.61 +/- 0.28
Tap Water	0.00	173.95 +/- 27.08	2.90 +/- 3.11	7.15 +/- 0.22

3.2. GCR Boiler Water Control Report

The GCR completes internal testing of the boiler, tender, and softener water. A copy of the control report thus far was provided by GCR. The report provided hardness, conductivity, pH, and various other parameters vital to proper operation of the boiler. The complete control report is available in Appendix A1.

Although speculative, it is believed that the SS16 is not being flushed out of the softener during regular maintenance. In regular zeolite softener maintenance, the softener is first backwashed, then SS16 is run through the softener to replace the hardness ions that have accumulated on the zeolite with sodium ions, and then a final rinse is completed to remove any unwanted traces of the SS16. Boiler water conductivity ranged from 1000-4000 µS/cm for all testing dates except the most recent test where the conductivity was 450 µS/cm. The GCR ran out of SS16 and BL1775 and so they were not used on the last testing date despite standard use for each treatment run. As SS16 is a high conductivity solution, the sudden drop in conductivity when SS16 was not used likely indicates a relationship between the two parameters.

4. Proposed Alternatives

4.1. Evaluation of Alternatives

Figure 5 shows the proposed alternatives, their advantages and disadvantages, and what was pursued. Despite the rejection of the replacement of the softener column, the GCR requested an economic analysis to be performed and an analysis of the overall operation and maintenance system.

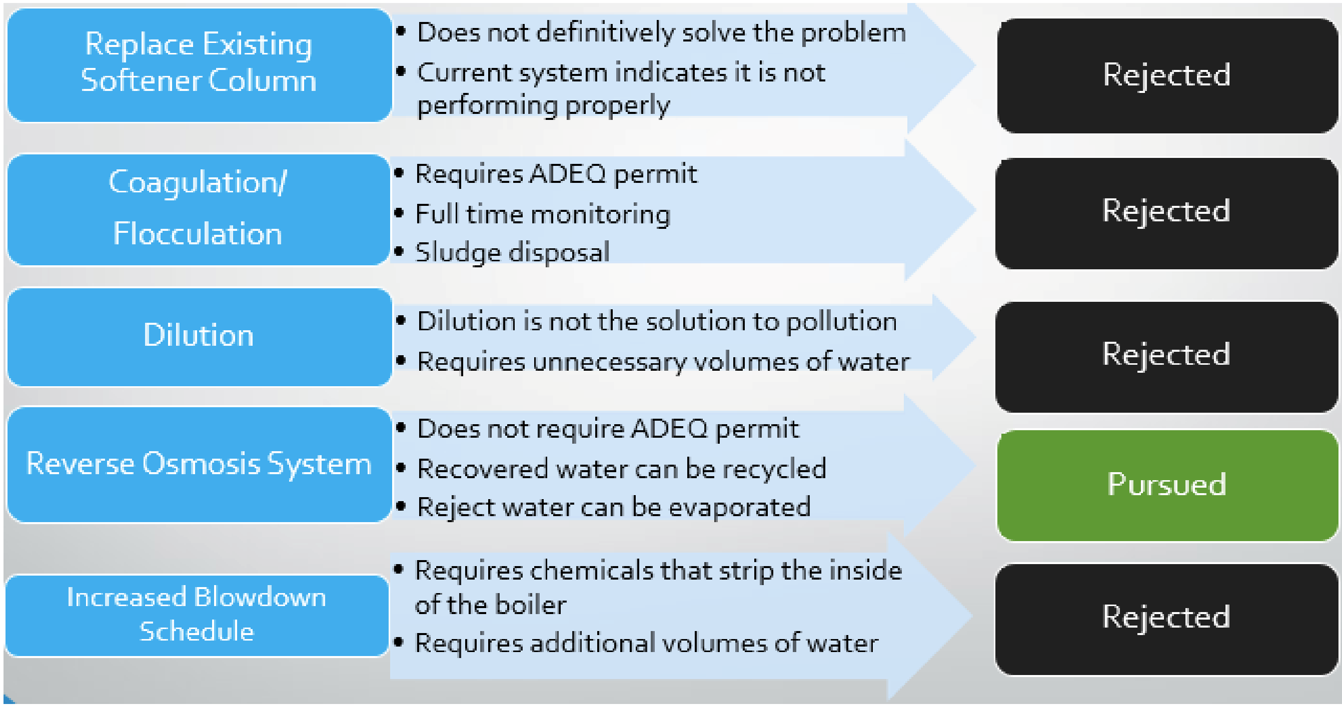

Figure 6: Evaluation of the proposed alternatives.

4.2. Alternatives to be Pursued

4.2.1. Alternative 1: Operation and Maintenance Improvements

The first alternative being pursued is to adjust the existing operation and maintenance aspects of the boiler water process. Below is a table that illustrates each of the operation and maintenance characteristics that require adjustment/improvement:

Table 5: Current and proposed operation and maintenance for the GCR.

Operation & Maintenance	Current O&M of GCRR	Proposed O&M for GCRR
Zeolite Softener Column	• Pressurized fiber glass column. • Influent water flows over a zeolite bed and exits the system through a 10-micron filter. • Currently, no back washing or zeolite bead replacement performed on a regular basis.	• Maintain fiber glass column however, replace the zeolite beads every two to three months (Chistophersen, 2015). • Backwashing is recommended to be performed at least every six months, depending on the average flow rate of the influent (Desilva, 2012).
Increased Blowdown Schedule	• The trains are being blown down once a year, for winterization. • This concentrates contaminants over time, more frequent blowdowns of the trains can keep the boiler from becoming over concentrated and prevent the wastewater from having high concentration of TDS.	• Implementing more frequent blowdowns (every other time the trains run) can keep the boiler from becoming over concentrated with solids. • A concern of this is that blowdowns require chemicals that can strip the inside of the boiler (GE, 2010).
Sand Filter Maintenance	• There is currently no frequent maintenance of the sand filter. • Pressurized environments can clog the filter with solids not easily removed through backwashing.	• Install a sand filter prior to entering the pressurized column so that influent is not under pressure. • Perform backwashing on the media every two to three months (Desilva, 2012).
SS16 Flush	• There is no known action being taken to regenerate the resin in the softener. • This can cause the resin to be filled with hardness (calcium, magnesium, and iron) and let hardness pass through.	• Practice a four-step process of regenerating the resin on a weekly basis: • Backwash the system. • Wash the resin with brine and SS16. • Perform a slow rinse to allow the bed to reclassify and rid of excess brine. • Fast rinse to re-compact bed (Manning, 2018).

4.2.2. Alternative 4: New Zeolite Softener

The second solution being pursued is to replace the existing zeolite softener with a new model. The zeolite softener has been in use for 15 years despite a seven-year lifecycle. As the softener is past the life cycle given by the manufacturer, the softener cannot be expected to perform as expected.

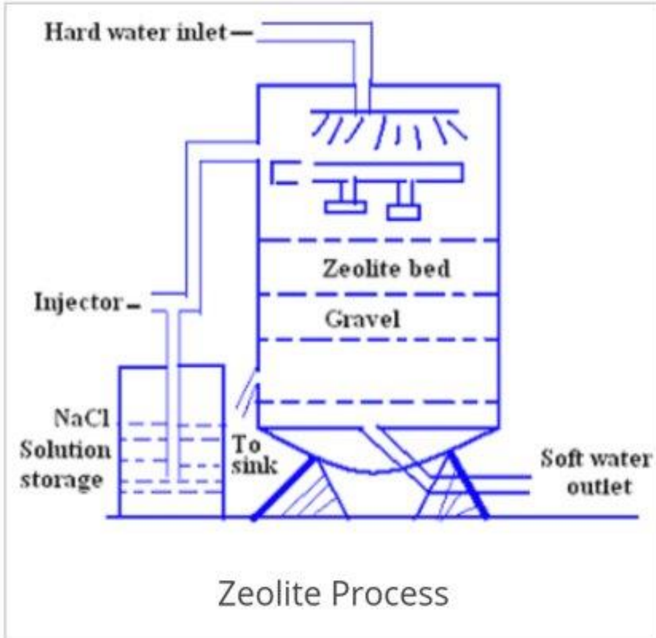

Figure 7: Zeolite softener schematic (Zeolite Process Flow Diagram, 2018).

The alternative of acquiring a new zeolite softener was considered once the conductivity results in appendix A1 were received. The results show a conductivity of 450 uS/cm on October 4th which correlates to a TDS value of about 225 mg/L. The inferred reason that the conductivity dropped so low in this instance is because SS16 was not added to the softener. The SS16 chemical is used to flush the softener, so that excess salts can be removed prior to running feed water through it. The assumption is that there are excess salts on the softener and the SS16 is stripping the zeolite and not flushing the salts. The day SS16 was not added, the salts were not stripped from the zeolite and therefore led to a lower conductivity. With a new softener and proper O&M to maintaining the zeolite bed, the TDS should be able to remain at a low level such as October 4$^{th.}$

4.2.3. Alternative 6: Reverse Osmosis and Reuse

The third alternative being pursued is a reverse osmosis or RO system. An RO water treatment system is commonly used in desalination. The RO process is where water high in TDS or conductivity is forced through a semipermeable membrane in the direction opposite to that of natural osmosis. Figure 6, below, displays the reverse osmosis process.

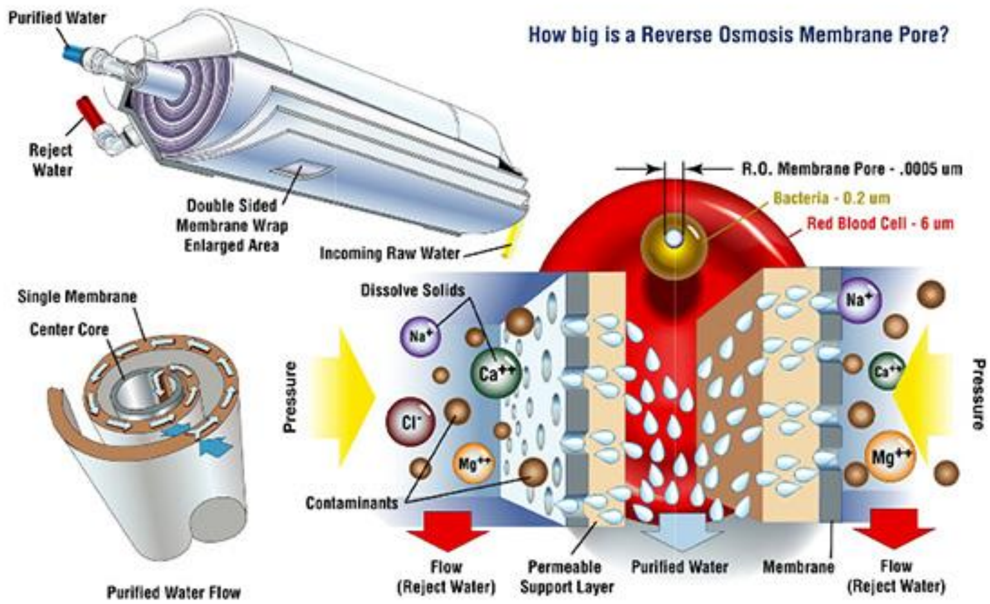

Figure 8. Illustration of how RO works (Reverse Osmosis Systems Review, 2018).

This process requires a large amount of pressure and produces TDS concentrated water as a byproduct. This system is the most viable for reuse of the water onsite because the water is treated to an acceptable level to be discharged or reused onsite. Potential issues behind the use of RO is the amount of concentrate water produced. Typical RO systems have a recovery rate of 50-75% (Davis, 2010) which would mean the concentrate water would likely need to be disposed of or shipped to an industrial wastewater treatment plant. However, the recovery rate outlined for RO systems typically assume 10,000 ppm or mg/L of TDS (AMPAC, 2018). Because of this, it is likely that the recovery rate on the treatment of the GCR's wastewater would likely be higher than the 50-75%. For the analysis of this project, 50% recovery will be assumed for waste storage and 75% for clean water storage to ensure a factor of safety in the treatment of the wastewater.

The following table shows the best times of the year to dispose of the rejected water into the rainwater reservoir for evaporation rates. June would be the month with the highest rate of evaporation, where the reject water could be evaporated within five to ten days.

Table 6: Evaporation rates by month for the dimensions of the onsite rainwater reservoir.

Month	Evaporation Rate (gal/month)	Evaporation Rate (gal/day)
May	37201	**1240**
June	48869	**1629**
July	44581	**1486**
August	36353	**1212**
September	30419	**1014**
October	22191	**740**

5. Final Design Recommendations

The AP6600-LX reverse osmosis system manufactured by AMPAC USA is the recommended alternative. It is able to treat 6,600 gallons per day, so it will take just over 2.25 days of all-day operation each year to treat the wastewater. It has a recovery rate of 50-75% so of the 15,000 total gallons to be treated, 7,500-11,250 gallons would be recovered as treated permeate water and 3,750-7,500 gallons would be rejected as concentrate water. It also has a rejection rate of 98%, so the permeate water will have a TDS ranging from 0.005-0.007 ounces TDS/gallon, less than the 0.04 ounces TDS/gallon maximum incoming wastewater requirements for the Williams WWTP. The RO system can adjust the pH to anywhere between 6.5-10.0 so the pH will be able to be set below the maximum incoming wastewater pH requirements at the Williams WWTP of 9. The permeate water will be able to be disposed of to the Williams WWTP or reused onsite. Onsite reuse will save 150-225 dollars each year assuming a 0.02 USD/gallon water cost.

The concentrate water will be sent to the rainwater catchment basin that is now repurposed as an evaporation basin. The basin is currently able to hold 225,000 gallons and has an HDPE liner, and so would not require an ADEQ aquifer protection permit. The concentrate would have 0.36-0.72 ounces TDS/gallon equating to approximately 187 pounds of solids each year in the evaporation pond. These solids can be disposed of in the local landfill.

This design would also require an 8,000-gallon plastic storage tank to store permeate water after treatment. A basic schematic of the final design is shown in figure 7, below.

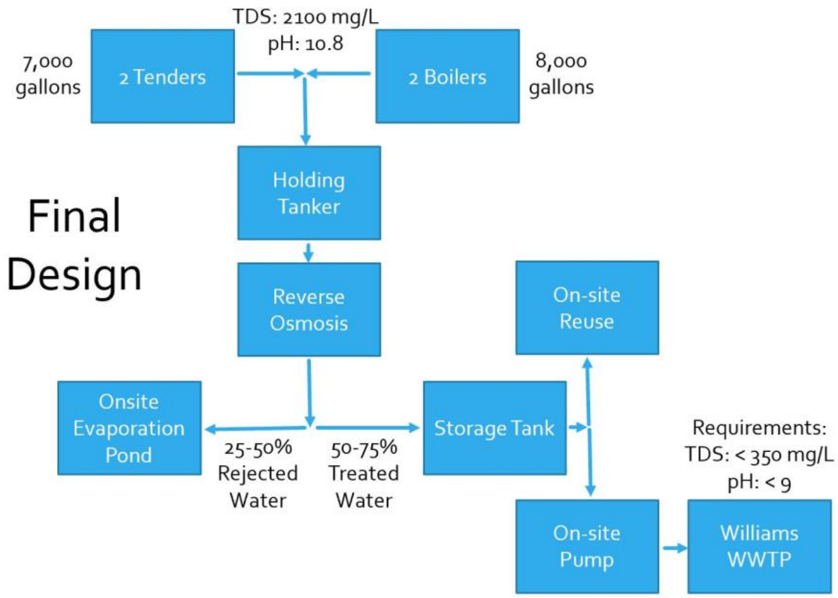

Figure 4. Final design schematic.

5.1. Lifecycle Analysis

5.1.1. Alternative 4: New Zeolite Softener

A replacement zeolite softener was provided by Watertec of Tucson, Arizona. This system cost about $3800 and will replace the old softener that is currently in place at GCR. The softener proposed has a lifecycle of about 7-10 years and a maintenance cost of 20% was assumed. This would include, zeolite bead replacement, backwashing and any other maintenance required on the system. Replacement of the current softener would likely return no significant profits or losses because the operating conditions of GCR's water treatment would remain the same. The overall cost per year of the new softener would be about $6,100 at a discount rate of 5%.

5.1.2. Alternative 6: Reverse Osmosis and Reuse

The reverse osmosis system chosen is a prefabricated system created by AMPAC USA. This system has an initial implementation cost of $19,270 this system has a life cycle of about 10-15 years. Maintenance on an RO system can be maintained at about 10% of initial cost per year. Membranes must be replaced; the system must be backwashed, and filters replaced. This cost equates over the lifespan of the system to about $2000 per year. Since, the system will return about half of the wastewater, the system will save GCR about $150-$200 on water cost by reusing the treated water in their boilers. This system equated to about $7,282 per year in annual cost at a discount rate of 5%.

5.2. External Impacts

5.2.1. Cultural

The cultural impacts associated with this recommendation are limited to the city of Williams. The site that this alternative is to be implemented is in a remote area within an industrial park. The RO system does not produce noise above 85 decibels or an odor that would cause harm to the public health.

5.2.2. Socioeconomic

The GCR is well-known for their green business practices and efforts to conserve and reuse water would fall in-line with that business ethic. The GCR also works closely with the U.S. National Parks who are deeply concerned with environmental practices. This wastewater management solution will improve the GCR's socioeconomic standing with the public as well as their corporate allies.

5.2.3. Environmental

The environment would be unaffected, if not improved by this alternative. The GCR is currently using large amounts of resources transporting the wastewater to and from Phoenix on a yearly basis. This amount of energy consumption surpasses the amount of energy needed to operate the RO system. Williams, AZ also has water supply issues and any conservation or reuse of water would be beneficial.

6. Cost of Implementing the Design

Table 7: Life cycle cost analysis.

Alternative	Ship to WWTP in Phoenix	Reverse Osmosis	New Softener and Increased Blowdown
Initial Cost ($)	0.00	24,259.00	3841.30
Maintenance ($)	500.00	2000.00	768.26
Operation ($)	2400.00	2220.00	4800.00
Salvage ($)	0.00	1284.67	320.11
Shipping and Treatment ($)	15,000.00	0.00	0.00
Total Annual Cost ($)	**18,200.00**	**7,282.00**	**6,124.00**
Total PW Cost ($)	**188,909.78**	**75,581.04**	**63,561.89**

7. Summary of Engineering Work

7.1. Scope and Schedule

Changes were made to the proposed schedule created for this project. The proposed schedule was the outline of how the project would progress. Through new client information and testing limitations, the schedule created at the beginning of the project was adjusted.

Table 8: Proposed schedule created before the project began

Task No.	Task	Start Date	End Date
1.0	Field Work	9/10/2018	9/22/2018
1.1	Site Map	9/10/2018	9/14/2018
1.2	Transport Forms	9/16/2018	9/20/2018
1.3	Sampling Plan	9/21/2018	9/22/2018
1.3.1	Boiler Blowdown Water	9/21/2018	9/22/2018
1.3.2	Rainwater Reservoir	9/21/2018	9/22/2018
2.0	Pretreatment	9/23/2018	10/15/2018
2.1	Testing the Wastewater	9/23/2018	9/30/2018
2.1.1	pH Measurement	9/23/2018	9/29/2018
2.1.2	Dissolved Solids Identification	9/24/2018	9/29/2018
2.2	Treatment Options	10/1/2018	10/15/2018
3.0	Design Wastewater Holding Tank	10/1/2018	10/27/2018
3.1	Holding Tank Design	10/1/2018	10/27/2018
3.1.1	Choose Premade Holding Tank	10/1/2018	10/6/2018
3.1.2	ArcGIS Site Map	10/7/2018	10/15/2018
3.2	Transport to Grinder Pump	10/16/2018	10/27/2018
3.2.1	AutoCAD Design	10/16/2018	10/21/2018
3.2.2	CHoose Pipe	10/22/2018	10/27/2018
4.0	Project Management	9/10/2018	11/29/2018
4.1	Group Meetings	9/10/2018	11/29/2018
4.2	Technical Advisory Meetings	9/10/2018	11/29/2018
4.3	Client Meetings	9/10/2018	11/29/2018
5.0	Deliverables	9/10/2018	11/29/2018

Tables 5 and 6 provide the original and adjusted schedules. Table 6 is the actual schedule used for the project. The items taken out of the scope have been highlighted red and the items added are highlighted in green.

Table 9: Actual schedule used for the project

Task No.	Task	Start Date	End Date
1.0	Field Work	9/10/2018	9/22/2018
1.1	Site Map	9/10/2018	9/16/2018
1.2	Transport Forms	9/10/2018	9/20/2018
1.3	Sampling Plan	9/21/2018	9/22/2018
1.3.1	Boiler Blowdown Water	9/21/2018	9/22/2018
1.3.2	Rainwater Reservoir	9/21/2018	9/22/2018
2.0	Pretreatment	9/17/2018	10/14/2018
2.1	Testing the Wastewater	9/17/2018	9/30/2018
2.1.1	pH Measurement	9/17/2018	9/23/2018
2.1.2	Dissolved Solids Identification	9/24/2018	9/30/2018
2.1.3	Iron	9/24/2018	9/30/2018
2.2	Treatment Options	9/30/2018	10/14/2018
3.0	Treatment Option Evaluation	10/15/2018	11/19/2018
3.1	Treatment Effectiveness	10/15/2018	11/5/2018
3.2	Treatment Feasibility	10/15/2018	10/29/2018
3.3	Economic Analysis of Treatment	10/22/2018	11/18/2018
3.4	Final Design Decision	10/30/2018	11/19/2018
4.0	Project Management	9/10/2018	12/2/2018
4.1	Group Meetings	9/10/2018	12/2/2018
4.2	Technical Advisory Meetings	9/17/2018	12/2/2018
4.3	Client Meetings	10/1/2018	11/26/2018
5.0	Deliverables	9/10/2018	12/6/2018

7.2. Adjustments to Scope and Schedule

The scope of the project changed due to information provided by the client. The initial scopes, task 3, included a wastewater holding tank design and a pipe design from the holding tank to the grinder pump onsite. During a client meeting, the team was informed that GCR currently uses transportable piping above ground and they will not require a piping design. They also asked that a prefabricated tank be used to minimize costs which eliminated task 3 from the scope.

Additions to the scope occurred because of the evolution of the project. The proposed schedule accounted for sample testing to be completed at an analytics lab. This was unable to be done so additional in-house testing was added to task 2. Task 3, Treatment Option Evaluation, was added to the scope because it was determined that analyzing the alternatives against each other would produce the best final design. Because of this, treatment effectiveness, treatment feasibility, and an economic analysis was added to the project's scope.

8. Summary of Engineering Costs

The staff necessary to complete the project was a senior engineer, junior engineer, intern, and an administrator. Changes to the scope of the project did not affect the staffing positions but it did affect the hours each position worked on the project. It was proposed that the project would take 747 hours to complete but at the projects end, 755 hours were spent on the project (table 7).

Table 10: Proposed versus actual staffing and costs for the Grand Canyon Railway Project

Personnel	Billing Rate ($/hr)	Proposed Hours	Actual Hours	Actual Cost
Senior Engineer	176	182	211	$118,835
Junior Engineer	65	213	217	$35,263
Intern	21	212	230	$7,245
Administrator	33	140	97	$9,603
Total	N/A	747	755	$170,946

The changes in hours for each position fall in line with the adjustments to the schedule. Additional time was added to the intern because total iron testing was completed in-house. The administrator saw a drop in time worked because testing was not sent to the analytical lab. It was proposed that the administrator would handle the communication with the lab but since it was not used, a reduction in hours occurred. The senior engineer's hours increased because of the technical conversations that took place with the RO and softener companies. The proposed engineering cost of the project was $157,652. With the adjustments to the work completed, the actual engineering cost of the project was $170,946.

9. Conclusion

The GCR capstone team recommends implementing a reverse osmosis system at GCR's maintenance shop to treat the boiler wastewater being produced. Additionally, the team recommends replacing the current softener to ensure the most efficient and effective water pretreatment process and utilizing the rainwater catchment basin as an evaporation pond to store the concentrate water produced. This recommendation would cost GCR about $28,100 in initial implementation cost but will help to ensure proper lifespan on the locomotive boilers used onsite and proper treatment of any wastewater produced. This project has a life cycle of about 15 years and should be reevaluated at the end of the 15-year lifecycle.

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Appendices

A1. Grand Canyon Railway Boiler Water Control Report

Grand Canyon Railway
Boiler Water Control Report   Locomotive: 4960   Year: 2018

GRAND CANYON Railway

Control Tests	Control Limits														
Date		15-Feb	27-Feb	3-Apr	19-Apr	3-May	31-May	9-Aug	13-Sep	4-Oct					
Boiler		Pre	Post	Post	Post	Post	Post	Post	PRE	Post	Post	Post	Post	Post	Post
Conductivity	<3500 uS/cm	1000	1300	2100	4200	4300	3000	4400	4000	450					
pH	Record	10.1	9.6	8.8	11.44	12	11.7	12.04	11.55	10.1					
OH Alkalinity	100-300 ppm	140	90	350	400	900	375	900	820	0					
Orthophosphate	20-40 ppm	3.9	2.4	40.4	11.9	14.9	18.6	21.9	13	9.6					
Iron (Ferrover)	Record	0.56	0.08	0.23	0.34	0.16	0.23	0.21	0.86	over					
Millipore Iron	Record	150	10	10	500	75	50	150	200	250+					
Oxygen Scav	80-320 ppb	7	140	302	OVER	321	308	249	UL	400					
Tender		Pre	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post	Post
Conductivity	Record	200	199	310	300	310	300		400	150					
pH	8.5-10.0	9.2	8.9	10.1	9.28	6.88	6.93		7.25	7.5					
Trace Hardness	<1 ppm	4	0	0	0	0	0		0	0					
Orthophosphate	20-40 ppm	4.7	2.2	2.5	5.5	25	27		8	3.1					
FFA (Titan 360)	0.2-1.0 ppm	0	0.5	0.3	0	0	0		0	0					
Iron (Ferrover)	<0.1 ppm	0.5	OVER	1.55	2.08	5.8	3.8		4.2						
Millipore Iron	Record	100	100	25	75	10	10		50	100					
Oxygen Scav	80-320 ppb	2	165	29	34	239	256		160	77					
Softener		13-Feb	28-Feb	3-Apr	19-Apr	3-May	31-May		12-Sep						
Trace Hardness	<1 ppm	0	0	0	0	0	0	0	0						
Treatment Added		17-Feb	3-Mar	7-Apr	21-Apr	5-May	2-Jun		15-Sep	6-Oct					
Oxygen Scavenger Initial Dosage = 1 Quart	BL1240	2 Gal	2 Gal	1 Gal	.5 Gal	.5 Gal	.5 Gal		3 Gal	1 gal					
Orthophosphate Initial Dosage = 1 gallon	BL1775	2 Gal	3 Gal	2 Gal	3 Gal	3 Gal	2.5 Gal		3 Gal	0 (out c					
Cetamine Initial Dosage = 1 gallon	BL8102	3 Gal	3 Gal	1.5 Gal	3 Gal	3Gal	2.5 Gal		3 Gal	3 gal					
Initial Dosage = 12 ounces	BL197	On Board	On Board	On Board	X1	On Board	On Board		On Board	On Board					
Initial Dosage = 1 Quart pe regeneration	SS16	X1	X1	X4	X1	X1	X3		x1	0					

A2. Water Quality Analysis Data

Table 11. Raw pH lab data.

	Sample Type	Boiler Wastewater			Post-Softener			Rainwater			Tap Water		
	Trial	1	2	3	1	2	3	1	2	3	1	2	3
pH	Oakton pH 700 Meter	11.80	11.71	11.68	6.85	6.71	6.74	6.23	6.28	6.70	7.08	7.39	7.45
	Cole Parmer pH Meter	11.70	11.66	11.64	7.19	7.31	7.12	6.80	6.87	6.76	6.88	7.02	7.07
	Average	11.70			6.99			6.61			7.15		
	Standard Deviation	0.06			0.25			0.28			0.22		

Table 12. Raw TDS lab data (sample volume = 50 mL).

	Sample Type	Boiler Wastewater		Post-Softener		Rainwater		Tap Water	
	Trial	1	2	1	2	1	2	1	2
TDS (g)	Empty Evap. Dish, M0	48.63087	47.33575	47.84139	46.33578	48.3306	49.0526	47.03082	48.54523
	M1	48.74148	47.44417	47.86047	46.35597	48.33072	49.05263	47.03843	48.55482
	M2	48.74183	47.44514	47.86111	46.35624	48.33067	49.05298	47.03869	48.55495
	Difference: M1-M2	-0.00035	-0.00097	-0.00064	-0.00027	5E-05	-0.00035	-0.00026	-0.00013
	Average M, MA	48.74166	47.44467	47.86079	46.35611	48.33070	49.05281	47.03856	48.55489
	Difference: MA-M0	0.11079	0.10891	0.0194	0.02033	9.5E-05	0.000205	0.00774	0.00966
	Average for Sample	0.10985		0.01986		0.00015		0.00870	
	Standard Deviation	0.00133		0.00065		0.00008		0.00135	

Table 13. Raw TSS lab data (sample volume 50 mL).

	Sample Type	Boiler Wastewater		Post-Softener		Rainwater		Tap Water	
	Trial	1	2	1	2	1	2	1	2
	Empty Evap. Dish, M0	1.37144	1.37243	1.37042	1.36918	1.36439	1.367	1.37654	1.3687
	M1	1.3723	1.37388	1.37119	1.37001	1.36546	1.36832	1.37656	1.36895
TSS (g)	M2	1.37231	1.37393	1.37111	1.37009	1.36552	1.3684	1.37659	1.36896
	Difference: M1-M2	-1E-05	-5E-05	8E-05	-8E-05	-6E-05	-8E-05	-3E-05	-1E-05
	Average M, MA	1.37231	1.37391	1.37115	1.37005	1.36549	1.36836	1.37658	1.36896
	Difference: MA-M0	0.00087	0.00148	0.00073	0.00087	0.0011	0.00136	3.5E-05	0.00026
	Average for Sample	0.00117		0.00080		0.00123		0.00014	
	Standard Deviation	0.00043		0.00010		0.00018		0.00016	

Table 14. Raw total iron lab data.

Total Iron	Sample Type	Boiler Wastewater	Post-Softener	Rainwater	Tap Water
	Concentration (mg Fe/L)	0.40	3.17	5.58	0.00