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Flexible Load Opportunities IRWD Recycled Water System Hydraulic Modeling

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WEST YOST ASSOCIATES

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SCE Flexible Load Opportunities

IRWD Recycled Water System Hydraulic Modeling

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PREFACE

In January 2015, Irvine Ranch Water District (IRWD) entered into a unique water-energy partnership with Southern California Edison (SCE). The purpose of the partnership is to identify, study, research, and recommend actions and strategies that enhance electric reliability while also helping IRWD build energy independence and efficiency.

This report documents one of many innovative water-energy activities conducted by the partners. The purpose of this project was to perform a "proof of concept" evaluation using output from a water system hydraulic model to estimate the impact of intentionally shifting water system operations to increase the amount of energy used during daily and seasonal overgeneration periods. None of the analyses performed for this demonstration are focused on or indicative of actual IRWD plans to expand or modify its systems or operations at the site used to create and demonstrate the tool.

This project showed that: (1) IRWD and other water and wastewater utilities can provide electric reliability support but some changes to systems and operations may be needed; (2) water sector hydraulic models can be used to estimate electric system impacts of changes to water and wastewater systems and operations; and (3) many hydraulic models are best suited to evaluating changes over short timeframes - evaluating seasonal impacts will likely require supplemental tools, such as the spreadsheet model developed for this project.

In many respects, this project is the epitome of water-energy collaboration. IRWD and other water and wastewater utilities have made significant investments developing and calibrating hydraulic models and other sophisticated water sector planning tools to effectively manage their systems. These same hydraulic models are uniquely well suited to be expanded to predict water sector electric impacts because they already know how changes to one part of a water or wastewater system will impact other parts. Insights as to how parts of a water system relate to others cannot be cost-effectively replicated by a separate electric forecasting tool.

ABSTRACT

Water and wastewater (W-WW) utilities have operational flexibility to potentially change the time of energy use on a daily and seasonal basis, impacting their electrical energy use with respect to overgeneration periods. This project developed a "proof of concept" evaluation using output from a water system hydraulic model to estimate the impact of intentionally shifting water system operations to increase the amount of electricity used during daily and seasonal overgeneration periods while meeting all water supply and hydraulic requirements. The existing IRWD Lake Forest recycled water hydraulic model was used to simulate two operational alternatives, shifting pumping operations on a daily basis (Alternative 1) and on a daily and seasonal basis (Alternative 2) into defined overgeneration periods. Each alternative supplies a consistent amount of recycled water to the Lake Forest service area, and each alternative meets the hydraulic requirements of IRWD. An excel workbook was developed to extrapolate limited-duration model energy results to a yearly summary while imposing the external constraints of the amount of recycled water entering and leaving the system. Results indicate that water system operations could be adjusted, both daily and seasonally, to significantly increase the total energy consumption and peak power demand during overgeneration periods. Table A-1 presents the results for the existing conditions and two operating alternatives, showing that the percent of total energy used during both the daily and seasonal overgeneration period ranged from 6 percent to 43 percent. The Alternative 1 impacts could be accomplished with daily changes to operations and minimal infrastructure investment. Alternative 2 would require substantial changes to operations on a seasonal basis, as well as significant new storage.

Table A-1. Results Summary – Total Annual Energy Consumed, Daily + Seasonal Overgeneration Period

Alternative	Pump Energy Consumed, kWh		Percent of Total Energy During Daily + Seasonal Overgeneration
	Total Energy Used	Total During Daily + Seasonal Overgeneration	
Existing Conditions	1,478,000	92,000	6%
Alternative 1 (Daily)	1,600,000	205,000	13%
Alternative 2 (Daily and Seasonally)	1,911,000	831,000	43%

EXECUTIVE SUMMARY

Background

There is a growing imbalance between daily electrical supply and demand patterns throughout California's energy grid due to the increase in electrical energy generated by solar and wind sources. "Overgeneration" is the term used for the periods when real-time supply exceeds real-time demand in the system. The operation of water and wastewater (W-WW) utilities – specifically moving and treating water – requires large amounts of energy. Shifting the time of W-WW utility operations through adjustments to daily time-of-use and seasonal storage availability has the potential to change the associated energy demand patterns. Southern California Edison's (SCE) Overgeneration Pilot Project is exploring how W-WW utilities could help increase electric reliability and mitigate the overgeneration situation. This study investigates if W-WW hydraulic models can be used to estimate how changes to water system operations impact time of electrical use while meeting all supply and hydraulic requirements, and in turn provide overgeneration mitigation support. Irvine Ranch Water District (IRWD) is an SCE water-energy partner and with SCE's approval selected the Lake Forest service area of their recycled water system and hydraulic model to be used as a case study for this project. It should be noted that although the official name of the system is the "non-potable water system," "recycled water system" is used throughout this report because recycled water is the dominant supply, and recycled water is the supply that was manipulated to assess power requirements in this analysis. In addition to recycled water, the system is supplemented with native supplies, imported water, and small amounts of groundwater.

Purpose

The purpose of this project was to develop a "proof of concept" for using a water distribution system hydraulic model to estimate how electrical use and its timing changes if water pumping is moved into periods of overgeneration. If proven successful and cost-effective, hydraulic models may help W-WW utilities identify and evaluate strategies for mitigating overgeneration.

Approach

This project was designed to utilize IRWD's existing hydraulic modeling tools to simulate shifting pumping operations to occur during periods of overgeneration. Daily overgeneration was assumed to be 9:00 am to 4:00 pm, and seasonal overgeneration was assumed to start on February 15 and end on June 15, based upon information provided by SCE. Two operational alternatives were developed and simulated within the hydraulic model. Alternative 1 maximized pumping between 9:00 am to 4:00 pm. Alternative 2 built on the daily adjustments of Alternative 1, and also maximized pumping between February 15 and June 15 by adding seasonal recycled water storage. Each alternative supplies a consistent amount of recycled water to the Lake Forest service area, and each alternative meets the hydraulic requirements of IRWD. Model results were used to quantify the impact of changing the pumping schedules in terms of annual energy use. The difference between the current energy use and the energy use of the two alternatives defined the potential for overgeneration mitigation support.

Evaluation and Results

Translating the hydraulic model results into energy consumption on both a daily and seasonal basis was a complex process and involved multiple tasks that were completed separately and then integrated. These tasks can be separated into four categories: modeling, constraints development, extrapolation, and energy calculation.

The modeling task included the preparation of the existing hydraulic model for energy analysis:

- Pump hydraulic curves were updated based upon the most recent pump tests conducted by SCE.
- Pump efficiency curves were added to the hydraulic model so that the energy module of the software could be utilized.
- Pump energy demand was verified against electrical billing data. Pump curves were refined such that modeled energy demand and historic billed electrical demand were within allowable tolerances.

The constraints task developed values that were used in the modeling and extrapolation tasks. The task involved defining the flow of recycled water in and out of the Lake Forest system, and consisted of these elements:

- A recycled water daily demand data set was created, based on historical data. This provided the amount of recycled water used on any given date.
- A maximum recycled water daily production data set was generated based on the amount of effluent being discharged from the recycled water treatment plant.
- Using the demand and production data, a water balance was prepared to calculate the daily inflow and outflow rates from the seasonal storage reservoir by comparing how much recycled water was used verses how much recycled water was being produced.

The extrapolation task consisted of extrapolating the existing model short-term simulation results (typically 10 days or less, since the model steadies into repeatable results patterns in that timeframe) to an annual timeframe, as this study was interested in annual energy consumption. Calculating the energy consumption for various alternatives required establishing values for the following variables:

- Annual recycled water demand in system
- Start and end date of recycled water demand period(s)
- Start date of the recycled water pumping period
- Start and end time of the daily overgeneration period
- Start and end date of the seasonal overgeneration period

The energy calculation task integrated the information generated in the other three tasks. An excel workbook-based tool was created that iteratively evaluated the above elements to estimate annual energy use for the current conditions (Baseline), Alternative 1 and Alternative 2. The workbook tool then separated the energy results into one of three energy timing categories: Energy used during Daily Overgeneration periods; Energy used during Seasonal Overgeneration periods; and Energy used during both Daily and Seasonal Overgeneration periods.

Table ES-1 displays the results for energy consumed during daily overgeneration and seasonal overgeneration periods. As shown in the table, the results of Alternative 1 indicate that energy used during daily overgeneration periods would be more than doubled compared to baseline conditions. As would be expected, Alternative 1 provides almost no improvement compared to baseline conditions with regard to energy consumed during seasonal overgeneration periods. Alternative 2, which incorporates the daily changes reflected in Alternative 1 in addition to the seasonal changes unique to Alternative 2, provides significant increases in energy consumption during both daily and seasonal overgeneration periods.

Table ES-1. Results Summary – Total Energy Consumed, Daily and Seasonal Overgeneration

Alternative	Pump Energy Consumed, kWh				
	Total During Daily Overgeneration	Total During Daily Non-Overgeneration	Total During Seasonal Overgeneration	Total During Seasonal Non-Overgeneration	Total Energy
Baseline (Existing Conditions)	471,000	1,007,000	288,000	1,190,000	1,478,000
Alternative 1 (Daily)	1,051,000	549,000	312,000	1,288,000	1,600,000
Alternative 2 (Daily and Seasonally)	1,243,000	668,000	1,287,000	624,000	1,911,000

The energy used during both daily and seasonal overgeneration periods consists of the intersection of the energy used during the daily overgeneration period and the energy used during the seasonal overgeneration period. As an intersection (subset) of these values, the energy used during both daily and seasonal overgeneration periods is a smaller value than either value separately. The results for this value for each alternative are shown in Table ES-2. Although increasing the energy consumed during any overgeneration period can be valuable, energy consumed during both the daily and the seasonal overgeneration periods provide a convenient summary of effectiveness for each alternative. The results in Table ES-2 indicate that proposed operational adjustments shifted energy consumption into periods of overgeneration on both a daily and seasonal basis. The percent of total energy used during both daily and seasonal overgeneration periods increased by 37 percent between the Baseline and Alternative 2 (6 percent to 43 percent).

Table ES-2. Results Summary – Total Annual Energy Consumed, Daily + Seasonal Overgeneration Period

Alternative	Pump Energy Consumed, kWh		Percent of Total Energy During Daily + Seasonal Overgeneration
	Total Energy Used	Total During Daily + Seasonal Overgeneration	
Baseline (Existing Conditions)	1,478,000	92,000	6%
Alternative 1 (Daily)	1,600,000	205,000	13%
Alternative 2 (Daily and Seasonally)	1,911,000	831,000	43%

KEY CONCLUSIONS AND RECOMMENDATIONS

1. Operations within the Lake Forest service area can be modified, both daily and seasonally, to significantly increase the total energy consumption during daily and seasonal overgeneration periods. The addition of two PRVs and 740 acre-feet of additional storage at the top of the service area would be required to implement these operational changes. The seasonal operational changes and the addition of 740 acre-feet of additional storage are significant potential modifications to IRWD's system.
2. Operational adjustments resulted in an increase in total energy consumption (29 percent increase in Alternative 2 compared to Baseline). This extra energy consumption is from 1) friction losses due to higher pipeline velocities, and 2) pumping a significant amount of water to the highest elevation in the service area during seasonal storage. Key infrastructure improvements (i.e. increased pipeline diameters, greater pumping capacity), and locating storage at strategic elevations could mitigate this situation.
3. The recycled water providers could ask their customers to adjust the timing of recycled water demand to further enable mitigation of overgeneration. It is understood that because of automation, demand timing adjustment is not as simple as it appears.

While the hydraulic model is critical for evaluation, this project demonstrated that translating external constraints and modeling results into spreadsheet format or similar, is equally important to an overgeneration analysis such as this. The excel workbook created for this project has scalable logic and controls that could be efficiently expanded to include the entire IRWD recycled water system, expanded to include an evaluation of the potable water system, or adapted to other W-WW districts' systems. The workbook's logic, use of constraints, calculation process, and summaries are not specific to any particular hydraulic model or service area and can span multiple model inputs from different systems.

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SCE FLEXIBLE LOAD OPPORTUNITIES
IRWD RECYCLED WATER SYSTEM HYDRAULIC MODELING

1.0 INTRODUCTION

Water and wastewater (W-WW) utilities appear to be able to offer a valuable opportunity to provide electrical reliability support during periods of overgeneration. Electrical energy overgeneration occurs when real-time electric supply exceeds real-time electric demand. It is a phenomenon that can occur during any hour, day or season, but it cannot be effectively predicted in advance. The highest value means to mitigate overgeneration is therefore the ability to increase electric use during periods of time when overgeneration occurs. Both water and wastewater treatment facilities can adjust certain treatment and pumping processes during specific time periods. Water utilities have the additional flexibility to shift energy consumption due to their ability to store water both diurnally (daily) and seasonally, and to equalize daily supply and demand.

1.1 Project Background

As part of Southern California Edison's (SCE) Overgeneration Pilot Project, Water Energy Innovations (WEI) is assisting SCE in determining whether a W-WW sector hydraulic model can be used to estimate how changes to W-WW systems, facilities and/or operations might be able to help mitigate overgeneration impacts. Irvine Ranch Water District (IRWD) is an SCE water-energy partner with extensive potable and recycled water distribution systems, as well as an extensive wastewater collection system. IRWD has invested tremendous resources in building and calibrating robust hydraulic models for all of these systems and continues to invest in the maintenance of these valuable tools. Due to their extensive W-WW systems and high energy usage, combined with well-developed hydraulic models, IRWD was chosen by SCE as a partner to evaluate the effectiveness of a hydraulic model as a water-energy evaluation tool. West Yost, as one of IRWD's hydraulic modeling consultants, was engaged to undertake the hydraulic modeling portion of the assignment in collaboration with WEI, IRWD, and SCE.

1.2 Project Purpose

The purpose of this project is to develop a "proof of concept" evaluation using output from a water system hydraulic model to estimate how changes to water system operations impact time of electrical use. If proven successful and cost-effective, hydraulic models may be useful in helping W-WW utilities identify and evaluate strategies for mitigating overgeneration while meeting all supply and hydraulic requirements.

The analysis focused on the technical feasibility of operational adjustments in the recycled water system, to demonstrate a methodology that could be applied elsewhere. For instance, the tools and techniques developed could be used on a larger scale, such as an evaluation of the entire IRWD recycled water service area, or for an analysis that integrates inputs and results from multiple utility systems.

Specific project objectives included:

- Test, evaluate, and recommend first whether, and second to what degree, IRWD's recycled water system hydraulic model can be used to estimate electrical energy impacts due to operational changes.

- Evaluate the amount of operational flexibility and related electric reliability benefits (especially with respect to overgeneration support) that IRWD could provide from the Lake Forest recycled water service area under existing infrastructure conditions.
- Recommend an approach for evaluating additional IRWD opportunities in other parts of its recycled water system to increase operational flexibility and potentially provide overgeneration mitigation support.

While the central purpose of this project is to demonstrate impacts to electrical energy use, parallel objectives included maximizing the recycled water resource and improving the reliability of IRWD's recycled water supply. These parallel objectives offer potential environmental and economic benefits and were also considered during the development and evaluation of project alternatives, but were not quantified as part of this study.

2.0 PROJECT APPROACH

Currently, IRWD does not consider any overgeneration periods during the operation of their recycled water systems. This project was designed to use the existing recycled water system hydraulic model to simulate operational adjustments which shift pumping operations to occur during periods of overgeneration. The model results were used to quantify the impact of proposed operational adjustments in terms of energy use, with respect to defined overgeneration periods. The estimated energy use during periods of overgeneration provides the potential overgeneration mitigation support.

The approach was developed and refined throughout the project and did not follow a linear progression. Many of the steps involved iterations and reevaluation due to the numerous known and unknown variables revealed throughout the project investigations. The final project approach undertaken for this study is outlined below as discrete steps. The approach has been refined to describe a streamlined and logical process that can be repeated and applied to future projects. Each of the steps below is expanded upon within in the body of the report.

Step 1: Select Study Area

IRWD recommended the Lake Forest service area of the IRWD recycled water distribution system as the study area. The Lake Forest service area is suitable for this study because it is relatively small and hydraulically uncomplicated, it is reasonably hydraulically isolated from the larger main service area of the IRWD recycled water model, and it has the potential for seasonal storage.

Step 2: Identify Alternatives to Test Operational Changes

Operational alternatives to be tested and evaluated in the hydraulic model were identified, refined, and vetted. Alternatives were developed and selected based on their potential to impact electrical energy use, specifically with respect to overgeneration periods. Because overgeneration is both a daily and a seasonal phenomenon, one daily and one seasonal operational alternative were identified. Alternative 1 adjusted operations to impact time of energy use on a daily basis. Alternative 2 adjusted operations to impact the time of energy use on a seasonal basis. Each alternative supplies a consistent amount of recycled water to the Lake Forest service area, and each alternative meets the hydraulic requirements of IRWD.

Step 3: Update and Calibrate Hydraulic Model to Real-World Conditions

The original IRWD hydraulic model did not contain the data required to utilize the energy demand module of the modeling software. The hydraulic model was updated to include the most recent pump curve and energy efficiency data IRWD and SCE had for the study area. After this update, preliminary results from the energy demand module output were compared to historical energy billing records to validate the results. Pump curves were adjusted to bring modeled energy demand within acceptable tolerances of billed energy demand. With these changes, the hydraulic model was ready to be updated with the operational scenarios selected in Step 2 and then evaluated using the energy demand module.

Step 4: Establish Baseline Energy Use

Using the updated and calibrated model discussed in Step 3, the Baseline energy use was established using existing daily and seasonal operational patterns. Baseline energy use was compared to energy use during adjusted operations to quantify the amount of energy that was shifted into overgeneration periods.

Step 5: Mass Balance: Confirm Supply vs. Demand

The ability of any operational alternative to fully utilize the water or energy resource was constrained by both the supply – the amount of water available to use, and the demand – the amount of water needed in the distribution system. This step was required to set boundaries on the annual flow balances in the Lake Forest service area, which would then be applied on each operational alternative. Historic monthly flow balances (wastewater influent in, recycled water out to Lake Forest, treated effluent out to ocean discharge) were evaluated to determine annual flow balance constraints.

Step 6: Evaluation of Operational Alternatives

Operational alternatives were set up, run, and iterated in the hydraulic model. The alternatives were constrained in the model by the IRWD design and performance criteria for recycled water systems. Results were then input and extrapolated using the Microsoft Excel workbook to estimate annual energy use.

Step 7: Extrapolate Model Results to Annual Energy Use

Hydraulic model simulations are generated on a limited-timeframe basis, typically no longer than 10 days. To estimate energy demand and consumption on an annual basis, an external tool was required to extrapolate model results while at the same time applying annual flow balance constraints. A Microsoft Excel workbook was developed to translate results from the 10-day hydraulic model and constraints from the annual flow balance into annual energy use.

Step 8: Comparison of Baseline to Alternatives to Assess Overgeneration Mitigation

To evaluate the potential of each operational alternative to provide overgeneration mitigation, estimated annual energy use was compared to the Baseline energy use. The difference between each alternative and Baseline energy use during daily, seasonal, or both daily and seasonal overgeneration periods defined the potential for overgeneration mitigation support.

2.1 Description of Study Area – IRWD's Lake Forest Recycled Water System

IRWD's recycled water system consists of a main service area that is primarily supplied by the Michelson Water Reclamation Plan (MWRP) and a Lake Forest service area that is primarily supplied by the Los Alisos Water Reclamation Plant (LAWRP). IRWD's Lake Forest service area of their recycled water system service area was selected by IRWD to be used as a case study for this project. In 2001, IRWD consolidated with the Los Alisos Water District, adding portions of Lake Forest to the IRWD service area. Prior to consolidation, Lake Forest had stand-alone wastewater, potable water, and recycled water systems. Although these systems have since been partially integrated with the larger main service area, they remain relatively isolated and can be operated as if isolated from the main service area. This allowed the service areas to be isolated and evaluated separately for this modeling project. The Lake Forest system is also relatively small and hydraulically uncomplicated, and has the potential for seasonal storage, which are other reasons why the Lake Forest service area was a suitable candidate.

2.1.1 IRWD Lake Forest Recycled Water System Description

The Lake Forest recycled water system service area serves approximately six square miles within the City of Lake Forest (City), providing recycled water to landscaping and public parkways south of the 241 Toll Road. Figure 1 (Appendix B) presents the service area key infrastructure for the existing Lake Forest recycled water system service area. Under typical operating conditions, recycled water is supplied from the LAWRP, which is located at the south end of the City near Highway 5 and Bake Parkway.

The Lake Forest recycled water system consists of three service levels, named Zone A, B, and C. Under typical operating conditions, Zone A pumps, located at LAWRP, pump treated recycled water to Zone A storage; Zone B pumps up to Zone B storage; and Zone C pumps up to Zone C storage. Water is distributed by gravity from each zone's dedicated storage facility to balance daily demands with daily pumping. Zone A and Zone B have covered storage tanks while Zone C's storage is the uncovered Oso Reservoir owned by Santa Margarita Water District.

IRWD utilizes a very limited amount of storage in Oso Reservoir to meet system pressure requirements, which prevents the need to pump continuously from Zone B. It is important to note the Lake Forest recycled water system currently does not contain pressure reducing valves (PRVs) that would allow recycled water to move from a higher zone to a lower zone (for example, from Zone C to Zone B). Therefore, under current operations, it is not possible to "backfeed" a lower zone from the storage in a higher zone. Table 1 describes the key infrastructure for the existing Lake Forest recycled water system. Figure 2 (Appendix B) presents the hydraulic grade line (HGL) profile of the existing Lake Forest recycled water system.

Table 1. Lake Forest Recycled Water System Key Infrastructure Details

Infrastructure Type, Name	Details/Capacity
Los Alisos Water Recycling Plant (LAWRP)	7.5 mgd Design Capacity 5.5 mgd Tertiary (Non-potable Water) Capacity 3.2 mgd Average Production
Pump Station into Zone A, RPS013 (LAWRP- Zone A)	(3) 2,800 gpm pumps
Zone A (HGL = 624')	
Recycled Water Pipeline, 8-18" diameter	19,200 feet
Covered Storage Tank, RRS011	2.0 MG
Pump Station out of Zone, RPS014 (Zone A-B)	(3) 3,700 gpm pumps
Zone B (HGL = 860')	
Recycled Water Pipeline, 4-24" diameter	109,500 feet
Covered Storage Tank, RRS012 Lake Forest West	7.8 MG
Covered Storage Tank, RRS013 Lake Forest East	3.2 MG
Pump Station out of Zone, RPS015 (Zone B-C)	(2) 1,500 gpm pumps
Pressure Reducing Valve, Zone B-B_RO1	Creates a sub-zone within Lake Forest Zone B
Pressure Reducing Valve, RPR100 (Lake Forest Zone B-Portola Zone C)	Provides connection to main recycled water service area (Lake Forest Zone B to Portola Springs Zone C)
Zone C (HGL = 945')	
Recycled Water Pipeline, 4-24" diameter	22,300 feet
Pump Station into Zone, RPS015 (Zone B-C)	(2) 1,500 gpm pumps
Storage Reservoir, Oso Reservoir	Total capacity ~ 1.3 billion gallons IRWD/Lake Forest Recycled Water System use of total capacity = ~1.0 MG
mgd = million gallons per day MG = million gallons	

The infrastructure in the study area that was evaluated for energy demand as part of this study consists entirely of the three pump stations described in Table 1. Treatment infrastructure at LAWRP, LAWRP pumping to the ocean outfall, and other associated infrastructure was not included in the study. Such infrastructure may have material impacts on the energy demand results and may be evaluated if this proof of concept study is expanded in scope.

2.1.2 SCE Systems within Study Area

Figure 3 (Appendix B) presents the location of the Lake Forest recycled water system relative to SCE's electric distribution infrastructure.

2.1.3 Typical Operation and Electrical Demand Drivers

Electrical demand in the system corresponds to the increase or decrease in recycled water demand. As recycled water demands increase, pumps are required to convey water from the production source, LAWRP, to fill storage facilities and/or satisfy demands in each system zone. This section describes the typical operation of the Lake Forest recycled water system under existing conditions, on a seasonal and daily basis.

Seasonal Operation

Recycled water demand in the Lake Forest recycled water system service area is predominantly driven by local irrigation demands. These demands are met in a manner that minimizes energy costs while meeting system criteria. Under current operating conditions, recycled water is produced "on-demand" at LAWRP when needed to meet summer irrigation demand. When demands increase for the summer irrigation period, recycled water production is started at LAWRP and pumped up the system through each zone (from LAWRP, to Zone A to Zone B to Zone C). Recycled water volumes in excess of the actual demand are discharged to the main service area through the interconnect at valve RPR100. Seasonal periods of demand when LAWRP is supplying recycled water are typically between mid-May and October. In the winter, when demands fall as irrigation requirements decrease, recycled water production at LAWRP is stopped and LAWRP effluent is discharged to the ocean. The threshold at which recycled water production is started at LAWRP is not defined by a demand volume but is operator-driven based on historical demand patterns. When LAWRP is not producing recycled water, demands are served from the main service area through interconnections in the piping systems. The amount of seasonal storage available is a significant constraint to seasonal operation. The current seasonal operating conditions can be simplified into two scenarios:

1. Winter demand – LAWRP discharging secondary treated water to ocean
2. Summer demand – LAWRP pumping tertiary treated water to Lake Forest

Daily Operation

During the summer period when LAWRP is supplying and pumping recycled water, daily operation is driven by the demands in each zone. Demand is supplied to each zone by its respective storage facility (tank or reservoir). When demands deplete storage volumes to a defined low threshold point, pumps turn on to refill the reservoir or tank. The historic operational mode was created to meet user demands while minimizing pumping during the traditional high time-of-use rate periods. This mode is constrained by the recycled water supply, available storage, conveyance capacity, and pumping capacity.

Current seasonal and daily operational patterns allow room for adjustments which can potentially change the time of energy use both on a daily and seasonal basis, impacting the electrical energy use with respect to overgeneration periods.

2.2 IRWD's InfoWater Hydraulic Model

Innovyze's InfoWater program is the hydraulic modeling software used to represent IRWD's recycled water system. This computer simulation model transforms information about the physical water distribution system into a mathematical model that solves for various flow conditions based on specified water demands and system operations. The computer model generates information on pressure, flow, velocity, and head loss, which can be used to analyze the recycled water system performance. When pump energy efficiency data is input to the model, the model performs an Energy Management Simulation to compute time-of-use pumping energy demand.

IRWD has invested significant effort in creating, calibrating, and maintaining their recycled water model. The existing model includes the main service area in addition to the more recently added Lake Forest service area. The model provided to West Yost by IRWD contained two calibrated scenarios: Average Day Demand and Maximum Day Demand. These simulations are both configured to run for 10-day periods, which is sufficient to reach stable hydraulic results.

2.3 Project Constraints and Assumptions

The following section discusses constraints that provided boundaries for development and refinement of operational alternatives during this project. Certain assumptions were also made in development of the alternatives to allow sufficient flexibility to optimize the use of both energy and water.

2.3.1 Overgeneration Periods

The time when overgeneration of electrical energy occurs in California, both daily and seasonally, depends on a wide variety of factors including but not limited to the quantity, types, and location of different types of electric generation facilities and resources, and micro-climates, and weather conditions that impact both real-time electric production and electric demand. For the purposes of this project, daily overgeneration was defined to occur between 9:00 AM and 4:00 PM. Seasonal overgeneration was defined to occur between February 12 and June 15. The daily and seasonal overgeneration periods were used to develop adjustments to operations with the goal of shifting electrical demands into these overgeneration periods.

2.3.2 IRWD Hydraulic Criteria

Water systems are operated to provide an acceptable level of service to customers while meeting specific hydraulic criteria. Hydraulic criteria can include standards for pressure levels, velocity and headloss in pipes, and water levels in storage facilities. IRWD's Water Resources Master Plan publishes some hydraulic design standards for recycled water systems. Additional hydraulic criteria specific to the Lake Forest Area were determined based on discussions with District Staff. A list of IRWD hydraulic criteria is listed in Appendix C1. Operational alternatives were iterated in the model to satisfy all District hydraulic criteria, whenever possible. If criteria were not able to be met, the violations were recorded and described as part of the evaluation reporting.

2.3.3 LAWRP Flow Balance Determination

The ability to shift recycled water flows, both daily and seasonally in the Lake Forest service area is constrained by the amount of wastewater influent that is tributary to LAWRP. LAWRP cannot generate more recycled water than wastewater inflow is provided, and it cannot generate a yearly volume of recycled water that is greater than the yearly volume of wastewater provided.

The flow balance at LAWRP (consisting of: wastewater into LAWRP, recycled water out of LAWRP, ocean discharge out of LAWRP, and recycled water demand in Lake Forest Service Area) was evaluated from 2012 to 2017 to establish representative flow balance constraints. This critical flow balance is shown on Figure 1. It was determined that the 2016 water year (October 1, 2015 to September 30, 2016) would be used to represent flow balance at the LAWRP because that timeframe represented the most recent full year for which electrical billing data was also available for comparison at all the Lake Forest pump stations. The following values were taken from this timeframe to establish a flow balance for the evaluation.

2016 Water Year:

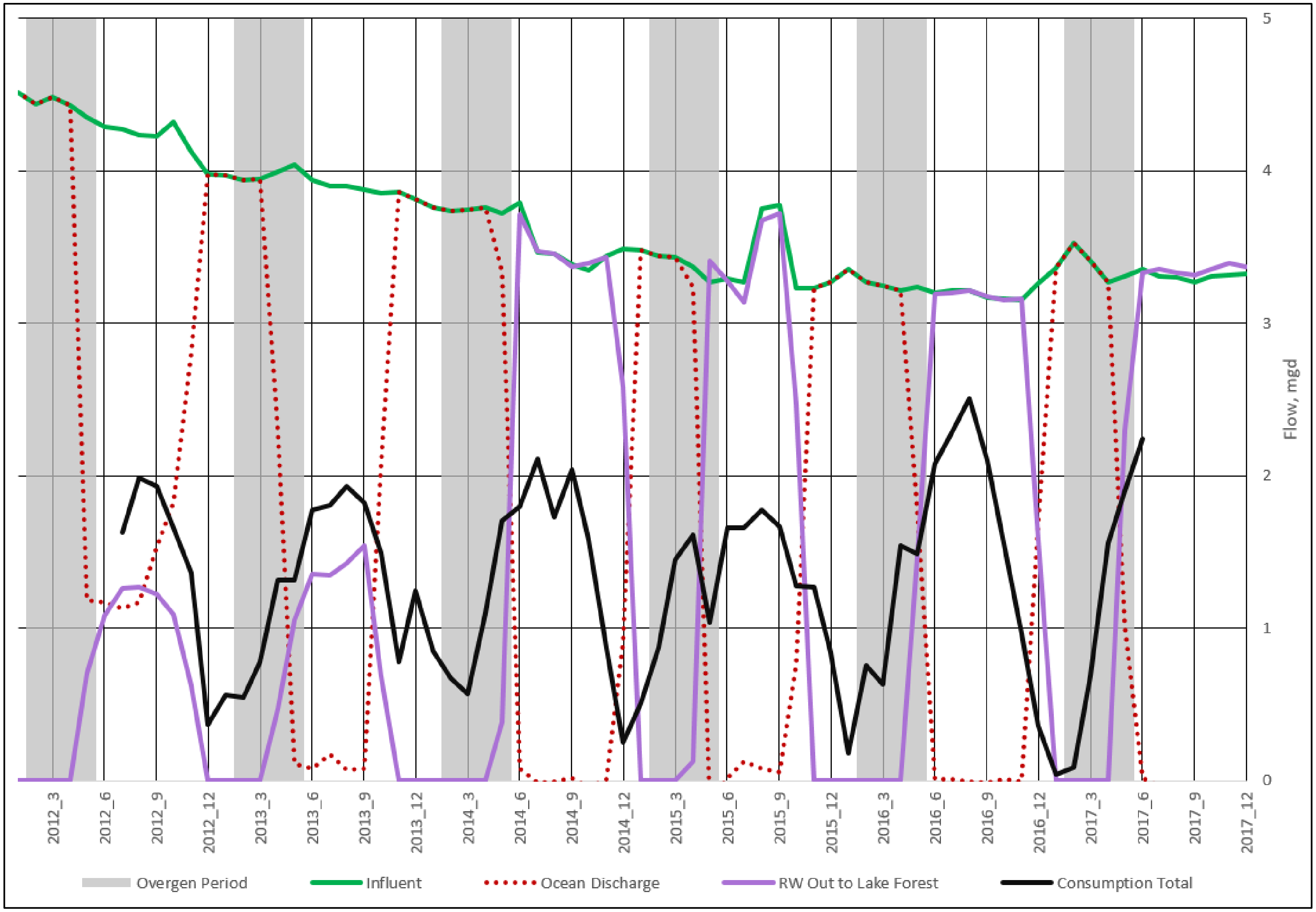
- LAWRP Influent: 3.23 million gallons per day (mgd)
- Lake Forest Service Area Recycled Water Winter Demands: 0.54 mgd
- Lake Forest Service Area Recycled Water Summer Demands: 2.53 mgd

Figure 1 presents the LAWRP flow balance from 2012 to 2017 and the seasonal overgeneration periods (in grey). The green plot shows the influent flow to LAWRP, the purple plot shows the recycled water delivered to the Lake Forest system, and the black plot shows the measured consumption in the Lake Forest System. A few items to note from the flow balance:

- The period from 2014-2017 illustrates the inverse relationship in LAWRP discharge between summer and winter demand conditions – in summer/high demand conditions, all recycled water is pumped to Lake Forest (purple plot) and in winter/low demand conditions, all treated effluent is discharged to the ocean (red dot plot) This reflects the two existing operating scenarios described above:
  1. Winter demand – LAWRP discharging secondary treated water to ocean.
  2. Summer demand – LAWRP pumping tertiary treated water to Lake Forest.
- The measured consumption plot (black line) differs from the recycled water used by Lake Forest plot (purple line) due to the sharing of flows between the Lake Forest and adjacent main service area, as described above.
- The influent wastewater flows (green plot) present a decreasing trend which has been observed across California W-WW utilities in the last seven years. This is due largely to the success of policies and programs targeting water use efficiency. A decrease in water use results in an associated decrease in wastewater produced and with it, the source of recycled water.

The LAWRP flow balance documentation can be found in Appendix C2.

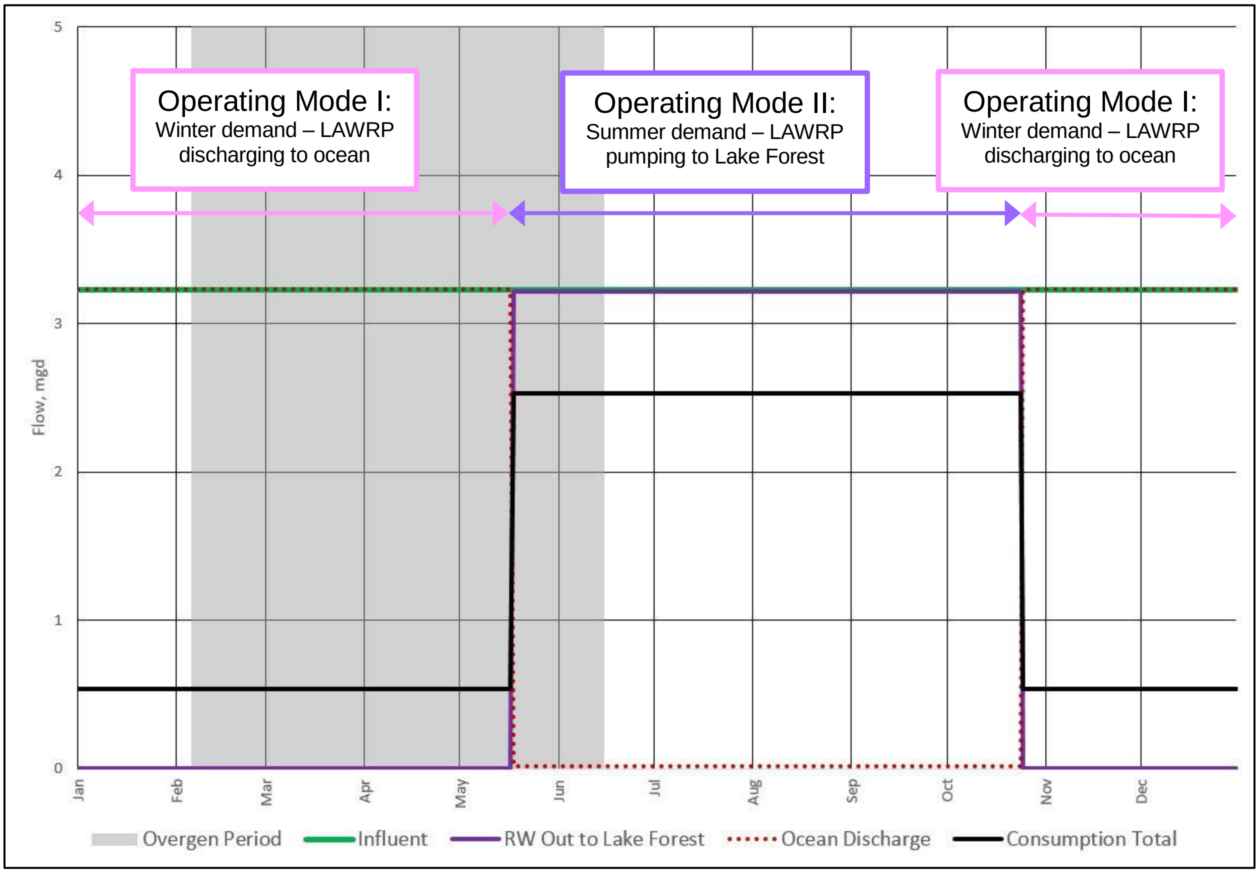
Figure 1. LAWRP Flow Balance (2012 – 2017)



2.3.3.1 Simplified Annual Flow Balance

The two current operating scenarios discussed previously and illustrated in Figure 1 were idealized to create a simplified seasonal flow balance for the system. The simplified operating scenarios were termed Operating Modes and used to simulate existing conditions within the hydraulic model. Figure 2 presents the simplified annual flow balance for Water Year 2016 and two current Operating Modes.

Figure 2. Annual Flow Balance – Current Conditions (2016 Water Year)



2.3.4 Upper Oso Seasonal Storage Reservoir (Oso Reservoir)

Oso Reservoir was used as a proxy for a seasonal storage facility due to its optimal elevation and because it was already represented in the existing hydraulic model. Oso Reservoir is owned and operated by Santa Margarita Water District (SMWD). IRWD has no contractual rights to any capacity in the Oso Reservoir but has been allowed by SMWD to connect Lake Forest Zone C to the reservoir because the resulting "open zone" configuration is much more efficient for IRWD's Zone C pump station than a "closed zone" configuration without the connection.

None of the analysis conducted for this project should be considered to imply that IRWD has or should acquire capacity rights in the Oso Reservoir. Seasonal storage could be provided at any similar location at a similar elevation, and the Oso Reservoir is not required for any of the outcomes evaluated.

2.3.5 Other Assumptions

Several further assumptions were made during this project. Both alternatives assumed that no external political or administrative constraints were placed on the selected operational changes. Considerations such as the feasibility of infrastructure upgrades, additional reservoir capacity, or an agency's willingness to accept operational complexity did not restrict the evaluation of full optimization of water and energy use. The initial assumptions and constraints discovered during evaluation have been documented for each alternative.

Unlike surface water, long-term storage of recycled water in open reservoirs in warm climates can negatively impact the water quality of the recycled water. This study does not address any water quality issues. It is recommended that if a project includes seasonal storage of recycled water a site-specific water quality study be conducted.

3.0 PREPARATION OF MODEL FOR STUDY USE

The IRWD InfoWater model provided to West Yost was not configured to run an energy analysis, so additional adjustments and verification were required to utilize the energy demand module. The hydraulic model was updated with the most recent pump performance curves and pump efficiency curves available. After this update, preliminary results from the energy demand module output were compared to historical energy billing records to validate the energy demand results.

3.1 Update and Verification of Model Pump Data

Accurate pump performance curves and pump efficiency curves that represent field conditions are critical for the hydraulic model to accurately simulate the energy consumed during pump operations. Results from SCE pump tests performed from 2003 to 2017 indicated that the pump performance and pump efficiency curves were degrading for all pumps located at the Zone B and Zone C pump stations. To account for the associated decrease in pump performance, existing pump performance curves in the model were adjusted using pump affinity laws. Affinity laws predict relationships in pumps among discharge, head, impeller speed or diameter, and required power. At the end of this iterative adjustment process, pump hydraulic performance as reported by the model matched pump performance as measured by the SCE pump tests, and the pump performance in all the Lake Forest pump stations was considered hydraulically verified. With hydraulic verification achieved, pump energy efficiency curves, which were not included in the existing model provided by IRWD, were added to the model using data obtained from the SCE pump tests.

The model, performance tests, and adjusted pump curves for each of the Lake Forest Service Area pumps are presented in Appendix C3 along with the historical SCE pump test results.

3.2 Energy Verification

The purpose of performing energy verification in the hydraulic model was to confirm that the model-simulated energy demand of the existing pumps matched the historical metered energy data, thereby confirming that the hydraulic model is a suitable tool for simulating energy demand.

Historical metered electricity data at 15-minute intervals was provided for the following facilities: LAWRP, Lake Forest Zone B pump station, and Lake Forest Zone C pump station. The Lake Forest Zone A pump station is located within the LAWRP. Electric usage by LAWRP, including the Zone A pump station, is recorded via a single SCE electric meter. Although IRWD sub-meters electric use for some functions within its water recycling plants such as LAWRP, this sub-meter data for the Lake Forest Zone A pump station is available only as monthly totalized data. The 15-minute billing data from the Zone B pump station and the Zone C pump station, as well as the monthly totalized energy consumption data for the Zone A pump station, was used to verify the energy demand predicted by the InfoWater hydraulic model.

3.2.1 Energy Verification Results

For the Lake Forest Zone B pump station and Lake Forest Zone C pump station, at which 15-minute energy demand billing data was available, the modeled energy demand results were compared against historical metered electricity usage data for dates in September 2016. These dates were selected as representative of maximum day demand condition during Water Year 2016 during which all three pump stations within the Lake Forest Service Area were in operation. Energy verification results are presented below, and further detailed in Appendix C4:

- Zone B pump station modeled energy demand matched within 4 percent of the 15-minute billed data for operations with a single pump in use, and within 1 percent for operations with two pumps in use.
- Zone C pump station modeled energy demand matched within 6 percent of the 15-minute billed data.

For both Zone B and C pump stations, because the billed data shows a small amount of energy demand even when no pumps are operating, it appears that the 1 percent to 6 percent variation may be due to the energy demand of non-pump infrastructure (lights, HVAC, SCADA, or similar) that is included in the billed data.

Unlike the pump stations described above, the Zone A pump station modeled energy demand could not be directly verified against 15-minute data due to the sub-meter configuration described above. The sub-meter totalizer for the Zone A pump station reported that 154,000 kWh were consumed by the pump station in September 2016. Hydraulic modeling results summarized for the same month indicate a total simulated energy consumption of 152,746 kWh, which agrees to the sub-meter data within 1 percent. Given that the monthly totalized results for the Zone A pump station agree within 1 percent, and that the hydraulic verification performed for the pumps within the Zone A pump station was identical to that performed for the other two pump stations (and the pump energy efficiency curves for the Zone A pump station were taken from the same source as those for the other two pump stations – SCE pump tests), it is reasonable to assume that the Zone A pump station energy demands simulated in the hydraulic model match the true demands in the field within the same 1 percent to 6 percent range seen for the Zone B and Zone C pump stations.

The energy verification described above, in which simulated energy demand results match within one percent to six percent of measured field data, is well within the industry-accepted tolerance of 10 percent for calibration of hydraulic models. This tolerance reflects the inherent limitations to: the quality of available input data; accuracy and precision of field measurements; and mathematical algorithms that simulate physical processes. In all cases, the precision of the verification required depends on the intended use of the model. The energy evaluations in this study are all based upon comparisons of baseline conditions simulated in the hydraulic model to proposed alternatives simulated in the hydraulic model. For the purposes of these comparisons, the hydraulic model is an accurate tool for simulating energy demand from the Lake Forest pump stations.

3.3 Infrastructure Modifications

Very limited infrastructure modifications to the hydraulic model were required for this project because of the focus on operational adjustments. The primary modifications were the addition of PRVs to the model to allow flow to backfeed from higher zones to lower zones. The PRVs were required to simulate Alternative 2, but they were not required to simulate the Baseline Alternative or Alternative 1.

PRVs can be installed adjacent to existing infrastructure and function by opening (under high pressure) or closing (when pressure reaches lower, acceptable levels) based on set pressure ranges. Water system pressures must be kept under set maximum levels to protect water system infrastructure and provide suitable water pressure to customers. Infrastructure modifications required under each operating alternative are described in the respective results section.

4.0 DEVELOPMENT OF OPERATIONAL ALTERNATIVES

Operational alternatives to be tested and evaluated in the hydraulic model were identified, refined, and vetted in collaboration with IRWD, WEI, and SCE. In addition to the two operational adjustment alternatives, a Baseline scenario representing the current operations and energy use was required to quantify the changes in electric impacts achieved by the two operational alternatives. The Baseline and two alternatives are described below.

4.1 Baseline – Current System Operation

A Baseline scenario was developed using current daily and seasonal operational patterns. IRWD currently operates pump stations in the Lake Forest recycled system with time-of-use (TOU) restrictions to avoid pumping during periods when electrical rates are highest. Under current SCE tariff schedules, the highest electric prices are "summer on-peak" – noon to 6:00 PM on summer weekdays (Monday through Friday, June through September). Seasonal operation is dictated by the onset of summer irrigation demands, typically running from mid-May through October. Appendix C5 presents the Baseline daily and seasonal operating conditions.

Calibrated electrical efficiency data (discussed in detail in Section 3.1) was applied to estimate daily and seasonal energy use based on the 2016 Water Year. The estimated Baseline energy use was used to evaluate the changes in TOU and seasonal electric impacts attributable to the adjusted operational alternatives.

4.2 Alternative 1 – Daily Time-of-Use Adjustments

The purpose of Alternative 1 was to evaluate IRWD's operational flexibility within the Lake Forest service area to 1) avoid or minimize pumping during high priced summer on-peak periods, and 2) maximize pumping during daily overgeneration periods. The summer time of day which is considered on-peak is expected to change due to overgeneration. This study assumes that on around March 2019, on-peak will change from noon to 6:00 PM, to 4:00 PM to 9:00 PM.

Alternative 1 updated the TOU controls in the model to minimize pumping from 4:00 PM to 9:00 PM and to maximize pumping during the overgeneration period from 9:00 AM to 4:00 PM. The controls were refined so that pumping was confined to the overgeneration window as much as possible while maintaining IRWD's hydraulic criteria. For Alternative 1, no seasonal adjustments were made. The system was assumed to operate seasonally as it had during Water Year 2016 – producing and supplying recycled water to Lake Forest from mid-May through October when needed to supply irrigation demand, and supplying recycled water from IRWD's main service area (fed primarily by MWRP) during other times of the year (the Baseline condition described above).

Appendix C5 presents the Alternative 1 daily and seasonal operating conditions. Note that the seasonal operating conditions in Alternative 1 are the same as the Baseline conditions.

4.3 Alternative 2 – Seasonal Storage Adjustments

The purpose of Alternative 2 was to evaluate the seasonal overgeneration mitigation potential achievable by providing additional seasonal storage within the Lake Forest service area. In addition to simply shifting seasonal pumping to better align pumping times with the seasonal overgeneration period, increased seasonal storage would increase recycled water supply to serve new demands within the Lake Forest system, other IRWD recycled water systems, and/or to provide recycled water for sale to other water purveyors.

IRWD's LAWRP provides recycled water for the Lake Forest service area. Under current seasonal operations, the LAWRP produces recycled water when irrigation demand is high (primarily summer months). During the winter months, LAWRP effluent is discharged through an ocean outfall. This seasonal operation is entirely demand driven and is not optimized in terms of matching pumping electrical demand to seasonal overgeneration periods because there is little winter demand, and no seasonal storage at this time.

Alternative 2 evaluated the hydraulics and energy impacts of capturing the flow that is normally discharged to the ocean and pumping this flow to storage during seasonal overgeneration periods. Seasonal storage simulated at the top of Zone C was distributed by gravity when demand was present in the lower zones of the system. The analysis evaluated existing system constraints for seasonally storing and using water, and identified infrastructure improvements (e.g., PRVs) to maximize available supply on an annual basis.

Appendix C5 presents the Alternative 2 daily and seasonal operating conditions. Note that the daily operating conditions in Alternative 2 are the same as Alternative 1 (the March 2019 daily time-of-use changes developed in Alternative 1 were applied). The seasonal operating conditions for Alternative 2 shift the recycled water production and pumping to align with the seasonal overgeneration period.

4.4 Extrapolation of Modeling Results to Annual Summary

The hydraulic model is the primary tool for evaluating the energy impacts of operational changes. However, the hydraulic model can only provide results for the 10-day periods contained in its scenarios. Furthermore, the hydraulic model has no way to account for constraints such as those provided by the LAWRP flow balance or the long-term fluctuations of storage facilities, as described above. A further tool is needed to 1) to impose constraints that are external to the distribution system, and 2) extrapolate the limited results presented by the model to a yearly summary.

4.4.1 Annual Simulation Tool

To address this, need a tool for both purposes that was developed for this project. The tool is named the *Annual Simulation Tool*. It is an Excel workbook that assigns the modeling results from the limited 10-day simulations to designated days throughout the year to create a full year's worth of results for each alternative. It then summarizes the pumping, storage, and energy results for the yearly period with respect to overgeneration periods and identifies times during which external constraints are violated so that the modeling operations can be modified, iterated, and reassessed.

The workbook functions are described further below and documented in detail in Appendix C5.

4.4.2 Operating Modes

The *Annual Simulation Tool* provides date controls and logic that apply model simulations over appropriate dates, or Operating Modes, to create a full year simulation. Operating Modes are based on a combination of recycled water demand conditions (summer or winter) and LAWRP pumping parameters (pumping or not pumping to Lake Forest). These combinations result in four distinct Operating Modes:

Operating Mode I: Winter demand; LAWRP not pumping to Lake Forest

Operating Mode II: Summer demand; LAWRP pumping to Lake Forest

Operating Mode III: Winter demand; LAWRP pumping to Lake Forest

Operating Mode IV: Summer demand; LAWRP not pumping to Lake Forest

Table 2 and Figure 3 on the following page show the two Operating Modes (Modes I and II) present in the Baseline and Alternative 1 operating conditions. Table 3 and Figure 4 show the operational adjustments applied in Alternative 2: the workbook controls were used to shift the start of LAWRP pumping to align with the seasonal overgeneration period. This shifting results in periods where there is 1) pumping recycled water when there is no recycled water demand, and 2) when there is recycled water demand, but no recycled water pumping. Therefore, all four Operation Modes are used by Alternative 2.

As shown in Figure 4, the start of pumping (Operating Mode III) is aligned with the start of the seasonal overgeneration period, even though the system is experiencing winter demand conditions.

Table 2. Baseline & Alternative 1 – Operating Modes

	Demand Condition																							
	Winter									Summer											Winter			
	January		February		March		April		May		June		July		August		September		October		November		December	
LAWRP Operation	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15
Pumping to Lake Forest															II									
Not Pumping to Lake Forest					I																	I		

Figure 3. Baseline & Alternative 1 – Operating Modes

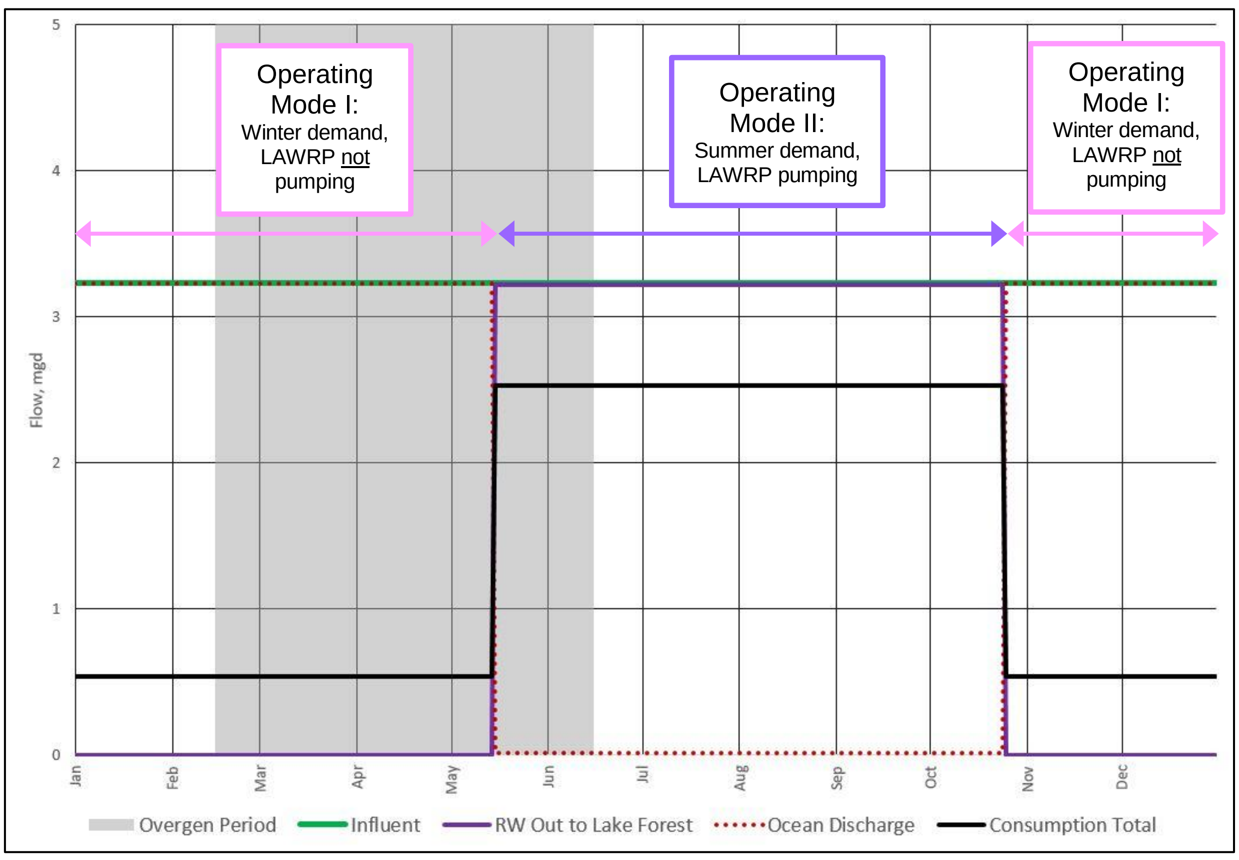
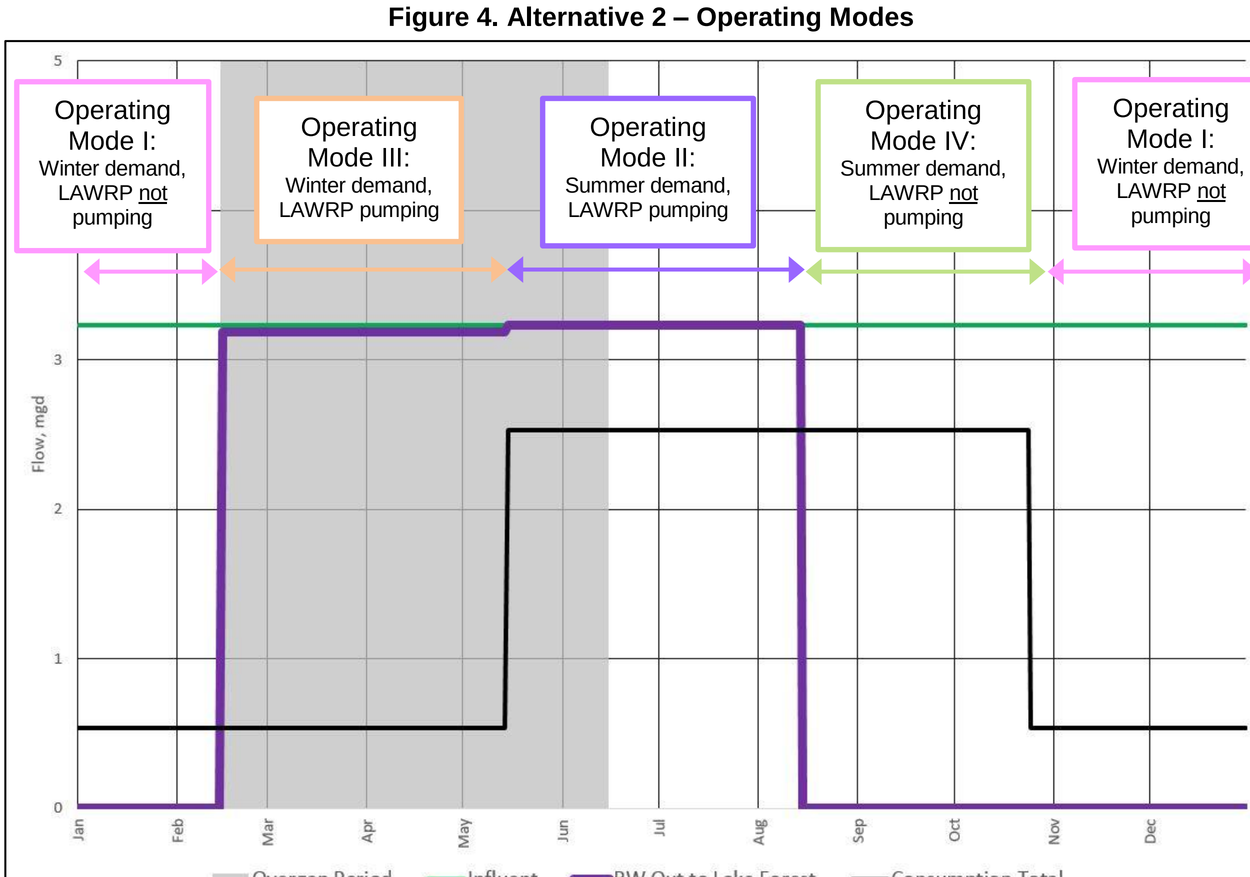


Table 3. Alternative 2 – Operating Modes

	Demand Condition																							
	Winter									Summer											Winter			
	January		February		March		April		May		June		July		August		September		October		November		December	
LAWRP Operation	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15
Pumping to Lake Forest							III						II											
Not Pumping to Lake Forest		I																IV				I		

Figure 4. Alternative 2 – Operating Modes



4.4.3 Energy Timing Categories

In the Tool, as Operating Modes are adjusted to suit the overgeneration periods, estimated annual energy use is calculated by extrapolating model results and Operating Mode timing over the entire year. The workbook breaks down energy results down according to the energy timing category:

- Energy used during Daily Overgeneration periods;
- Energy used during Seasonal Overgeneration periods; and
- Energy used during both Daily and Seasonal Overgeneration periods.

4.4.4 Summary of Alternatives

Table 4 provides a summary of pumping parameters used for each operational alternative. As can be seen, each alternative builds on the previous alternative TOU and overgeneration optimization.

Table 4. Comparison of Alternatives

Pumping Parameters	Baseline	Alt. 1	Alt. 2
Avoid Pumping Noon to 6:00 PM	●		
Avoid Pumping 4:00 PM to 9:00 AM		●	●
Pump during Overgeneration Daily Periods		●	●
Pump during Overgeneration Seasonal Periods			●

5.0 OPERATIONAL ALTERNATIVE EVALUATION AND RESULTS

Results from evaluation of the Baseline and operational Alternatives 1 and 2 are presented below.

5.1 Baseline Alternative – Current System Operation

5.1.1 Energy Results

The energy results from the Baseline (current operation) analysis can be seen in Table 5. As shown in the table and Figure 3, pumping takes place and energy is consumed only during the 5.5 months of Operating Mode II (mid-May through end October, when demands are high enough to operate the recycled water production at the LAWRP). Based upon the timing of recycled water production from the 2016 Water Year, one month of Operating Mode II corresponded to the overgeneration period, but the majority (4.5 months: mid-June through end October) did not.

Using existing hydraulic model controls, the majority of the pumping that occurred during the simulated year took place outside of the daily overgeneration period as well. According to the hydraulic simulation, approximately 1.48 million kilowatt hours (kWh) are consumed in pumping during the year. Using the existing daily controls, approximately 32 percent of this energy is consumed during the daily overgeneration period as shown in Table 5. The energy consumption shown in Table 5 is summarized for an entire year.

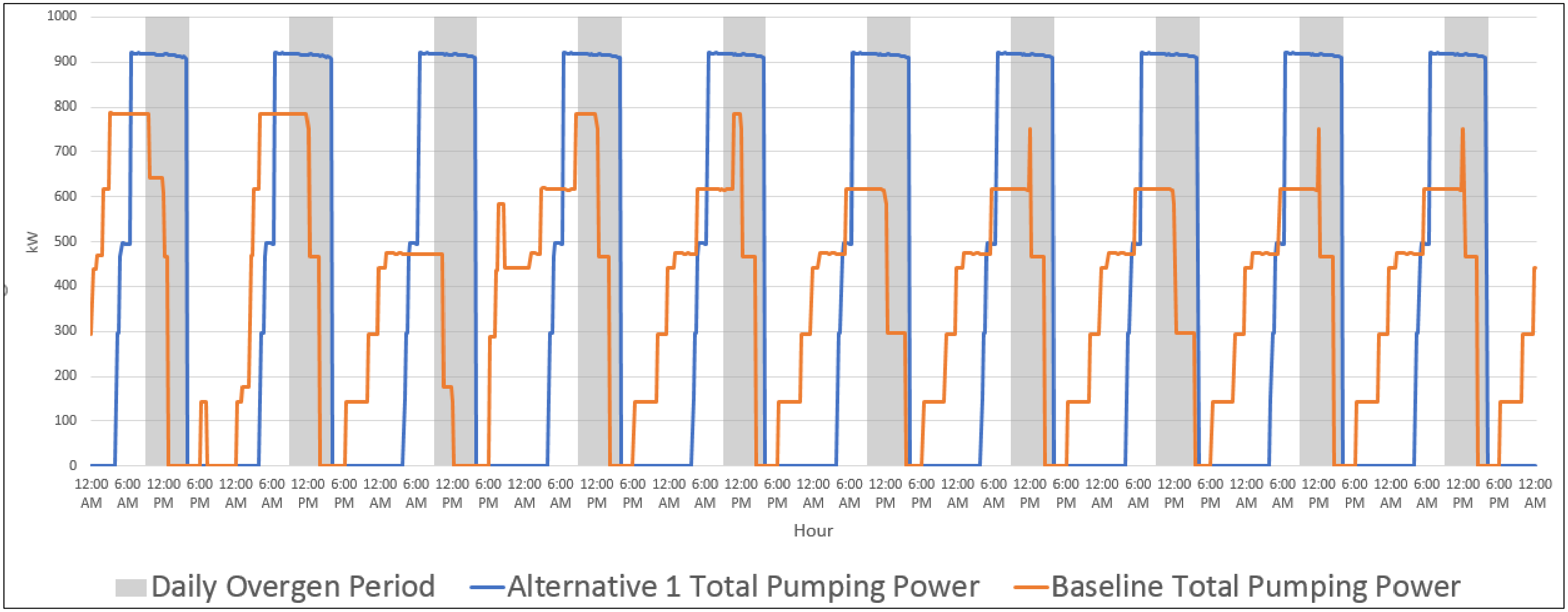
Table 5. Baseline – Energy Use Summary for 2016 Water Year

Seasonal Electricity Overgeneration	Operating Mode	Existing Daily Pump Energy Consumed, kWh		
		Total Energy Used	Total During Daily Overgeneration	Total During Daily Non-Overgeneration
Yes	I	-	-	-
Yes	II	288,000	92,000	196,000
No	II	1,190,000	379,000	811,000
No	I	-	-	-
	Total	1,478,000	471,000	1,007,000
		Percent of Total	32%	68%

5.1.2 Power Results

The power results from the Baseline are shown on Figure 5, in the orange plot (*Baseline Total Pumping Power*). As can be seen, under existing operations the maximum power demand for all three pump stations in the Lake Forest service area is approximately 790 kW. Peak power demand varies throughout the day due to operational timing of filling reservoirs and cannot be expected to occur during the daily overgeneration period consistently. The pumping pattern, and therefore power demand pattern, falls into a repeatable pattern over the last five days of the simulation except a very brief spike that occurs on some days because the system is right on the edge of requiring one particular pump to turn on. Because the power results are taken from the instantaneous power requirements reported by the hydraulic model and therefore do not require annual summarizing, the power results are taken directly from the 10-day simulation of the hydraulic model. It should be noted that these results include the power for the booster pump stations in the system, not for the process pumps contained in the LAWRP.

Figure 5. Daily Pumping Power Requirements, Baseline



5.1.3 Hydraulic Results

As expected, the Baseline operating conditions did not show any hydraulic deficiencies based on IRWD criteria. The hydraulic results from the Baseline operations are detailed in Appendix D1.

5.2 Alternative 1 – Daily Time-of-Use Adjustment

5.2.1 Energy Results

The energy results from the Alternative 1 daily TOU adjustments are presented in Table 6. When Table 6 is compared to Table 5 (Baseline), it can be seen that the Alternative 1 results, like the Baseline, have no pumping during the winter scenario – Operating Mode I (Alternative 1 did not seek to produce, deliver, and store recycled water from LAWRP during winter months). For Alternative 1, the energy consumption during the daily overgeneration period more than doubled from the Baseline conditions (471,000 kWh to 1.05 million kWh). Table 6 shows that 66 percent of the total annual energy consumption for the simulated year occurs during daily overgeneration periods (compared to 32% for the Baseline Alternative).

For Alternative 1, the total annual energy consumed by pumping increased, from 1.48 million kWh to 1.60 million kWh (8 percent increase) even though the same amount of water was pumped in both cases. Focusing pumping activity to the overgeneration period results in running multiple pumps more frequently, and the higher flows resulting from this operation produce higher frictional losses and therefore required more energy.

Table 6. Alternative 1 – Proposed Daily Pumping Strategy for 2016 Water Year Energy Summary

Seasonal Electricity Overgeneration	Operating Mode	Proposed Daily Pump Energy Consumed, kWh		
		Total Energy Used	Total During Daily Overgeneration	Total During Daily Non-Overgeneration
Yes	I	-	-	-
Yes	II	312,000	205,000	107,000
No	II	1,288,000	846,000	442,000
No	I	-	-	-
	Total	1,600,000	1,051,000	549,000
		Percent of Total	66%	34%

5.2.2 Power Results

The power results from Alternative 1 are shown on Figure 5, in the blue plot (*Alternative 1 Total Pumping Power*). As can be seen, under Alternative 1 adjusted operations, the maximum power demand for the pump stations in the Lake Forest service area is approximately 920 kW. This power demand can be consistently generated during the daily overgeneration period with the modified controls proposed in Alternative 1.

5.2.3 Hydraulic Results

The hydraulic results from Alternative 1 are detailed in Appendix D2. As shown in the appendix, the proposed operations result in larger tank level variations throughout the Lake Forest service area, but all other IRWD design and performance criteria are met throughout the simulation.

5.3 Alternative 2 – Seasonal Storage Adjustment

5.3.1 Energy Results

The energy results from the seasonal adjustments of Alternative 2 are presented in Table 7. It should be noted that the seasonal adjustments included in Alternative 2 also incorporate the daily control adjustments developed for Alternative 1. Therefore, the results in Table 7 indicate that approximately 65 percent of the pumping is taking place during the daily overgeneration period, comparable to the daily results in Table 6 for Alternative 1 (66 percent).

Table 7. Alternative 2 – Proposed Seasonal Pumping Strategy for 2016 Water Year Energy Summary

Seasonal Electricity Overgeneration	Operating Mode	Proposed Daily Pump Energy Consumed, kWh		
		Total Energy Used	Total During Daily Overgeneration	Total During Daily Non-Overgeneration
Yes	III	954,000	611,000	343,000
Yes	II	333,000	220,000	113,000
No	II	624,000	412,000	212,000
No	I	-	-	-
No	IV	-	-	-
	Total	1,911,000	1,243,000	668,000
		Percent of Total	65%	35%

When Table 7 is compared to Table 5 (Baseline), the most prominent result is that total energy consumption has increased by approximately 29 percent in Alternative 2 (1.48 million kWh to 1.91 million kWh). This increase accounts for the 8 percent increase described above when daily controls are modified, in addition to a remaining 21 percent increase in total energy consumption. This extra energy consumption is the result both of higher friction losses that result from 1) higher velocities (more water is being moved in a shorter time, resulting in higher velocities and greater energy required to pump) and 2) a significant amount of water is pumped and stored at the highest elevation in the service area during seasonal storage. Additional energy may have been consumed due to the shift in operating point of individual pumps under adjusted operating conditions. Changes to pump operating points and the associated energy impacts were not evaluated as part of the analysis.

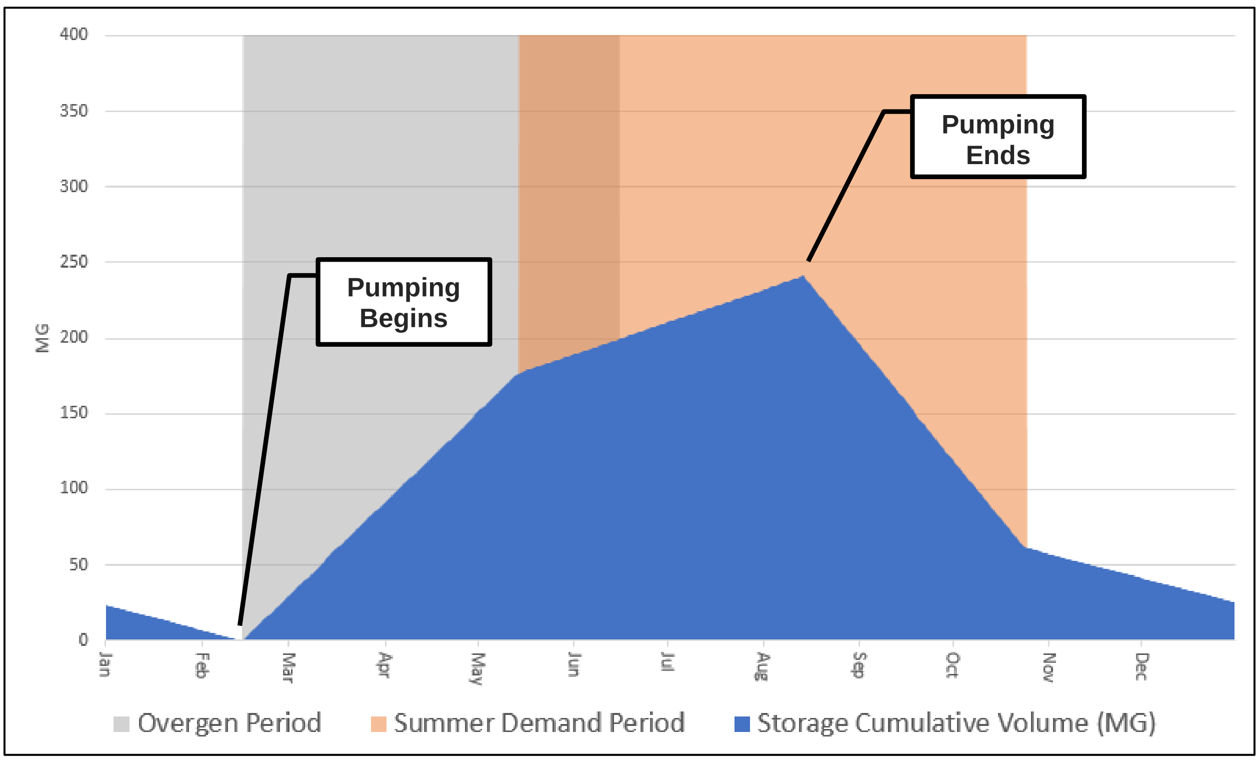
Comparing Table 7 to Table 5 shows that the proposed seasonal adjustments result in a significant amount of pumping energy consumed (611,000 kWh, or 32 percent of total energy use) during the winter overgeneration period (Operating Mode III). Operating Mode III was not present in the Baseline conditions. This winter energy consumption results from the fact that recycled water is intentionally pumped in significant quantities to the top of Zone C for storage during the winter. This water is then fed by gravity to customers during the summer, resulting in much less energy consumption during the summer. Customers in Zone A and Zone B are fed by gravity from water that was pumped up to the Zone C storage, whereas under existing operations this water would only be pumped to the zone that demanded it.

In Alternative 2, the energy consumption during the daily overgeneration period is maintained at 65 percent of the total annual energy consumption. However, the amount of energy consumed during the seasonal overgeneration periods is greatly increased (6 percent in Baseline, increased to 43 percent in Alternative 2).

5.3.2 Seasonal Storage Results

Figure 6 shows the amount of recycled water stored in seasonal storage over the course of the simulated year of operation for Alternative 2. Starting in February when the seasonal overgeneration period begins, pumping starts, sending water from LAWRP to the top of Zone C for storage. Pumping continues through early August, until the total volume of stored recycled water is sufficient to satisfy the existing Lake Forest recycled water demand for the remainder of the year (a maximum volume of 242 MG).

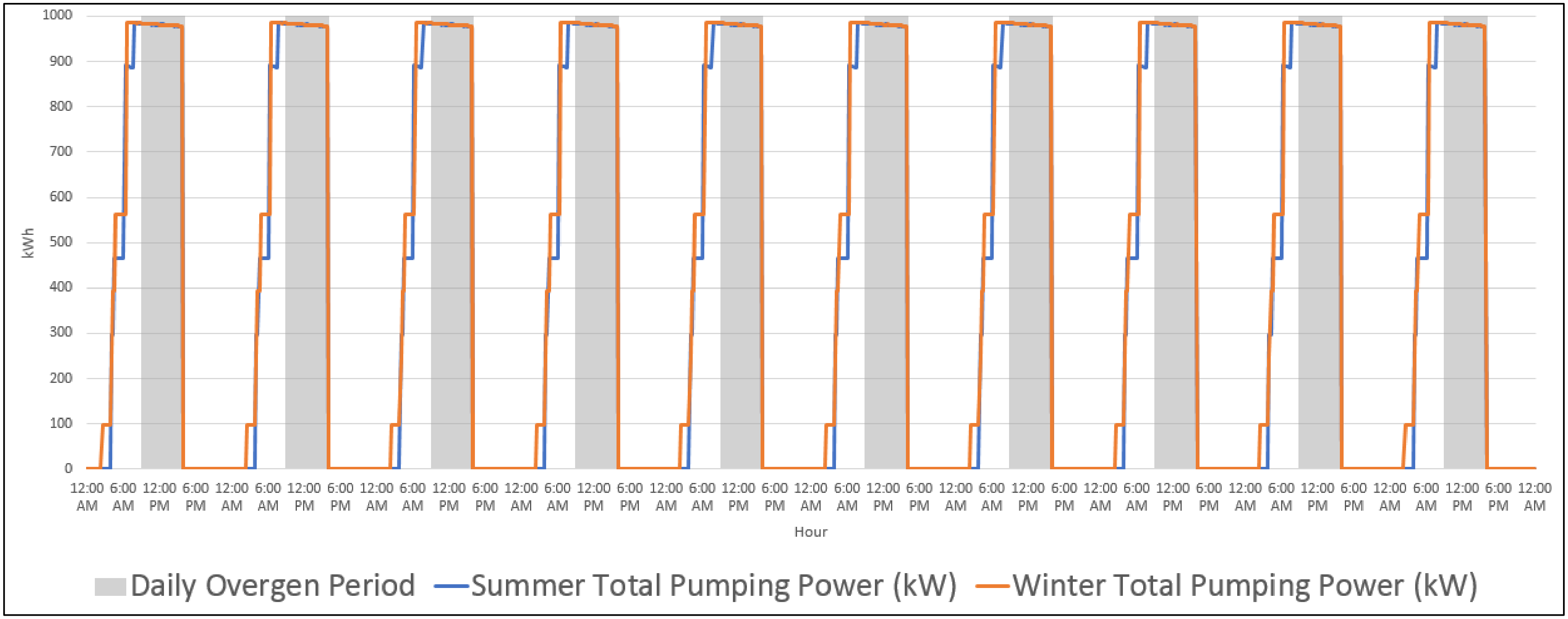
Figure 6. Seasonal Storage Volume in Zone C, Alternative 2



5.3.3 Power Results

The power consumption using the proposed seasonal operational changes is shown on Figure 7. As shown, the peak power consumption is approximately 990 kW. The peak power consumption is increased from that of existing operation because more power is being used to convey water into Zone C storage at the top of the system. With the proposed daily and seasonal operational changes that are included in Alternative 2, the peak power consumption can be reliably targeted to both the daily and the seasonal overgeneration periods.

Figure 7. Daily Pumping Power Requirements, Alternative 2



5.3.4 Hydraulic Results

Hydraulic results indicated that infrastructure improvements were required to allow seasonal storage in Zone C to feed the entire service area. PRVs were added at the connection point between Zone A and B, and Zone B and C to reduce pressure coming from higher zones. PRVs were placed in close proximity to existing pump stations because they have large diameter pipelines for feed and discharge, which can be easily retrofit. This configuration also maintains the existing hydraulic backbone for both existing pump operations and for the hypothetical backfeeding operations.

The hydraulic results from Alternative 2 are detailed in Appendix D3.

5.4 Analysis Summary

Table 8 presents a summary of the energy results for the Baseline and two operational alternatives. The table displays the results for energy consumed during daily overgeneration and seasonal overgeneration periods. As shown in the table, the results of Alternative 1 indicate that energy used during daily overgeneration periods would be more than doubled compared to Baseline conditions. As would be expected, Alternative 1 provides almost no improvement compared to Baseline conditions with regard to energy consumed during seasonal overgeneration periods. Alternative 2, which incorporates the daily changes reflected in Alternative 1 in addition to the seasonal changes unique to Alternative 2, provides significant increases in energy consumption during both daily and seasonal overgeneration periods.

Table 8. Results Summary – Total Energy Consumed, Daily and Seasonal Overgeneration

Alternative	Pump Energy Consumed, kWh				
	Total During Daily Overgeneration	Total During Daily Non-Overgeneration	Total During Seasonal Overgeneration	Total During Seasonal Non-Overgeneration	Total Energy
Baseline (Existing Conditions)	471,000	1,007,000	288,000	1,190,000	1,478,000
Alternative 1	1,051,000	549,000	312,000	1,288,000	1,600,000
Alternative 2	1,243,000	668,000	1,287,000	624,000	1,911,000

Table 9 presents the total energy used during both daily and seasonal overgeneration periods simultaneously. The energy used during both daily and seasonal overgeneration periods consists of the intersection of the energy used during the daily overgeneration period and the energy used during the seasonal overgeneration period. As an intersection (subset) of these values, the energy used during both daily and seasonal overgeneration periods is a smaller value than either value separately. Although increasing the energy consumed during any overgeneration period can be valuable, energy consumed during both the daily and the seasonal overgeneration periods provide a convenient summary of effectiveness for each alternative. The results in Table 9 indicate that proposed operational adjustments shifted energy consumption into periods of overgeneration on both a daily and seasonal basis. The percent of total energy used during both daily and seasonal overgeneration periods increased by 37 percent between the Baseline and Alternative 2 (6 percent to 43 percent).

Table 9. Results Summary – Total Energy Consumed, Daily + Seasonal Overgeneration

Alternative	Pump Energy Consumed, kWh: Total Energy	Pump Energy Consumed, kWh: Total During Daily + Seasonal Overgeneration	Percent of Total Energy During Daily + Seasonal Overgeneration
Baseline (Existing Conditions)	1,478,000	92,000	6%
Alternative 1	1,600,000	205,000	13%
Alternative 2	1,911,000	831,000	43%

The results of the evaluation as described above indicate that operations within the Lake Forest service area can be modified, both daily and seasonally, to significantly increase the total energy consumption and the peak power demand supplied during daily and seasonal overgeneration periods. These impacts could be realized with minor infrastructure improvements. However, as indicated on Figure 6, with existing infrastructure, a significant amount of storage must take place during summer demands and outside of the overgeneration period to make the seasonal mass balance complete. With the addition of further pumping capacity, particularly into Zone C, pumping time and therefore energy demand and consumption could be further focused into the overgeneration periods. The Alternative 1 impacts could be accomplished with daily changes to operations and minimal infrastructure investment. The Alternative 2 impacts would require substantial changes to operations on a seasonal basis, as well as significant new storage.

The results for both Alternative 1 and Alternative 2 indicate that one of the costs for creating higher energy demands during the overgeneration periods is higher overall energy consumption. Part of this higher consumption is due to increased peak pumping and therefore increased velocities and headloss. The increased headloss could be mitigated by replacing key pipelines in the distribution system with larger diameter pipeline. Another part of this increased consumption is because all seasonal storage water, even that which will be consumed in lower zones, is assumed to be pumped to the top of Zone C, and then backfed as necessary. Seasonal storage that is distributed among the distribution system zones would eliminate some of this extra power consumption. Given the rarity of locations that are large enough and at the right elevations to provide seasonal storage, such storage facilities may be difficult and potentially costly to site.

6.0 VALIDATION OF EVALUATION RESULTS

Energy demand for individual pumps was validated at the beginning of this evaluation, as described in Section 3.1. The energy demand during operation of the Zone B and Zone C pumps was validated to energy records, also as described above.

Monthly energy consumption for Zone A, Zone B, and Zone C pump stations were totaled monthly for the 2016 Water Year that was simulated in the model for the Baseline condition; these consumption values were then compared to the energy billing data. During months in which the pump stations are simulated to operate, electrical consumption data from the model corresponded to electrical billing data within 6 percent in all cases. During months for which the pump stations were simulated not to operate, there was still electrical demand at the pump stations according to the billing records, although at much smaller amounts. Therefore, the yearly validation totals do not quite correlate, but this result is likely an artifact of not understanding how the study area currently operates during existing winter conditions, and not an artifact of calibration errors in the model. The results could be modified in the results spreadsheet with a better understanding of winter operations.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The results presented in this report indicate that there is potential to mitigate overgeneration, both on a daily and seasonal basis, in the Lake Forest service area of the IRWD recycled water system. The mitigation impact identified and described above is based primarily on operational changes. The Alternative 1 impacts could be accomplished with daily changes to operations and minimal infrastructure investment. The Alternative 2 impacts would require substantial changes to operations on a seasonal basis, as well as significant new storage. The infrastructure changes required to implement the operational changes described above include the addition of 1) PRVs between Zones, A, B, and C to allow for backfilling of lower zones from Zone C to implement seasonal storage and 2) additional storage at an elevation and location at the top of Zone C. No pipeline improvements were required to achieve the results contained in this report. However, pipeline improvements could enhance the results by reducing the overall energy increase that was reported.

7.1 Enhancements to Evaluation of Current Study Area

Future evaluations could be performed to further enhance the potential for overgeneration mitigation at this location.

1. Additional infrastructure improvements may offer the ability to further align energy use within overgeneration periods. Additional pumping capacity in the study area would allow pumping to be targeted more closely to overgeneration periods, both daily and seasonally. Any proposed increase in pump capacity should be evaluated in conjunction with pipeline constraints and possible pipeline improvements with the aim of minimizing increased headloss and associated increases in energy use.
2. Recycled water demand timing, both daily and seasonally in the study area, impacts the ability to align pumping periods with overgeneration periods. It is possible that at least some recycled water customers could alter the timing of their irrigation demand to enable more mitigation of overgeneration. No effort was made to evaluate the impact of changing demand timing.
3. Alleviating the hydraulic model demand constraint to allow maximizing production and use of all recyclable water at LAWRP could substantially change the timing and magnitude of electric use. Additional recycled water could be used both within Lake Forest and other parts of IRWD's service area, and potentially through selling excess recycled water to other water districts. In combination with sufficient seasonal storage, it is conceivable that much more electric use may coincide with periods of overgeneration.

7.2 Further Lessons Learned from Evaluation

Beyond the technical results obtained from the evaluation of the study area, several critical lessons were identified during this project:

1. While the hydraulic model is critical for evaluation, the hydraulic model can only provide a snapshot of a particular hydraulic scenario. Furthermore, the hydraulic model cannot independently determine the constraints (for example, LAWRP recycled water output) that are critical to an evaluation such as this. This project demonstrated that translating external constraints and results modeled, into spreadsheet format or similar, is equally important to the hydraulic model for an overgeneration analysis such as this. The workbook created for this project has scalable logic and controls that could be efficiently expanded to include the entire IRWD recycled water system, expanded to include an evaluation of the potable water system, or adapted to other W-WW districts' systems. The workbook's logic, use of constraints, calculation process, and summaries are not specific to any particular hydraulic model or service area and can span multiple model inputs from different systems.
2. Originally this project focused on the hydraulic modeling portion of the assignment as the primary tool for evaluation. As development of operational alternatives progressed, it became clear that significant effort would be required to understand, define, and quantify external constraints applied on each alternative by the LAWRP flow balance. If this type of project was to be undertaken again, it would be prudent to fully understand the boundary conditions before estimating a level of effort for evaluation and modeling, or making conceptual conclusions about potential impact to energy use.
3. Seasonal storage provides the ability to mitigate seasonal overgeneration. However, it is difficult to locate and expensive to construct. In addition, in this evaluation, this ability to mitigate comes at the expense of greater overall energy consumption because all the water in seasonal storage is pumped to the top of the system in the Lake Forest service area configuration. In the case of the overall IRWD recycled water model, storage may be available at a location that is not at the top of the system, and thus the overall energy increases may be mitigated in an analysis. Seasonal storage that is distributed among pressure zones, though not always feasible, may prove critical.
4. A water quality evaluation of the impacts of open-reservoir storage of recycled water was not part of this study and should be considered in future studies if such a project is being seriously considered.
5. W-WW hydraulic models can be a valuable tool for assessing electric impacts of changes to W-WW systems and operations and provided the basis for the evaluation. Although IRWD's Lake Forest recycled water system is fairly isolated from the larger overall service area, there is still a sharing of flows which was not fully reconciled in the model. Therefore, the accuracy and relevance of the results included in this report would be increased by broadening the evaluation to include the entire IRWD recycled water model. Because of the groundwork put in place as part of this study, such an expansion of the study area could be accomplished relatively efficiently.

6. For other potential study areas looking to be evaluated for overgeneration impacts, a preliminary feasibility evaluation method should be developed. The feasibility evaluation could utilize a simplified version of the Annual Simulation Tool developed as part of this project to estimate the potential benefits to overgeneration impacts in the study area at a feasibility level. With such an estimate in place, both the electrical utility and the W-WW utility could understand the benefits and costs of undertaking a full hydraulic model evaluation of a potential study area.