Orange County Utilities Northwest Water Reclamation Facility: Expansion Design

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As a pedagogical exercise to provide hands-on experience in wastewater treatment plant design, the Florida Water Environmental Association (FWEA) conducts an annual student competition for universities in the state.

The design problem for the academic year 2005-2006 was the expansion of Orange County Utilities' Northwest Water Reclamation Facility (NWRF), located in Apopka.

The NWRF facility employs an advanced secondary biological wastewater treatment unit operation and is permitted to treat 7.5 million gallons per day (MGD) of wastewater on an annual average daily flow (AADF) basis. The facility began operations in 1987, underwent its first expansion in 1994, and is scheduled to undergo another expansion to meet flow demands for the year 2025 because of increasing development and population in the NWRF sewershed.

The NWRF is situated on 700 acres of land within the 300,000-acre environmentally sensitive Wekiva Study Area (WSA). As a result, the Florida Department of Environmental Protection (FDEP) has proposed more stringent controls on effluent wastewater quality.

Recommendations were based on definable areas recharging the Floridan Aquifer. Three protection zones were created to define required total nitrogen (TN) reduction levels, based on vulnerability to wastewater discharge as per the findings of the Florida Aquifer Vulnerability Assessment. The recommended TN limits form the basis of the plant expansion design options and are defined as follows (FDEP, 2004):

- Primary Protection Zone TN: < 3 mg/L
- Secondary Protection Zone TN: < 6 mg/L
- Tertiary Protection Zone TN: < 12 mg/L

The NWRF resides within the Secondary Protection Zone of the WSA, but its proximity to the Primary Protection Zone necessititates investigations to the extent of treatment for 2025 flows. This is due to the Karst geology of the WSA that forms a complex system of underground conduits, feeding and interconnecting springs. Considering that the travel time of water from the ground surface to the aquifer and springs ranges from a few days to as many as 40 years, the impact of land-use changes made today would be observed after several years.

The effluent discharge regulations into treatment wetlands are listed in Table 1. Figure 1 is a representative flow diagram of the existing facility, with arrows in blue indicating liquid flow. The red arrows indicate movement of solids and the yellow arrows represent gaseous emissions.

Currently the plant treats wastewater at AADF of 4.5 MGD and the facility achieves effluent quality below permitted levels. Table 2 displays the wastewater effluent quality of the facility within the years 2000-2004.

There are no regulations limiting the amount of total phosphorous (TP) discharged, but recent trends throughout the state have promulgated TP concentration levels; therefore, TP could become a future concern for wastewater facilities in the WSA. Also, this reclaimed water achieves Class I Reliability, established by FDEP, and is used for groundwater recharge through rapid infiltration basins, created wetlands, lake augmentation, on-site irrigation, and public-access reuse.

This article presents the design approach

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The authors are members of "Prima Squadra," the University of Florida student design team that won the FWEA Student Design Competition at the 2006 Florida Water Resources Conference and also won the National Student Design Competition at WEFTEC 2006. John Sansalone, professor of environmental engineering sciences at the university, is the team's faculty advisor.

Table 1. NWRF wastewater effluent quality recorded for 2000-2004. All values reported as annual averages unless otherwise noted.

Parameter	Permit Limit [mg/L]	Annual Average [mg/L]				
		2000	2001	2002	2003	2004
BOD_5	20	2.0	1.8	2.3	2.0	2.3
TSS (grab)	5	1.8	2.2	2.7	1.9	2.0
TN	12	3.8	2.3	4.3	4.3	3.2
TP	--	0.85	0.98	1.2	1.3	1.0

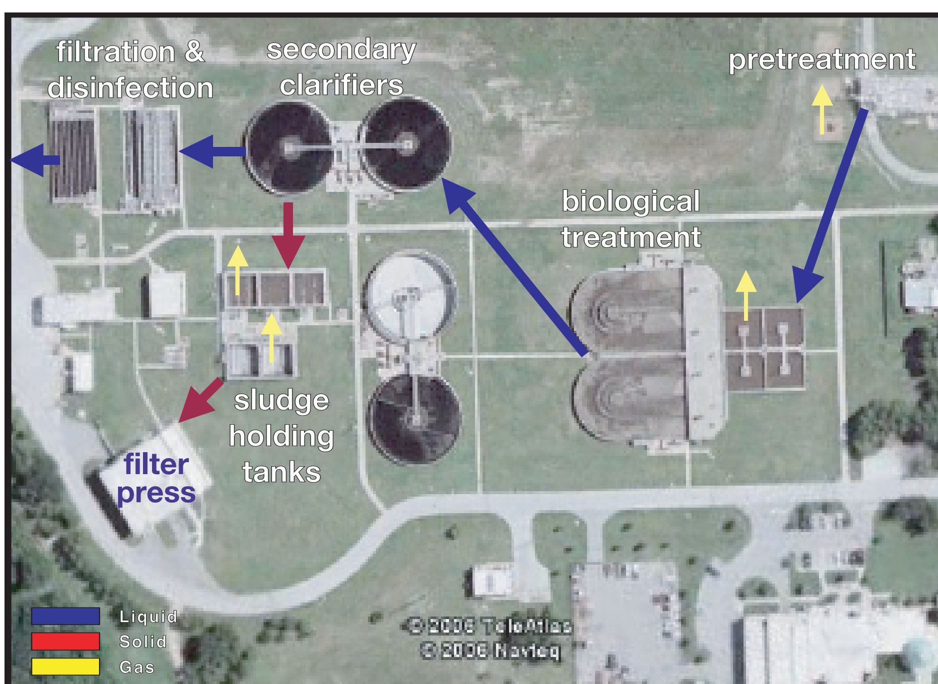

Figure 1. Aerial photograph of the NWRF taken in 2006 with liquid, solid, and gaseous flows.

Option	Process	WSA specifications achievable
1	Expansion of MLE	Secondary protection zone (TN < 6 mg/L)
2	Upgrade to four-stage Bardenpho	Primary protection zone (TN < 3 mg/L)
3	Upgrade to five-stage Bardenpho	Primary protection zone and P removal (TN < 3 mg/L)

Table 2. Design options of biological wastewater treatment for 2025 flows

Continued from page 47
provided by team Prima Squadra for the expansion of the NWRF to the projected 2025 AADF of 12 MGD and discusses the treatment and technological upgrade alternatives provided to the client. The designs will enable the NWRF to achieve TN limits conforming to specifications listed in the WSA. The design alternative recommended by Prima Squadra, arrived through arguments of technical merits and preliminary cost analysis, is also presented.

Methodology

The background, procedure, and methods used in the design of each unit operation of the NWRF configurations for 2025 flows are outlined in this section. All unit operations were designed to meet Class I Reliability, as specified by the FDEP. Methods followed in the cost analysis for treatment configurations are also discussed.

Flow Analysis

The influent flow in wastewater treatment plants is subjected to a significant degree of variation through the day. Hence, all unit operations for the liquid flow entering the plant were designed based on an hourly peaking factor.

Projected 2025 average annual daily flow specified for this design is 12 MGD. Historical flow data of the plant were used to calculate hourly peak flows and were projected to obtain hourly influent peak flows for 2025.

In estimating projected flows, hourly flow data from the NWRF for 2004 were compiled and analyzed. Flow data between 11 p.m. and 6 a.m. were not recorded at the facility, so typical hourly flow variations in municipal wastewater treatment plants were obtained from Metcalf and Eddy (2003) to estimate data for the missing hours. From this data set, mean hourly flow, mean daily flow, mean peaking factor, and maximum peaking factor were calculated.

Preliminary Treatment

Preliminary treatment serves as the first line of defense for a wastewater treatment plant and offers an important, inexpensive form of treatment. The NWRF uses a Parshall Flume at 40 MGD capacity for depth (flow) measurement and a mechanical bar/filter screen at 18 MGD capacity to separate coarse particles to protect pumps.

Grit removal to separate inorganics such as sand, gravel, cinders, and other heavy solid materials from organics is facilitated by a grit separator. This unit is designed for flows of 20 MGD and achieves separation by vortex action.

Spreadsheets were prepared to calculate necessary additions to the preliminary treatment unit to handle wastewater volumes in 2025 at peak hourly flows. Organics that stay suspended due to density difference are the predominant contaminants that flow to downstream processing units of the plant.

Equalization

An equalization basin was considered as a possible alternative to achieve flow and pollutant loading attenuation, with the prospect to reduce size expansions of downstream unit operations and thus minimize expansion costs.

The required volume of the equalization basin was calculated using mass conservation equations and standard methods described in wastewater treatment handbooks (Metcalf and Eddy, 2003). Projected flow variations for 2025 obtained by flow analysis were used in the inflow. Projected daily flow rates of 12 MGD were used for the outflow. A safety factor of 50 percent and a standard depth of five feet were used to estimate the basin footprint.

Biological Treatment and Secondary Clarification

Biological wastewater operations oxidize biodegradable contaminants into environmentally benign end products and reduce nutrients such as nitrogen (N), and phosphorus (P). Biological treatment is based on metabolic functions of a host of microorganisms in aerobic, anaerobic, and anoxic processes, achieved through suitable reactor conditions.

The facility presently uses the Modified Ludzack Ettinger process that achieves advanced secondary treatment. Expansion/upgrade options summarized in Table 2 were designed with the objective of meeting wastewater standards that conform to the WSA primary and secondary protection zone specifications.

Option 1: Modified Ludzack-Ettinger process

The Modified Ludzack-Ettinger (MLE) process is a two-stage operation comprised of anoxic and oxic processes followed by secondary clarification (Figure 2). Stage 1 is the anoxic process in which biological denitrification of nitrate to nitrogen gas occurs. Denitrification is represented by the following characteristic reaction, considering methanol as a representative substrate:

$$5CH_3OH + 6NO_3^- \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$$

Stage 2 is the oxic process in which biological oxidation of ammonia to nitrate occurs. The characteristic reaction for nitrification is:

$$NH_4^+ + 2.5O_2 \rightarrow NO_3^- + 2H_2O$$

Effluent from the MLE process is clarified through secondary settling tanks/clarifiers to sediment solids generated in the oxic process. A recirculation stream from the oxic reactor is fed to the anoxic tank to improve conversions. A portion of the microorganism-rich sludge that settles in the clarifier is recycled to maintain mixed liquor suspended solids levels in the anoxic and oxic reactors.

Design parameters evaluated for 2025 flows were the expansions required of the anoxic and oxic basin volumes, clarifier surface area, solids retention time (SRT) of both reactors, internal recycle flow from oxic to anoxic basin, and recirculation rate of activated sludge (RAS) from the clarifier to the anoxic basin.

Total suspended solids (TSS) balances about the oxic and anoxic reactors and secondary clarifier were used to arrive at defining equations that relate flow rates with reactor volumes, clarifier area, internal recirculation rates, and sludge recycle rates. Nitrification rates were estimated using the WEF and ASCE model (1998), and deni-

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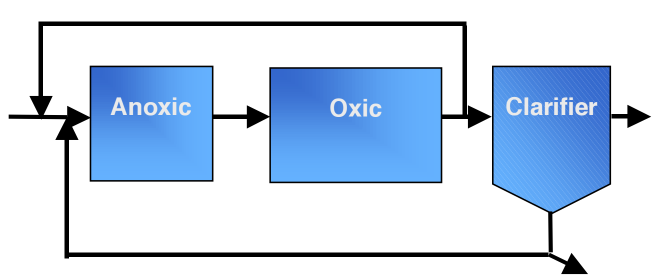

Figure 2. Flow diagram of Modified Ludzack-Ettinger (MLE) process.

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trification rates were calculated using the single sludge model of WPCF (1983).

Mixed liquor suspended solids of both reactors were maintained at 3000-3500 mg/L. Sludge settling rates in the clarifier were modeled using the one dimensional Vesilind model. The SRT of the oxic reactor was estimated using a mixed liquor temperature of 18∞C and design safety factor of 2.

Anoxic and oxic reactor volumes were sized as per suggested values of hydraulic retention times (HRT) in Metcalf and Eddy (2004). The clarifier surface overflow velocity was empirically related to the limiting solid settling flux by standard methods described in Metcalf and Eddy (2004).

Optimized design parameters were evaluated by simultaneous solutions of non linear relations, using the solver function in Microsoft Excel.

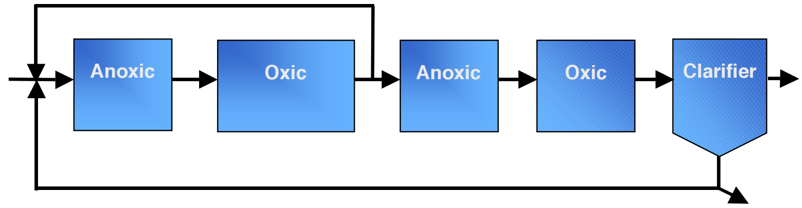

Figure 3. Flow diagram of the four-stage Bardenpho process diagram.

Option 2: Four-Stage Bardenpho

The four-stage Bardenpho design is a technological upgrade of the MLE process with an additional anoxic-oxic zone. Endogenous carbon from the oxic basin serves as an electron acceptor in the anoxic basin (Figure 3). The result is higher reduction in TN in the effluent stream of less than 0.3 mg/L.

A spreadsheet model based on 2025 influent flow was prepared to evaluate design parameters of the reactors, as described by the methods discussed in the previous section. Typical HRT values from Metcalf and Eddy (2004) were used in sizing the pre-anoxic, pre-oxic, anoxic, and oxic reactors.

Option 3: Five-Stage Bardenpho

The five-stage Bardenpho process design (Figure 4) is an upgrade over the four-stage Bardenpho process in that an anaerobic reactor precedes the Four-Stage process. This configuration has the capability of increased reduction of TN as well as reduction of biological P. The design of the Five-Stage process was carried out on similar lines of the Four-Stage process and the anaerobic reactor volume was sized using typical HRT values from Metcalf and Eddy (2004).

Filtration

Filtration serves primarily to remove from the effluent suspended solids that are too small to settle out in the clarifier. The NWRF currently uses a sand-bed, continuous-flow, low-head, up-flow filter process. The filtering unit is divided into two trains of seven cells, each with a surface area of 200 square feet and a media depth of nine feet. The existing medium is granular sand with a diameter of 0.9 mm, and the existing filter capacity is at 7.5 MGD AADF.

The 2005 data indicated a TSS of 20 mg/L entering the filters and a TSS of 2 mg/L exiting the filters. To design for 2025 flows, the Kozeny-Carmen equation was used to calculate headloss, and optimization of Darcy's Law was carried out to obtain the appropriate surface area.

Disinfection

Disinfection is achieved by using chlorine contact tanks that receive effluent from the filters, inactivating or eliminating fecal coliform and other microorganisms in wastewater. The NWRF uses sodium hypochlorite as the disinfectant and is required to maintain a minimum chlorine (Cl) residual of 1.0 mg/L, as specified for effluent discharge standards into treatment wetlands.

Class I Reliability requires the chlorine contact tanks to have 50 percent of the volume in service when the largest tank is out of service. Another design criterion specified in the permit is for the product of the minimum Cl residual and contact time at peak hourly flow (PHF) to be greater than 25.

The design of the chlorine contact tanks for 2025 flows is based on flow analysis. For an AADF of 12 MGD and the determined PHF from the flow analysis, the required volume of the contact tanks, contact time for AADF and PHF, flow through each basin, and channel dimensions were calculated. A spreadsheet was created to include all the parameters with mathematical algorithms used to determine appropriate upgrades (FDEP, 2002).

Hydraulics

Pipes and pumping are crucial to any wastewater facility, and it was necessary to examine whether the existing infrastructure capacity meets 2025 projected flows. Headloss due to expansion may require pumps to be added along the main flow stream of the facility.

The current facility layout was first scrutinized for any significant sources of headloss (i.e., unit operations, processes, pipelines). Handbooks and literature provided design tools to predict the headloss at the specific units (Metcalf and Eddy 2003 and Manteca 2006).

Preliminary Costing

CapdetWorks, a costing model by Hydromantis Inc., was used in the preliminary cost estimation of wastewater treatment processes. Project cost estimates from CapdetWorks account for construction, land and equipment costs, as well as costs associated with operation and maintenance.

Calibration of the program has yielded results within 20 percent of actual wastewater facility costs in the state of Florida (LEES, 1997). Information required by the program includes average daily flow, peaking factors, influent wastewater characteristics, unit operations and processes included in the treatment configuration, and desired effluent quality. The user may provide values for allowable loadings and unit costs specific to a particular case, or may rely on default values available in the CapdetWorks database.

Cost estimation was performed using the default U.S. July 2000 database and was inflated to 2005 dollars using the Marshal and Swift, Engineering News Record, and Pipe Indices. Cost estimates of the current NWRF facility that include cost for treating biosolids formed the baseline in the costing procedure.

Cost estimations for upgrades to various wastewater treatment configurations based on effluent TN standards and 2025 flows were evaluated. These estimates were made for configurations employing equalization to attenu-

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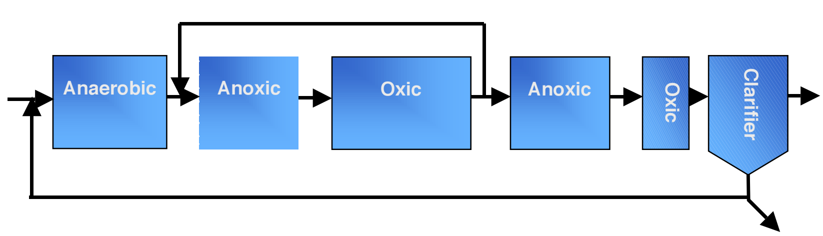

Figure 4. Flow diagram of the five-stage Bardenpho process diagram

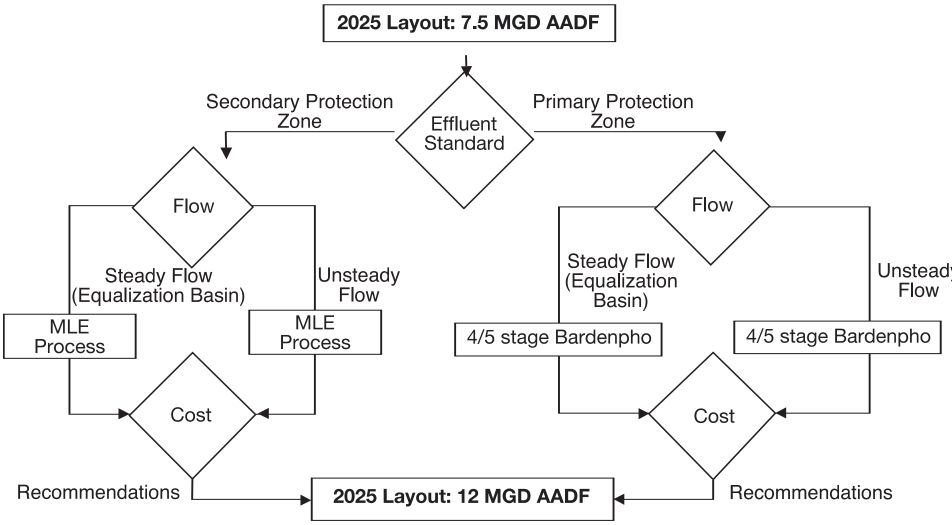

Figure 5. Design decision matrix based on effluent standards and cost analysis.

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ate influent flow, as well as for configurations that do not use flow equalization.

A sensitivity analysis of 2025 configurations as a function of peaking factors and effluent TN standards was also performed. Costs were evaluated in 2005 U.S. dollars and reported as per the following notations:

- Total project costs in dollars ($)
- Annualized project costs in dollars per year ($/year)
- Unit cost in dollars to treat 1,000 gallons of wastewater ($/1,000 gallons)

The costing exercise forms a critical basis in arriving at the design decision leading to a specific wastewater configuration, thereby providing concrete recommendations to the NWRF based on technical merit and economic constraints. The approach and decision flow chart is summarized in Figure 5.

Project Results

On the following pages, Tables 3, 4, and 5, along with Figure 6, show the results of each unit operation when designing to the projected 2025 flows into the NWRF. Tables 6-11 show the results of the three options for biological treatment expansion and upgrades, with Tables 6-8 outlining the existing design parameters and anticipated design values for 2025 flows, considering three different processes.

Parameter	2004	2025
Mean flow, MGD	4.6	12.0
Maximum of mean hourly flows, MGD	6.3	16.5
Maximum hour peak, MGD	13.0	29.1
Mean peaking factor	1.37	1.37
Maximum peaking factor	2.83	2.83

Table 3. Flow data for 2004 and resulting 2025 projected flow data.

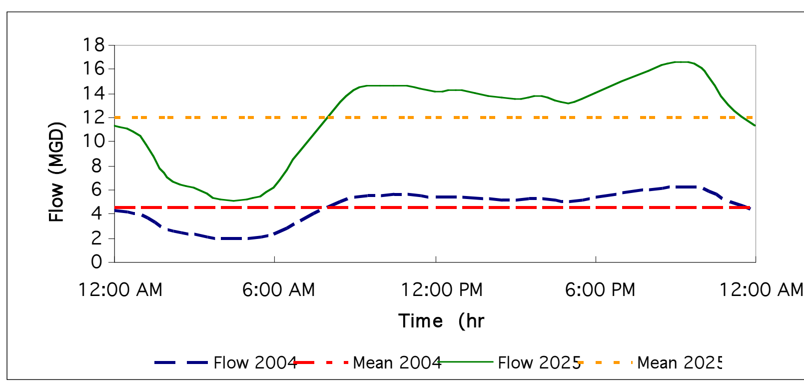


Figure 6. Mean daily flow variation for 2004 and 2025 projections.

Component	2005 Design Value	2005 # of units	2025 Design Value	2025 # of units
Parshall flume	2 to 40 MGD	1	--	1
Ultrasonic water level meter	0 to 72 inches	1	--	1
Aquaguard mechanical bar screen	0 to 18 MGD	1	--	2
Manual bar screen	--	1	--	2
Grit separator	20 MGD	1	30 MGD	1

Table 4. Summary of existing 2005 components and 2025 components necessary to meet increased flows into the unit operation.

Parameter	2025 Design
Basin volume, Mgal	1.496
Safety factor	1.5
Final volume, Mgal	2.245
Area, acres	1.378

Table 5. Summary of equalization basin values to meet 2025 projected inflows.

Component	2005 Design Value	2005 # of Units	2025 Design Value	2025 Units Added
Anoxic reactor (Mgal.)	0.788	4	1.33	3
Oxic reactor (Mgal.)	2.78	2	3.99	1
Total SRT (days)	14	--	9	--
O_2 requirement (lb/hr)	470	--	1,050	--
Secondary clarifier (ft^2)	34,636	4	40,445	1
Sludge produced (lb/day)	2,680	--	4,230	--

Table 6. Option 1, Modified Ludzack-Ettinger: Summary of 2005 and 2025 design values for expanding the MLE process.

Component	2005 Design Value	2005 # of Units	2025 Design Value	2025 Units Added
Pre-anoxic reactor (Mgal.)	0.788	4	1.33	3
HRT pre-anoxic reactor (hours)	--	--	2.66	--
Pre-oxic reactor (Mgal.)	2.78	2	3.99	1
HRT pre-oxic reactor (hours)	--	--	7.98	--
Post-anoxic reactor (Mgal.)	--	--	1.0	5
HRT post-anoxic reactor (hours)	--	--	2.0	--
Post-oxic reactor (Mgal.)	--	--	0.25	1
HRT post-oxic reactor (hours)	--	--	0.5	--
Total SRT (Days)	14	--	12	--
Secondary clarifier (ft^2)	34,636	4	40,445	1
Sludge produced (lb/day)	2,680	--		--

Table 7. Option 2, Four-Stage Bardenpho: Summary of 2005 and 2025 design values for expanding the four-stage Bardenpho process.

Component	2005 Design Value	2005 # of Units	2025 Design Value	2025 Units Added
Anaerobic basin (Mgal.)	--	--	0.25	1
HRT anaerobic reactor (hours)	--	--	0.50	--
Pre-anoxic reactor (Mgal.)	0.788	4	1.33	3
HRT pre-anoxic reactor (hours)	--	--	2.66	--
Pre-oxic reactor (Mgal.)	2.78	2	3.99	1
HRT pre-oxic reactor (hours)	--	--	7.98	--
Post-anoxic reactor (Mgal.)	--	--	1.0	5
HRT post-anoxic reactor (hours)	--	--	2.0	--
Post-oxic reactor (Mgal.)	--	--	0.25	1
HRT oxic reactor (hours)	--	--	0.5	--
Total SRT (Days)	14	--	12	--
Secondary clarifier (ft^2)	34,636	4	40,445	1
Sludge produced (lb/day)	2,680	--		--

Table 8. Option 3, Five-Stage Bardenpho: Summary of 2005 and 2025 design values for expanding the five-stage Bardenpho process.

Parameter	2005 Design Value	2025 Design Value
Design dosage rate [mg/L]	10	10
Design dosage rate at average flow (lbs/day)	625	998
Design dosage rate at peak flow (lbs/day)	1,563	2,495
Design chlorine residual [mg/L]	1.1	1.1
Influent fecal coliform [#/100ml]	<1,000	<1,000
Flash mixer (hp)	7.5	7.5
Total # of Basins	**3**	**4**
Contact time each basin @ ADF (min)	57	58
Contact time @ PHF (min)	23	23
SMALL BASINS	**2**	**2**
Design flow each small basin (MGD)	1.95	4.87
Volume of each small basin (gal.)	77,840	77,840
Small basin channel width (ft)	4.5	4.5
Small basin channel depth (ft)	4.55	4.55
LARGE BASIN	**1**	**1**
Design flow large basin (MGD)	3.6	9.03
Volume of large basin (gal.)	144,300	144,300
Large basin channel width (ft)	8	8
Large basin channel depth (ft)	8	8
NEW BASIN	**--**	**1**
Design flow new basin (MGD)	--	11.22
Volume of new basin (gal.)	--	179,200
New basin channel width (ft)	--	12.15
New basin channel depth (ft)	--	12.15

Table 10. Summary of parameters for the 2005 and projected 2025 design values for the chlorine contact tanks.

Component	2005 Design Value	2025 Design Value
Avg. daily flow (MGD)	7.5	12.0
Peak hr. flow (MGD)	18.75	30.0
Loading rate at ADF (gpm/ft^2)	1.86	4.00
Loading rate at PHF (gpm/ft^2)	4.65	4.50
# of cells	14	26
SA per cell (ft^2)	200	200
Headloss (in.)	36	35.2
Media depth (ft)	9	7

Table 9. Summary of existing design values and the projected 2025 design values for the filtration units.

Table 11 outlines the headloss across each unit operation for the existing design and the 2025 design.

	Headloss (ft)			
Unit/Section	2005 Design	Modified Ludzack-Ettinger	Four-Stage Bardenpho	Five-Stage Bardenpho
Channel before screening unit	0.66	0.66	0.66	0.66
Screening unit	2.00	2.00	2.00	2.00
Separator grit	2.50	2.50	2.50	2.50
Pipe preliminary treatment-biological reactor	0.87	1.64	1.64	1.64
Biological reactor	4.75	4.73	7.65	9.89
Pipe biological reactor-clarifier	1.77	2.22	2.22	2.22
Clarifier	0.16	0.20	0.20	0.20
Pipe clarifier-filters	0.89	1.68	1.68	1.68
Filters	8.50	8.43	8.43	8.43
Total	**22.1**	**24.1**	**27.0**	**29.2**

Preliminary Costing

Figures 7 through 9 display results of the sensitivity analysis, in conjunction with project costs for upgrading the NWRF to an MLE, four-stage, and five-stage Bardenpho process. Total project cost, annualized project cost, and unit cost are graphed for peaking factors between the ranges of 2 and 3 and for the 2005 design set-up, compared to the 2025 design with and without equalization. Table 12 summarizes the project costs of the three design options as reported by Capdetworks simulations.

Figure 7(a)

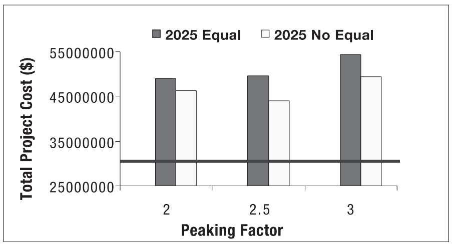


Figure 7(b)

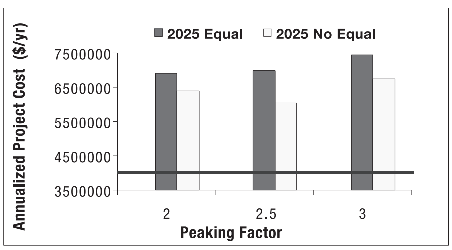
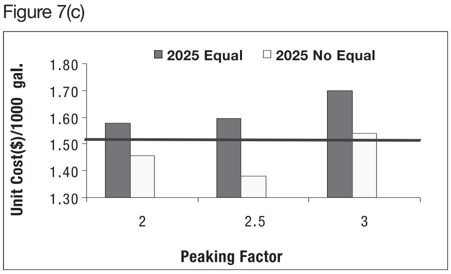


Figure 7(c)



Figures 7. Sensitivity analysis of costs as a function of peaking factor for 2025 MLE configuration treating wastewater to Secondary Protection Zone Standards. (a) Total Project Cost ($), (b) Annualized Project Cost ($/yr), (c) Unit cost to treat 1,000 gallons of wastewater ($/1,000 gallons). The blue lines in Figures 7 (a-c) represent the corresponding costs for the current NWRF configuration at a peaking factor of 2.5.

Figure 8(a)

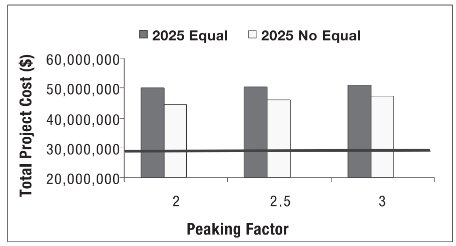


Figure 8(b)

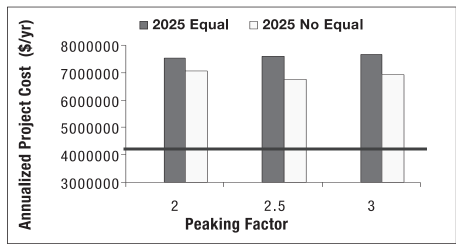
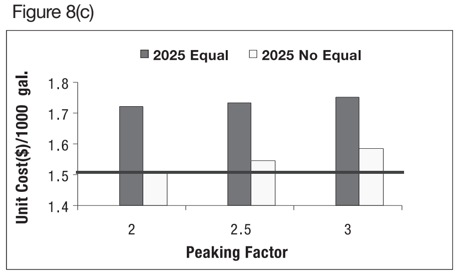


Figure 8(c)



Figures 8. Sensitivity analysis of costs as a function of peaking factor for 2025 four-stage Bardenpho configuration treating wastewater to Primary Protection Zone standards. (a) Total Project Cost ($), (b) Annualized Project Cost ($/yr), (c) Unit cost to treat 1,000 gallons of wastewater ($/1,000 gallons). The blue lines in Figures 8 (a-c) represent the corresponding costs for the current NWRF configuration at a peaking factor of 2.5.

Discussion

The three design options provided to the client conform to the objectives outlined in the competition design package. Cost and sensitivity analysis provided the means to arrive at a single recommendation best suited for the NWRF.

Flow analysis supplied the necessary hourly flow variations needed for designing each unit operation. The resulting mean daily flow in 2025 is precisely 12 MGD and concurs with projected values provided in the design package.

Metcalf and Eddy (2003) suggest a minimum of three years of data to complete a flow analysis. Although data provided to complete this flow analysis was for only one year, the calculated peaking factor of 2.83 was within range of the peaking factor of 2.5 provided by the FWEA student design competition package; therefore, an AADF of 12 MGD with a peaking factor of 2.5 for the year 2025 forms the design basis for unit operation and processes of the NWRF.

Preliminary treatment design data indicates the existing Parshall Flume has the capacity to handle the projected flows of 2025 and therefore requires no additional units. One additional mechanical bar screen is necessary for expansion and one additional manual bar screen is needed for redundancy and Class I reliability standards. The existing preliminary treatment infrastructure is able to support these additions. The grit separator requires an upgrade to meet the 2025 peak flows of 30 MGD because the existing 12 MGD model will not be able to handle this peak flow.

The equalization basin requires a footprint of 1.38 acres, but preliminary costing indicated equalization to be less economical than not installing equalization. The cost analysis for equalization indicated higher costs for all three options, essentially due to construction and land costs and costs associated with mixing and aeration. Also, costs for odor control and sludge management were neglected, which would imply an even higher cost, so equalization was not considered economical for this expansion project.

Figure 9(a)

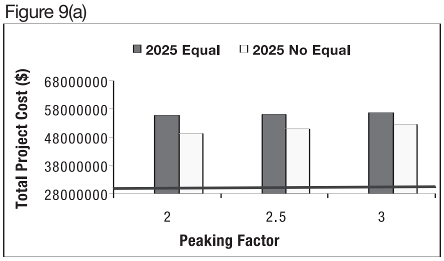


Figure 9(b)

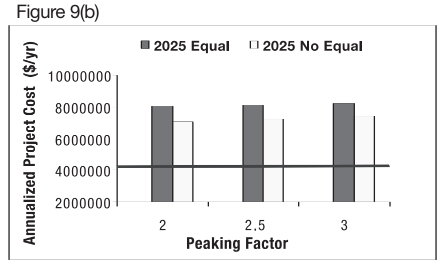
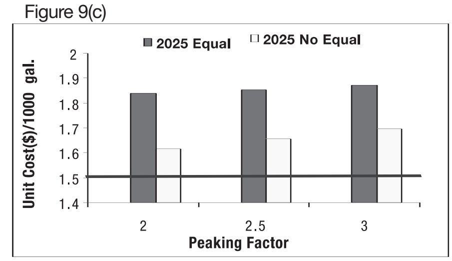


Figure 9(c)



Figures 9. Sensitivity analysis of costs as a function of peaking factor for 2025 five-stage Bardenpho configuration treating wastewater to Primary Protection Zone standards and facilitates P removal. (a) Total Project Cost ($), (b) Annualized Project Cost ($/yr), (c) Unit cost to treat 1,000 gallons of wastewater ($/1,000 gallons). The blue lines in Figures 9 (a-c) represents the corresponding costs for the current NWRF configuration at a peaking factor of 2.5.

Existing Facility Value = $29.8 Million Existing Treatment Cost = $1.5/1000 gallons	2005 Project Cost (Million $)	2005 Treatment Cost ($/1,000 gal)	% Increase in Treatment Cost
Option 1: Expansion of MLE	14.30	1.38	- 8.43
Option 2: Expansion and upgrade to four–stage Bardenpho process	16.10	1.54	2.45
Option 3: Expansion and upgrade to five–stage Bardenpho process	21.20	1.65	9.71

Table 12. Summary of estimated costs for all options for 2025 flows with peaking factor of 2.5 and unsteady flow.

Expanding the facility to meet the 2025 projected flows and the recommended Secondary Protection Zone standards using the MLE process (Option 1) provides the lowest cost of all options analyzed. Total expansion project cost for this option was $14.3 million in 2005 dollars, while providing a savings of 8.43 percent in unit costs to treat 1,000 gallons of water when compared to the 2005 design. An expansion using Option 1 entails adding three anoxic reactors, one oxic reactor, and one secondary clarifier.

Expanding the facility to a four-stage Bardenpho process (Option 2) provides a slightly higher expansion project cost of $16.1 million in 2005 dollars. When compared to the current 2005 facility, this process costs 2.45-percent more to treat 1,000 gallons of water, but it is capable of achieving an effluent TN < 3 mg/L, along with slight removal of phosphorous. An expansion using Option 2 requires an installation of three pre-anoxic reactors, one pre-oxic reactor, five post-anoxic reactors, one post-oxic reactor, and one secondary clarifier.

To achieve TN concentrations of < 3 mg/L and phosphorous concentrations of ~ 0.1 mg/L, the five-stage Bardenpho process (Option 3) may be utilized. Implementing this process requires one anaerobic basin, three pre-anoxic reactors, one pre-oxic reactor, five post-anoxic reactors, one post-oxic reactor, and one secondary clarifier. Option 3 resulted in a total expansion project cost of $21.2 million in 2005 dollars and an increase of 9.71 percent in unit cost to treat 1,000 gallons.

The filtration unit will need an additional 12 cells to meet the 2025 peak hourly flows of 30 MGD while maintaining the effluent TSS standard. The resulting total surface area of 5,200 ft^2 allows a peak loading rate of 4 gpm/ft^2 while keeping headloss under three feet.

A new chlorine contact basin is required to handle the 2025 peak hourly flows passing through the unit. The three existing basins can treat higher flows than currently utilized, and the remaining excess volume will be treated with the new basin. The contact time for peak hourly flows remained at 23 minutes, but the contact time at average daily flow increased by one minute to 58 minutes per basin.

The total headloss across the entire facility increases two feet for design to an MLE expansion, 4.9 feet for design to a four-stage Bardenpho expansion, and 7.1 feet for design to a five-stage Bardenpho expansion. The increase in headloss is due to the subsequent additions of pipelines and expansion of biological treatment.

Looking at the performance fields of pumps, a pump upgrade is needed, regardless of the design option chosen. The increase in flow rate is the major cause for the needed pump upgrade, even if headloss remained the same for the 2025 designs. Existing pump curves indicate that additional pumps are required to meet necessary flow rates and Class I Reliability standards.

Recommendations

Four-stage Bardenpho

Cost and sensitivity analysis provided the means to arrive at a single recommendation best suited for the NWRF. The design team recommended that Orange County Utilities adopt a four-stage Bardenpho process in the expansion of the NWRF. This design not only meets FDEP-proposed TN regulations for a Secondary Protection Zone, but also exceeds them without a substantial increase in total project cost. The design also has the advantage of being easily upgradeable to the five-stage Bardenpho process should TP concerns arise in the future.

Ever-increasing, stringent regulations being promulgated through the state of Florida provide a valid argument for investing in the initial project costs. By conforming to Primary Protection Zone standards achieved by the four-stage Bardenpho process, Orange County Utilities has the opportunity to continue its reputation for being a forerunner in environmental stewardship and innovation.

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